UNDERSTANDING TEXTILES FOR A MERCHANDISER

Engr. Shah Alimuzzaman Belal, C.Text. ATI (U.K)
UNDERSTANDING TEXTILES
FOR
MERCHANDISER

Textile fibres; Yarn and yarn manufacturing;
Weaving technology; Fabric structure and design; Special woven fabric production;
Weft and warp knitting technology; Knitted fabric design; Special knit fabric production;
Sweater knitting;
Dyeing, printing and finishing.

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INTRODUCTION TO TEXTILES

The word “textile” originally applied only to woven fabrics, now generally applied to fibres, yarns, or fabrics or products made of fibres, yarns or fabrics. The term textile originates from the Latin verb texere – to weave – but, as the Textile Institute’s Terms and Definitions Glossary explains, it is now “a general term applied to any manufacture from fibres, filaments or yarns characterized by flexibility, fineness and high ratio of length to thickness”.

Textiles, especially fabric is the fundamental component of a ready made garment, because it is the basic raw material of a garment. So it is important to know the manufacturing sequence of fabric from fibre. The quality product is the main goal at present time. Without knowledge of Textile manufacturing i.e. fibre, yarn and fabrics it is impossible to maintain the quality of a garment. Before elaborating on whole process of grey fabric manufacturing let us look on what is textile fibre, yarn and fabric and what are the process flow chart of Textile Manufacturing can be described.

- **Textile:**

  A term originally applied only to woven fabrics, but the terms textile and the plural textiles are now also applied to fibres, filaments and yarns, natural and manufactured, and most products for which these are a principal raw material.

- **Textile Fibre:**

  Any substance, natural or manufactured, with a high length to width ratio and with suitable characteristics for being processed into fabric; the smallest component, hair like in nature, that can be separated from a fabric.

- **Yarn:**

  An assemblage of fibres that is twisted or laid together so as to form a continuous strand that can be made into a textile fabric. So a yarn is a strand of natural or man made fibres or filaments that have been twisted or grouped together for use in weaving, knitting, or other methods of constructing textile fabrics. The type of yarn to be manufactured will depend on the fibres selected; the texture, or hand, of the fabric to be made; and qualities such as warmth, resiliency, softness, and durability required in the fabric’s end uses.
• Fabric:

Fabric is a flexible planar substance constructed from solutions, fibres, yarns, or fabrics, in any combination. Textile fabrics can be produced directly from webs of fibres by bonding, fusing or interlocking to make non-woven fabrics and felts, but their physical properties tend to restrict their potential end-usage. The mechanical manipulation of yarn into fabric is the most versatile method of manufacturing textile fabrics for a wide range of end-uses.

Flow chart of textile processing:

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TEXTILE FIBRES

Any substance, natural or manufactured, with a high length to width ratio and with suitable characteristics for being processed into fabric; the smallest component, hair like in nature, that can be separated from a fabric.

Properties of Textile Fibres:

Primary properties of textile fibres:

- High length to width ratio
- Tenacity
- Flexibility
- Spinning quality (Cohesiveness)
- Uniformity

Secondary properties of textile fibres:

- Physical shape
- Elastic recovery and elongation
- Resiliency
- Flammability and other thermal reactions
- Density
- Luster
- Colour
- Moisture regain

Primary properties of textile fibres:

High length-to-width ratio:

Fibrous materials must possess adequate staple (fibre length) and the length must be considerably greater than the diameter. The length is a very important fibre property. Natural fibres, except for silk, are mostly some millimeters up to several centimeters long. Synthetic fibres are actually filaments (indefinite length) or are chopped into (shorter) staple fibres, which can, in their turn, be spun.
**Flexibility:**

Flexibility is the property of bending without breaking that is the third necessary characteristic of textile fibre. In order to form yarns or fabrics that can be creased, that have the quality of drapability and the ability to move with the body and that permit general freedom of movement, the fibres must be bendable, pliable or flexible. The degree of flexibility determines the ease with which fibres, yarns and fabrics will bend and is important in fabric durability and general performance.

**Spinning quality (Cohesiveness):**

This characteristic refers to the ability of the fibre to stick together in yarn manufacturing processes. Cohesiveness indicates that fibres tend to hold together during yarn manufacturing as a result of the longitudinal contour of the fibre or the cross-section shape that enables the fibre to fit together and entangle sufficiently to adhere to one another.

**Uniformity:**

To minimize the irregularity in the final yarn, it is important that the fibres be somewhat similar in length and width i.e. be uniform. The inherent variability in the natural fibre can be averaged out by blending natural fibres from many different batches in order to produce yarn that are uniform.

**Secondary properties of textile fibres:**

**Physical shape (fine structure and appearance):**

The fibre shapes i.e. the surface structure is important for the fibre behaviour in a yarn and in a fabric. A rough scaly surface of wool fibres, for example, influences the felting and shrinkage properties of wool fabrics. The scales enable fibres to grip one another when a yarn is spun.

The smooth, glassy surface of a fibre such as the nylon fibre, affects the lustre of the fibre. A smooth surface will not cling to dirt so readily. The cross-sectional shape of a fibre influences the behaviour of the fabric. A circular or near-circular cross-section (wool) gives an attractive or comfortable feel as compared to a flat, ribbon-like cross-section (cotton). Circular fibres often have a poorer covering-power than the flatter or triangular ones. A flat or triangular cross-section gives more lustre. Serrated or indented cross-sections (viscose) give better colour absorption as a result of the larger area. More colour is also needed in the case of fine filaments. The latter also give a softer handle or feel.

**Elastic recovery and elongation:**

A fibre, which is subjected to a force, will stretch to a certain degree. This stretching can also be expressed as a percentage of the original fibre length, which is the elongation. The elongation of
a fibre may be measured at any specified load or as the elongation reached when the fibre breaks.

When a fibre is subjected to a small force (or stretched to a small degree), it may exhibit almost perfect elasticity. Elasticity is the property of a fibre to recover its original length after stretching caused by a load.

The term breaking elongation refers to the amount of stretch that occurs to the point where the fibre breaks. Elastic Recovery designates the percentage of return from elongation or stretch toward the original length or measurement. If a fibre returns to its original length from a specified amount of attenuation, it is said to have 100% elastic recovery at X% elongation.

**Resiliency:**

It is the ability of a fibre to return to shape following compression, bending or similar deformation. It is important in determining the crease recovery of a fibre or fabric, and it plays a significant role in the rapidity with which flattened carpet pile will regain its shape and restore its appearance.

Resilience is the property of a fibre which enables it to recover from a certain load or stretched position and flexibility is that property to resist repeated bending and folding. A supple fibre has a low resilience and is easily compressible. A stiff fibre has a high resilience and cannot be easily compressed.

**Flammability and other thermal reactions:**

Burning characteristics of the fibres are important in determining care and use, and they serve as helpful guidelines in the fibre identification. Federal legislation on textile inflammability is an important consumer issue and a variety of types of textile end-use products must meet a specified resistance to flames.

All fibres are affected in one-way or another as they are heated. Some, like wool, begin to decompose before melting; others, like polyethylene or acetate will soften and melt before decomposition sets in. The behaviour of fibres on heating and their ignition properties are of great practical importance. Indeed, fabrics should withstand the temperatures used in ironing, laundering (with water or solvent) etc. Since synthetic fibres are thermoplastic substances (i.e. they will soften as they are heated), this softening will largely determine their practical usefulness.

In the presence of air, most fibres will burn. In this context, the term LOI is used. It stands for Limiting Oxygen Index. The higher the value of LOI, the more difficult a substance will ignite since LOI is a measure of the amount of oxygen which has to be present in the air to let a substance (continue to) burn. On average, most substances have an LOI of about 20. Efforts are made to reduce the flammability of textile materials in order to limit accidents. These efforts are
The staple length of natural fibres is not an easy property to define because the fibre length can vary over a great area. A statistical interpretation of the data obtained on fibre length in a laboratory, makes it possible to determine the staple length (an average length). In order for a fibre to be spinnable, i.e. to be twistable, and therefore offer sufficient cohesion to the whole, a fibre must at least have a length of 5 to 15 millimetres. Fibres which are longer than 150 millimetres require specialized spinning machines which make the spinning process more expensive.

The most common natural fibres have a ratio length / thickness which equals one thousand or several thousands (cotton: 1500; wool: 3000; flax: 1200). Coarser fibres such as jute and sisal have ratios between 100 and 1000. When filaments of man-made fibres are chopped into shorter fibres, an effort is made to bring the ratios close to those of natural fibres, i.e. between 1000 and 4000.

**Tenacity:**

Second necessary property for a product to qualify for textile fibre is adequate strength, termed as tenacity. Tenacity is defined as the tensile stress expressed as force per unit linear density of the unstrained specimen.

The strength of a fibre is generally dependent on the length of the polymer chain, the degree of orientation of these polymer chains, the strength and types of the forces of attraction between the polymer chains (interpolymer forces). The longer a polymer chain is, the higher the degrees of orientation and crystallization and, hence, the stronger the interpolymer forces. Crystalline systems feel stiff and present less resistance to repeated bending or folding. Stronger fibres will lead to stronger yarns under the appropriate conditions of twist.

The tensile strength or breaking load is commonly described as the force required to reach break.

In the case of a fibre, the strength is described as tenacity (specific stress at break)

\[
\text{Tenacity} = \frac{\text{breaking load}}{\text{mass per unit length}}
\]

Tenacity is expressed in terms of (centi)newtons per tex (cN/tex or N/tex).

It is important to note that the fibre strength does not always indicate comparable yarn or fabric strength. Fibres with high strength are useful in seer and lightweight fabrics. Fabrics used in work cloths and various industrial applications are better from high tenacity fibres. Fibre tenacity does not always reflect the actual strength of textile yarn. It is possible for yarns to be made so that fibre slippage occurs; this does not make optimum use of the actual fibre tenacity.
made both in the field of synthesis of fibres (chemical modification) and, afterwards, by using substances which slow down or resist burning.

Chemically speaking, vegetable fibres have almost identical composition, and consist of cellulose, which is a combination of carbon, hydrogen and oxygen. They all burn as paper or wood, ignite readily, leave little or no ashes and release a distinctive fire smell of burnt paper.

Fibres of animal origin also have a similar chemical composition; they all contain nitrogen and will therefore not easily burn through. They shrivel and form charred ashes. They leave a fire smell of burnt feathers.

Exceptions are weighted natural silk (leaves ashes which keep the form of the yarn) and acetate where introducing acetate groups in the polymer chains makes the fibre melt before it can ignite.

Man-made fibres based on protein burn as fibres of animal origin. Fully synthetic fibres melt without ignition.

**Density:**

Fibres with different densities but of equal diameter will have different covering power that is the ability to cover a surface. Fabrics made with fibres of different densities will have difference in fabric appearance, flexibility, air permeability and cover.

The density, also called volumic mass or mass density, is the mass per unit volume and has ρ as its symbol. It is usually expressed in grams per cubic centimeter. Another term is specific gravity, which is the ratio of the mass of a fibre material and the mass of an equal volume of water (density 1g/cm³). The specific gravity of a substance vis-à-vis water equals the numerical value of the (absolute) density of this substance if it is expressed in g/cm³. Every fibre is characterized by its density, which can be measured in various ways.

Measurement of density can be carried out with a gradient column, where the liquid in the tube has a density which varies in height. If a fibre is dropped in the tube, it will sink to the point at which the fibre density equals the liquid density, and remain suspended there.

This experiment is based on the fact that a fibre which is submerged in a liquid with the same density will sink nor drift but float, and that the density of a liquid can easily be measured. Treatments for finishing fibres, can influence the results. Foreign substances on or in the fibres must be removed before doing the experiment.
The list below gives an overview of the most important fibres and their densities.

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<tr>
<td>Cotton</td>
<td>1.55</td>
<td>Raw</td>
</tr>
<tr>
<td>Cotton</td>
<td>1.54</td>
<td>Mercerized</td>
</tr>
<tr>
<td>Flax</td>
<td>1.50</td>
<td></td>
</tr>
<tr>
<td>Jute</td>
<td>1.50</td>
<td></td>
</tr>
<tr>
<td>Wool</td>
<td>1.30</td>
<td>No brand</td>
</tr>
<tr>
<td>Silk</td>
<td>1.33</td>
<td>Natural</td>
</tr>
<tr>
<td>Silk</td>
<td>1.60</td>
<td>Weighted</td>
</tr>
<tr>
<td>Silk</td>
<td>1.32</td>
<td>Tussah</td>
</tr>
<tr>
<td>Polyester</td>
<td>1.22</td>
<td>Kodel, vestan</td>
</tr>
<tr>
<td>Polyester</td>
<td>1.38</td>
<td>Terylene, Dacron</td>
</tr>
<tr>
<td>Viscose</td>
<td>1.53</td>
<td></td>
</tr>
<tr>
<td>Cuprammonium</td>
<td>1.53</td>
<td>Lycra</td>
</tr>
<tr>
<td>Polyurethane</td>
<td>1.15</td>
<td>Meraklon</td>
</tr>
<tr>
<td>Polypropylene</td>
<td>0.90</td>
<td>Courlene</td>
</tr>
<tr>
<td>Polyethylene</td>
<td>0.92</td>
<td>Courlene X3</td>
</tr>
<tr>
<td>Polyethylene</td>
<td>0.95</td>
<td>Perlon</td>
</tr>
<tr>
<td>Nylon 6</td>
<td>1.13</td>
<td>Tri-nylon</td>
</tr>
<tr>
<td>Nylon 66</td>
<td>1.14</td>
<td>Orlon (staple/filament)</td>
</tr>
<tr>
<td>Acryl</td>
<td>1.14 – 1.17</td>
<td>Kuralon, vinal</td>
</tr>
<tr>
<td>Polyvinyl alcohol</td>
<td>1.30</td>
<td></td>
</tr>
</tbody>
</table>

**Lusture:**

It refers to the gloss, sheen or shine that a fibre has. It is the result of the amount of light reflected by a fibre, and it determines the fibre's natural brightness or dullness.

**Colour:**

Natural colour of fibres vary from pure white to deep gray, tan or black. Man-made fibres are usually white or off-white as they are produced.

**Moisture regain or effect of moisture:**

All fibres tend to absorb moisture when in contact with the atmosphere. The amount absorbed depends on the relative humidity of the air.

For absorption of moisture of a fibre, the term regain is used. This is the amount of moisture present in a textile material expressed as the percentage of the oven-dry weight (dry weight) of the textile. This dry mass is the constant weight of textile obtained after drying at a temperature of 105°C to 110°C. If B is the dry weight and A is the conditioned weight (the weight after being in a normalized atmosphere of 20°C and 65% relative humidity), the regain expressed in percentage will be:
Moisture Regain = \( \frac{A - B}{B} \times 100 \)

Another relevant term is moisture content and, expressed in percentage, is:

\[ \text{Moisture content} = \frac{A - B}{A} \times 100 \]

The moisture content is the mass of moisture in a fibre and is expressed as a percentage of the total weight. It is a measure of the amount of water held under any particular set of circumstances. The moisture content is always lower than the regain.

Fibres can present great variations in the amount of moisture they will absorb. Wool has a regain of 16%, cotton of 8.5%, acetate only of 6%. Fibres, which can absorb sufficient moisture, are most suitable for processing into clothing because they will absorb perspiration from the body and will hold considerable amounts of moisture without feeling clammy. The ability of a fibre to absorb moisture will also affect the processing and finishing of fibres. Fibres which easily absorb moisture, will therefore let dyestuffs penetrate more easily during the dyeing process. Synthetic fibres, which often absorb little moisture, are easily washed and dried by comparison with fibres, which absorb a lot of moisture. On the other hand, this entails the phenomenon of electrostatic charging.

The strength of a fibre is affected significantly by the water it absorbs. Fibres, which easily absorb moisture, will usually be less strong when wet (except for flax and cotton) and will present increased elongation at break. One should also realize that absorption of moisture can also make the fibre swell to a considerable degree, which is important for fixating dyestuffs.
Classification of Textile Fibres:

Textile Fibres

- Natural Fibres
  - Animal fibre (Protein)
    - Silk (sheep)
    - Wool (sheep)
    - Hair (alpaca, camel, cow, goat, horse, rabbit etc.)
  - Vegetable fibre (Cellulose)
    - Seed fibre (Cotton, coir)
    - Bast fibre (flax, hemp, jute, ramie, etc.)
    - Leaf fibre (abaca, sisal, etc.)
  - Mineral fibre (Asbestos)

- Man-made Fibres
  - Synthetic fibre (synthetic polymer)
    - Alginate (elastodiene)
    - Rubber (elastodiene)
    - Regenerated fibre (natural polymer)
      - Cellulose ester
        - Animal (casein)
        - Vegetable
          - Acetate
          - Triacetate
          - Viscose
          - Cupro
          - Modal
          - Lyocell
  - Regenerated fibre
    - Cellulose

- Other (carbon, glass, metal, ceramic, etc.)

Synthetic polymers:

- Polymethyl -ene urea
  - Polyethylene
- Polyolefin
derivatives
- Polyvinyl
- Polyurethane or nylon
- Polymide
- Polyamide
- Polystyrene
- Synthetic polyisoprene
- Acrylic
- Modacrylic
- Chlorofibre
- Fluoro fibre
- Trivinyl
- Polystyrene
Fibre Identification:

The identification of textile fibres is a very important part of the study of textile science. At one time, simple fibre identification was a relatively easy task; most consumers could tell by appearance and hand whether a fabric was cotton, wool, silk, or linen. Once the first manmade fibres were introduced, the process became a bit more difficult. Consumers usually could identify the fibre composition of fabrics made of 100 percent rayon or acetate, but blends of some fibres were difficult to identify. As more fibres were introduced, the task became progressively more difficult. Today, sophisticated techniques are usually required for accurate fibre identification.

The purpose of the Textile Fibre Products Identification Act was to provide information on fibre content of textiles at the point of sale. Consumers were at once relieved of the responsibility to identify fibre content of items they purchased; however, professionals working with textile products still must be able to identify fibres accurately. Such individuals include retailers who suspect some textile products they bought for resale have been labeled inaccurately; customs officials who must identify imported fibres; dry cleaners who must clean an item from which all the labels have been removed; extension home economists who are asked to help solve a consumer’s problem with a textile product; and forensic scientists who must use a textile sample to help solve a crime.

For most individuals, the only information needed is a qualitative analysis of fibre content: what fibre or fibres are present in this product? For others, a quantitative analysis of the product is also important: in what percentages are the fibres present? With the numbers of fibres available today and the variety of blends being produced, neither analysis is easy.

Methods for qualitative identification of fibres include such procedures as burning tests, microscopy, density determination, moisture regain analysis, dye staining, chemical solubility, melting point determination, infrared spectroscopy, and chromatography. Simplified versions of the first six procedures are relatively easy to perform in most laboratories. They require the use of a drying oven, an analytical balance sensitive to 0.005 gram, a compound light microscope capable of 200 × magnification, laboratory glassware, and a supply of chemicals.

A. Burning Test:

The burning test is a good preliminary test for categorizing fibres. Observation of burning provides information on behavior in a flame, smoke generation, odor during burning, and ash or residue. It never should be used as the only method of identifying a fibre, but it provides valuable information that may be used with other evidence to make a positive identification of an unknown fibre.

Blends of fibres are difficult to test using this procedure. The reaction of the predominant fibre may mask the presence of a second fibre, which could have entirely different burning characteristics. Finishes, especially flameretardant finishes, can also give misleading information. Although the test is easy to perform, it does involve the use of an open flame, making it necessary to observe certain safety precautions. Use a small flame source in an area where there is no danger of igniting other materials. A candle in a stable base or a small alcohol lamp is preferable to a hand-held match. A nonflammable pad should be used under the burning material to provide protection from molten drip and smoldering ash. Do not touch ash or tweezers while they are still hot.
Procedure:

The sample to be tested should be in fibre form. A single yarn from a woven or knitted fabric should be untwisted to produce a tuft of fibres for testing. Use the following instructions, and observe the reactions of the burning fibre very carefully.

1. Hold the tuft of fibres with a pair of tweezers.
2. Move the tuft close to the side of the flame; do not place the fibres above or below the flame. Observe carefully to see if the fibres melt, shrink, or draw away from the flame.
3. Slowly move the fibre tuft into the flame to observe its burning behavior, and then slowly and carefully remove the tuft from the flame to observe the reaction once the flame source is no longer present. Careful observation provides an answer to these four questions: (a) When introduced to the flame, does the fibre burn rapidly or slowly, or does it show no sign of ignition? (b) Does the material begin to melt? (c) Does the material produce a sputtering flame, a steady flame, or no flame at all? (d) When the fibre is removed from the flame, does it continue to burn, or does it self extinguish?
4. If the material is still burning when it is removed from the flame, blow out the flame. Note the odor and colour of the smoke, or note that no smoke was produced when the fibre was removed from the flame.
5. Observe the residue remaining after burning. Does a residue drop from the tweezers? Does that residue continue to burn? How much residue is left? Does the residue remain red, indicating that it is still very hot? What colour is the ash that remains? Is the ash the shape of the fibre, light and fluffy, or is it bead-shaped?
6. After it cools off, touch the residue or ash. Is it soft or brittle? Can it be crushed easily between the fingers, or is it hard to crush?

Results:

Typical fibre reactions for the major natural and manmade fibre types are given in the following table. When interpreting results, remember:
1. It is difficult to detect the presence of blends with a burning test. One fibre in a blend may completely mask the proper ties of another fibre.

2. Dyes and finishes affect test results. Flame-retardant finishes are especially misleading.

3. Coloured fibres, especially those produced with pigments, may retain the colour in the ash or residue.

**Table for burning characteristics of fibre:**

<table>
<thead>
<tr>
<th>Fibre</th>
<th>Approaching flame</th>
<th>In flame</th>
<th>Remove from flame</th>
<th>Odor</th>
<th>Residue</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cotton &amp; flax</strong></td>
<td>Does not shrink away; ignites on contact with flame</td>
<td>Burns quickly</td>
<td>Continues to burn; afterglow</td>
<td>Similar to burning paper</td>
<td>Light, feathery; light to charcoal gray in colour.</td>
</tr>
<tr>
<td><strong>Rayon</strong></td>
<td>Does not shrink away; ignites on contact with flame</td>
<td>Burns quickly</td>
<td>Continues to burn; afterglow</td>
<td>Similar to burning paper</td>
<td>Light, fluffy ash; very small amount</td>
</tr>
<tr>
<td><strong>Polyester</strong></td>
<td>Fuses; melts &amp; shrinks away from flame</td>
<td>Burns slowly</td>
<td>Self-extinguishes</td>
<td>Chemical odor</td>
<td>Hard, tough gray or tawny bead</td>
</tr>
<tr>
<td><strong>Acrylic</strong></td>
<td>Melts &amp; fuses away from flame; ignites readily</td>
<td>Burns rapidly</td>
<td>Continues to burn; hot molten polymer drops off while burning</td>
<td>Acrid</td>
<td>Irregularly shaped, hard black bead</td>
</tr>
<tr>
<td><strong>Nylon</strong></td>
<td>Melts away from flame; shrinks, fuses</td>
<td>Burns slowly</td>
<td>Self-extinguishes</td>
<td>Cooking celery</td>
<td>Hard, tough gray or tan bead</td>
</tr>
<tr>
<td><strong>Olefin</strong></td>
<td>Fuses; shrinks &amp; curls away from flame</td>
<td>Burns slowly</td>
<td>Continues to burn</td>
<td>Chemical odor</td>
<td>Hard, tough tan bead</td>
</tr>
<tr>
<td><strong>Wool</strong></td>
<td>Curls away from flame</td>
<td>Burns slowly</td>
<td>Self-extinguishes</td>
<td>Similar to burning hair</td>
<td>Small, brittle black bead</td>
</tr>
<tr>
<td><strong>Silk</strong></td>
<td>Curls away from flame</td>
<td>Burns slowly</td>
<td>Usually self-extinguishes</td>
<td>Similar to singed hair</td>
<td>Crushable black bead</td>
</tr>
<tr>
<td><strong>Spandex</strong></td>
<td>Fuses but does not shrink away from flame</td>
<td>Burns with melting</td>
<td>Continues to burn with melting</td>
<td>Chemical odor</td>
<td>Shape of fibre or fabric (weighted)</td>
</tr>
</tbody>
</table>

**B. Light Microscopy Test:**

A compound microscope capable of at least 200× magnifications is required for fibre identification. A magnification of 200× may be adequate for tentative identification, especially of the natural fibres, but is not adequate for viewing the details of fibre structure. The lens and objectives of the microscope, as well as the slides and cover glasses, must be clean and free of scratches. The light source should be adjusted for maximum visibility prior to looking at prepared slides. Have materials at hand to sketch the fibres viewed, and have access to a source of photographs of known fibres to make comparisons for identification. The following figure shows the longitudinal and cross-sectional views of the most common fibres.
Longitudinal mounts:

It is possible to mount a single fibre, but it is less frustrating for most microscopists to use several fibres. A minimum of ten fibres is useful when the material to be studied is a blend. Too many fibres on a slide makes it difficult to focus on a single fibre to observe the details of its surface contour. When taking a sample from a yarn in a fabric, untwist the yarn completely to separate the fibres. The basic steps for making a longitudinal mount are as follows.

1. Place a single drop of water, glycerine, or mineral oil on the center of the glass slide. Mineral oil provides the best definition, but the other materials are adequate.

2. Carefully place the fibres in the drop of liquid with the length of the fibres parallel to the long dimension of the slide.

3. Place the cover glass lightly over the drop of liquid and the specimen. Tap the cover glass gently to remove air bubbles.

4. With the objective in its highest position, place the slide on the stage of the microscope. Lower the objective carefully before trying to focus the slide. It is very easy to damage the objective by scratching it or smearing it with oil.

5. Focus on low power and observe the fibre before focusing on high power. Note the general shape of the fibre, then look at it carefully for signs of scales, convolutions, pockmarks, striations, and other features. Look carefully to see if more than one type of fibre is present.

6. With the microscope focused on high power, move the fine adjustment very slowly to see if variations in surface contour are visible. Again, look carefully to see if more than one fibre type is present.

7. Sketch the fibres as seen through the microscope, then compare your sketch with standard photographs to conclude which fibres might be present.

![Regular cotton (X-section)](image1)
![Regular cotton (longitudinal view)](image2)
![Mercerized cotton (X-section)](image3)
Cross-sectional mounts:

Special plastic and metal plates are available for making fibre cross-sections. Special fibre microtomes are used for more sophisticated work. Where such aids are not available, it is possible to make a section using a piece of cork, a threaded sewing machine needle, and a sharp single-edge razor blade. The instructions follow.

1. Use a small piece of fine-grain cork no more than 1 cm (0.5 inch) thick. Cut so that it is flat on one side. The cork wedge should be of a diameter small enough to slice easily.

2. Thread the sewing machine needle, and carefully force the point of the needle through the cork until a loop of thread can be formed.

3. Form a thread loop around your finger and pull the needle back through the cork. The needle may then be removed; it was needed just to push the thread through the cork to form the loop.

4. Make a small bundle of fibre to fit through the thread loop. Then, using the free ends of the thread, carefully pull the looped fibre back through the cork. The fibre should be packed firmly in the hole of the cork, and fibre ends will be visible on both sides of the cork. After a little practice, estimation of the exact amount of fibre to use becomes easier.

5. Place the flat side of the cork down on a cutting board and use the razor blade to cut a thin slice perpendicular to the fibre embedded in the cork. The slice should be no more than 0.5 mm thick. Make the cut with a single, continuous motion, not a sawing motion.

6. Place the cork slice on a glass slide. Do not use a mounting medium or cover glass. Focus the microscope and observe the cross sections of the fibres.

Results:

Look carefully at the shape of the fibre, and compare it with photomicrographs of known fibres. Most natural fibres can be identified by simple light microscopy, but positive identification of manufactured fibres is often difficult with this technique. When a fibre blend is present, it is possible to approximate the blend level by counting the fibres. Microscopy is also a good way to determine the number of fibres present in a blend.

C. Chemical Solubility Tests:

Chemical solubility tests are necessary to identify most manufactured fibres. They are usually performed after burning tests and microscopic examination of the fibres. Preliminary burning tests usually provide some information about the specific fibres that may be present or the fibres that are definitely not present, and microscopy provides information on the number of fibres to be identified and the predominant fibres in a blend.

The solubility procedure described in this section is based on the chemicals specified in the AATCC (American Association of Textile Chemists and Colourists) qualitative identification test method. In some instances, the term solubility is a misnomer as the material does not dissolve, but merely degrades. A material that dissolves in a solvent can be recovered from that solvent, whereas a material degraded by a solvent breaks apart but does not dissolve, and so cannot be recovered from the solvent. When observing solubility tests for fibres, it is not always possible to determine whether a fibre has actually dissolved or has merely disintegrated.
All chemical tests should be conducted in a room with proper ventilation and chemical safety protection devices. The required Material Safety Data Sheet (MSDS) for each chemical should be posted in areas where the chemical is used. Although only very small amounts of chemicals are needed for testing, accidents sometimes happen. Adhere to chemical safety rules in performing fibre identification tests. Wear protective eye goggles when using chemical solvents. Organic solvents and heated liquids should be used only in a fume hood! Follow local laboratory regulations for disposing of used solvents and fibres.

**Procedure:**

The following **Chemicals used for solubility test** table lists the chemicals and test conditions used in chemical solubility testing. When there is no prior knowledge of the fibres that may be present, the material should be tested in the solvents in the order presented in the table. Once a positive identification is made, solvent testing may be terminated. Where prior information indicates that certain fibres may be present, test the unknown fibre only in those solvents required for its identification. The general procedure for solvent identification follows.

1. When solvents are used at room temperature, the tests may be performed in a watch crystal, a 50-ml beaker, or a small test tube. Place a small amount of the fibre in the container and add the solvent. Use about 1 ml of solvent for 10 mg of fibre.

**Chemicals used for solubility test:**

<table>
<thead>
<tr>
<th>Chemical</th>
<th>Concentration (%)</th>
<th>Temperature (°C)</th>
<th>Minutes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Acetic acid</td>
<td>100</td>
<td>Room</td>
<td>5</td>
</tr>
<tr>
<td>2. Acetone</td>
<td>100</td>
<td>Room</td>
<td>5</td>
</tr>
<tr>
<td>3. Sodium hypochlorite</td>
<td>5</td>
<td>Room</td>
<td>20</td>
</tr>
<tr>
<td>4. hydrochloric acid</td>
<td>20</td>
<td>Room</td>
<td>10</td>
</tr>
<tr>
<td>5. Formic acid</td>
<td>85</td>
<td>Room</td>
<td>5</td>
</tr>
<tr>
<td>6. 1,4-Dioxane</td>
<td>100</td>
<td>101</td>
<td>5</td>
</tr>
<tr>
<td>7. m-Xylene</td>
<td>100</td>
<td>139</td>
<td>5</td>
</tr>
<tr>
<td>8. Cyclahexanone</td>
<td>100</td>
<td>156</td>
<td>5</td>
</tr>
<tr>
<td>9. Dimethylformamide</td>
<td>100</td>
<td>90</td>
<td>10</td>
</tr>
<tr>
<td>10. Sulfuric acid</td>
<td>59.5</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>11. Sulfuric acid</td>
<td>70</td>
<td>38</td>
<td>20</td>
</tr>
<tr>
<td>12. m-Cresol</td>
<td>100</td>
<td>139</td>
<td>5</td>
</tr>
<tr>
<td>13. Hydrofluoric acid</td>
<td>50</td>
<td>Room</td>
<td>20</td>
</tr>
</tbody>
</table>

*a* Use in a fume hood.

*b* Use a nonglass beaker.

2. Tests performed at the boiling point of the solvent require the use of a ventilated fume hood. Pour the solvent into a small beaker and place the beaker on a hot plate inside the fume hood. Adjust the temperature of the hot plate to maintain a slow boil. Add the fibre to the boiling liquid. Watch the reaction carefully to make sure the solvent does not boil dry. Never add additional solvent to the heated beaker!

3. For tests conducted at intermediate temperatures, heat a beaker of water on a hot plate under the fume hood, and adjust the temperature using a thermometer. Place the fibre and solvent in a test tube, then set the test tube in the beaker of heated water.
4. Watch the fibre in the solvent carefully to observe the speed with which it breaks down and the amount of the material dissolved. Note whether the material actually dissolves, degrades into small pieces, or forms a plastic mass. If all fibres are not dissolved in a specific solvent, carefully remove the undissolved fibres. Rinse them in water, and attempt to dissolve them in another solvent.

Results:

The following **Solubility of Fibres** table provides fibre solubility test results. Compare the results to identify a fibre. Some of the chemicals in the table are commonly found in the home. Other household products containing similar solvents will also damage or dissolve fibres. Acetone is often a component of nail polish, nail polish remover, paint thinners, and paint removers. Amyl acetate, a similar chemical, may damage acetate, modacrylic, and vinyon fibres. Vinegar is a dilute solution of acetic acid; it does not dissolve fibres, but it may damage the same fibres that are dissolved by glacial acetic acid.

### Solubility of Fibres (Chart for finding the solvent of a particular fibre)

<table>
<thead>
<tr>
<th>Fiber</th>
<th>Acetic acid</th>
<th>Acetone</th>
<th>Sodium hypochlorite</th>
<th>Hydrochloric acid</th>
<th>Formic acid</th>
<th>1,4-Dioxane</th>
<th>m-Xylene</th>
<th>Cyclohexanone</th>
<th>Dimethylformamide</th>
<th>Sulfuric acid (59.5%)</th>
<th>Sulfuric acid (70%)</th>
<th>m-Cresol</th>
<th>Hydrofluoric acid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetate</td>
<td>S</td>
<td>S</td>
<td>S</td>
<td>S</td>
<td>S</td>
<td>S</td>
<td>S</td>
<td>S</td>
<td>S</td>
<td>P</td>
<td>S</td>
<td>S</td>
<td>S</td>
</tr>
<tr>
<td>Acrylic</td>
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<td>Aramid</td>
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<tr>
<td>Cotton</td>
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<td>Flax</td>
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<td>Glass</td>
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<tr>
<td>Nylon</td>
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<tr>
<td>Olefin</td>
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<td>Polyester</td>
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<tr>
<td>Rayon</td>
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<tr>
<td>Saran</td>
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<td>Wool</td>
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</table>

S = soluble. I = insoluble. SP = partially soluble. N = nylon 6, soluble; nylon 6,6, insoluble.

Sodium hypochlorite, which has about 5 percent available chlorine and a pH of about 11, is the active ingredient in undiluted household chlorine laundry bleaches. Some laboratories use undiluted bleach as the chemical reagent in fibre solubility tests instead of mixing a 5 percent sodium hypochlorite solution.

**Cresol** is sometimes a component of household disinfectants and antiseptics. It is not present in a sufficiently high concentration to dissolve fibres, but it may damage acetate, acrylic, modacrylic, nylon, nytril, polyester, spandex, and vinyon fibres.
YARN AND YARN MANUFACTURING

An assemblage of fibres that is twisted or laid together so as to form a continuous strand that can be made into a textile fabric. So a yarn is a strand of natural or man-made fibres or filaments that have been twisted or grouped together for use in weaving, knitting, or other methods of constructing textile fabrics. The type of yarn to be manufactured will depend on the fibres selected; the texture, or hand, of the fabric to be made; and qualities such as warmth, resiliency, softness, and durability required in the fabric's end uses.

Types of Fibres:

All the textile fibres are classified according to their staple length into two categories, such as staple fibre and filament.

Staple fibres:

It has a limited length that varies according to the type, such as cotton, wool, jute etc. There are two types of staple fibre, one is short staple fibre another one is long staple fibre. Cotton is mainly short staple fibre and other maximum natural fibres are long staple except silk. Silk is only natural fibre that is filament.

Filament:

It has continuous length that means the length of filament is equal to the length of yarn. All man-made fibres are filament. Man-made fibres are produced as filament, although they used as staple fibres if necessary. So filaments are used as staple fibre but staple fibres never used as filament.

Classification of Yarn:

Classification of yarn according to their structure:

Yarns may be divided into three types according to their structure as follows:

1. Staple fibre yarns or Spun yarns (Single yarn):

Spun yarns are made by mechanical assembly and twisting together (spinning) of staple fibres. Ring spinning, Rotor spinning, Wrap spinning, Air-jet spinning etc. machines are used to produce this spun or single yarns.
2. Ply yarn:

Single yarns are used in the majority of fabrics for normal textile and clothing applications, but in order to obtain special yarn features, particularly high strength and modulus for technical and industrial applications, ply yarns are often needed. A *folded or ply yarn* is produced by twisting two or more single yarns together in one operation, and a *cabled yarn* is formed by twisting together two or more folded yarns or a combination of folded and single yarns. The twisting together of several single yarns increases the tenacity of the yarn by improving the binding-in of the fibres on the outer layers of the component single yarns. Ply yarns are also more regular, smoother and more hard wearing. The direction of twisting is designated as S or Z, just as in single yarns. Normally the folding twist is in the opposite direction to that of the single yarns.
3. **Filament yarns:**

A filament yarn is made from one or more continuous strands called filaments where each component filament runs the whole length of the yarn. Those yarns composed of one filament are called **monofilament yarns**, and those containing more filaments are known as **multifilament yarns**. For apparel applications, a multifilament yarn may contain as few as two or three filaments or as many as 50 filaments. In carpeting, for example, a filament yarn could consist of hundreds of filaments. Most manufactured fibres have been produced in the form of a filament yarn. **Silk is the only major natural filament yarn.**

According to the shape of the filaments in the yarn, filament yarns are classified into two types, **flat and bulk**. The filaments in a flat yarn lie straight and neat, and are parallel to the yarn axis. Thus, flat filament yarns are usually closely packed and have a smooth surface. The bulked yarns, in which the filaments are either crimped or entangled with each other, have a greater volume than the flat yarns of the same linear density.

**Texturing is the main method used to produce the bulked filament yarns.** A textured yarn is made by introducing durable crimps, coils, and loops along the length of the filaments. As textured yarns have an increased volume, the air and vapour permeability of fabrics made from them is greater than that from flat yarns. However, for applications where low air permeability is required, such as the fabrics for air bags, flat yarns may be a better choice. Textured yarns are used for Stockings and tights, swimwear, sportswear, outerwear, underwear, carpets, sewing and overedge stitching threads for extensible fabrics.

**Classification of Yarns according to their use:**

Yarns may be divided into two classifications according to their use:

**Weaving yarns and knitting yarns.**

**Weaving Yarns:**

Yarns for woven cloth are prepared for the intended end use. Yarns to be used in the warp, the lengthwise direction of a cloth, are generally stronger, have a tighter twist, and are smoother and more even than are yarns used for filling, the crosswise direction of a cloth. Novelty yarns may be used in the warp, but they are generally found in the filling. Highly twisted crepe yarns are usually found used as filling yarns.
Knitting Yarns:

These may be divided into yarns for hand knitting and yarns for machine knitting. Knitting yarns are more slackly twisted than yarns for weaving. Hand knitting yarns are generally ply, whereas those for machine knitting can be either single or ply. The following are some of the yarns used for hand knitting:

1. Knitted worsted: The four-ply all-around yarn used for accessories, for the house, and for apparel. This is the most common weight of hand-knitting yarn, comprising 90 percent of the handmade yarn business.
2. Fingering (baby or sock) yarn: The fine yarn that was originally wool, but is found most commonly in acrylic for comfort and ease of care.
3. Sport yarn: The three-ply yarn used for socks, sweaters, and hats.
4. Shetland yarn: The two-ply yarn used for sweaters.
5. Fashion or novelty yarn: Any novelty structure.

All the yarns listed may be found in any fibre. Of the major fibres, rayon is the least likely to be used in the handmade yarn business.

Types of cotton yarn:

There are two types of cotton yarn according to their manufacturing process as follows:

I. Carded yarn
II. Combed yarn

Flow chart of carded yarn manufacturing with input or feed and output or delivery product:

<table>
<thead>
<tr>
<th>Input or Feed product</th>
<th>Manufacturing process</th>
<th>Output or Delivery product</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cotton bale</td>
<td>Blow-Room</td>
<td>Lap</td>
</tr>
<tr>
<td>Lap</td>
<td>Carding</td>
<td>Carded sliver</td>
</tr>
<tr>
<td>Carded sliver</td>
<td>Drawing</td>
<td>Drawn sliver</td>
</tr>
<tr>
<td>Drawn sliver</td>
<td>Simplex</td>
<td>Roving</td>
</tr>
<tr>
<td>Roving</td>
<td>Ring - Spinning</td>
<td>Yarn (spinning bobbin)</td>
</tr>
<tr>
<td></td>
<td>(Spinning Frame)</td>
<td></td>
</tr>
<tr>
<td>Spinning bobbin</td>
<td>Winding</td>
<td>Cone</td>
</tr>
<tr>
<td></td>
<td>(Auto coner)</td>
<td></td>
</tr>
</tbody>
</table>
Blowroom Section:

**Basic operation in the Blow-room:**

- Opening the cotton bale
- Cleaning the cotton fibre
- Dust removal
- Mixing and blending of fibres
- Even or uniform feed of material to the next process i.e. card.

**Objects of Blow-room:**

The basic purpose of blow-room line is to supply following qualities of fibre tufts to the carding process.

- Small fibre tufts
- Homogeneously mixed or blended tufts
- Clean fibre tufts
- Convert fibre tufts into a fibrous sheet, is called lap.

Blending: The method of mixing different fibres within a specific ratio is known as blending.

Mixing: The method of combining identical fibres in various grade of different ratio is known as mixing.

**Conventional Blowroom line:**

There are different types of conventional blow-room line. It differs manufacturer to manufacturer. For example a typical blow-room line as follows:

1. Hopper bale opener
2. Ultra cleaner or step cleaner
3. Vertical or twine opener or cleaner
4. Hopper feeder –1
5. Porcupine opener
6. Hopper feeder –2
7. Scutcher.

Typical conventional Blow-room line
Flow chart of combed yarn manufacturing with input or feed and output or delivery product:

<table>
<thead>
<tr>
<th>Input or Feed product</th>
<th>Manufacturing process</th>
<th>Output or Delivery product</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cotton bale</td>
<td>Blow-Room</td>
<td>Lap</td>
</tr>
<tr>
<td>Lap</td>
<td>Carding</td>
<td>Carded sliver</td>
</tr>
<tr>
<td>Carded sliver</td>
<td>Pre-combed Drawing</td>
<td>Drawn sliver</td>
</tr>
<tr>
<td>Drawn sliver</td>
<td>Lap former</td>
<td>Lap</td>
</tr>
<tr>
<td>Lap</td>
<td>Combing</td>
<td>Combed sliver</td>
</tr>
<tr>
<td>Combed sliver</td>
<td>Post-combed Drawing</td>
<td>Drawn sliver</td>
</tr>
<tr>
<td>Drawn sliver</td>
<td>Simplex</td>
<td>Roving</td>
</tr>
<tr>
<td>Roving</td>
<td>Ring - Spinning</td>
<td>Yarn (spinning bobbin)</td>
</tr>
<tr>
<td></td>
<td>(Spinning frame)</td>
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<tr>
<td>Spinning bobbin</td>
<td>Winding</td>
<td>Cone</td>
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<td></td>
<td>(Auto coner)</td>
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### Process and Product of the Cotton Ring Spinning:

<table>
<thead>
<tr>
<th>Process</th>
<th>Product</th>
<th>Process</th>
<th>Product</th>
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</thead>
<tbody>
<tr>
<td>1. Mixing and Blending</td>
<td>Cotton bale</td>
<td>6. Combing</td>
<td>Combed sliver</td>
</tr>
<tr>
<td>2. Blow-Room</td>
<td>Cleaned cotton</td>
<td>7. Finisher Drawing</td>
<td>Drawn sliver</td>
</tr>
<tr>
<td>3. Carding</td>
<td>Carded sliver</td>
<td>8. Simplex</td>
<td>Roving</td>
</tr>
<tr>
<td>5. Lap forming</td>
<td>Comber lap</td>
<td>10. Winding</td>
<td>Yarn (cone)</td>
</tr>
</tbody>
</table>
Process Layout of the yarn manufacturing system with a modern Blow-room line:

- Bale Plucker
- Metal Detector
- Uniclean
- Unimix
- Uniflex
- Vision Shield
- Condenser
- Chute feed
- Carding

**FOR CARDED YARN**
- Breaker Drawing
- Finisher Drawing
- Simplex or Roving frame or Speed frame
- Ring frame (Spinning frame)
- Auto coner
- Heat setting
- Packing

**FOR COMBED YARN**
- Pre-comb Drawing
- Lap Former
- Comber
- Post-comb Drawing or Finisher Drawing
- Simplex or Roving frame or Speed frame
- Ring frame (Spinning frame)
- Auto coner
- Heat setting
- Packing
A modern blow-room line as follows: The following blow-room line provide by the Trützschler.

- Bale plucker or bale opener
- Electronic metal extractor (Trützschler)
- Rieter Unimix
- Trützschler RN cleaner
- Regulated feed of material in the blowroom
- Optical regulation
- Trützschler chute feed

Modern Blow-room section
Carding Section:
Carding is a process in which fibres are opened (almost to single fibre staple), parallelised and removes dust, impurities, neps, short fibres to produce a continuous strand of fibres called sliver of uniform weight per unit length.

Objects of Carding:
Carding is one of the most important operations in the spinning process as it directly determines the final features of the yarn, above all as far as the content of neps and husks are concerned. There are many objectives of the carding process and these can be summarized as:

- Individualization of the cotton fibre at a single fibre staple state i.e. opening the tufts into individual fibres;
- Elimination of the remaining impurities i.e. eliminating all the impurities contained in the fibre that were not eliminated in the previous cleaning operations;
- Disentangling of neps i.e. removal of neps;
- Selecting the fibres on the basis of length, removing the shortest ones;
- Fibre blending and orientation;
- Parallelising and stretching of the fibre;
- Finally produce a continuous strand of fibres called sliver of uniform weight per unit length i.e. transformation of the lap into a sliver, therefore into a regular mass of untwisted fibre.

The carding operation is carried out by the card, a machine that in practice is a system of rotating organs, mobile and fixed flats, covered with steel spikes that go by the name of wiring.

Doubling and Drawing:
In preparing the fibre tufts for spinning, doubling and drawing represent two essential operations and their combined effect permits a sliver with a more regular section to be obtained (through doubling) equipped with parallel fibres (through drawing) as well as the count requested by the spinning plan.
The drawing operation done with the machine called the drawframe, permits a homogeneous blend both with fibres of the same nature as well as fibres with a different nature; the doubling steps are usually between four and eight.

On a par with fibre characteristics such as length and fineness, a sliver with parallel fibres permits a yarn with better regularity and resistance. The drawing depends on some factors such as the number of doublings carried out and the value of the count of the entry sliver and delivery sliver. With drawing, curls, crimps and hooks are also eliminated, meaning the fibres folded in on themselves, present in the carded sliver.

Drawing is a process in which the sliver is elongated by passing it through a series of pair of rollers, each pair moving faster than the previous. This permits combination of several slivers and drawing and elongating them to straighten and create greater uniformity to form a regular sliver of smaller diameter. This action pulls the staple lengthwise over each other, thereby producing longer and thinner slivers. Finally the sliver is taken to the sliver can.

The main objects of the Draw-Frame are below:

- Crimped, curled and hooked fibres are straightened;
- Parallelisation of fibres;
- Reduction of sliver weight per unit length;
- Reduce irregularities of fibres by doubling and drafting;
- Remove remaining dust from sliver;
- Blending of fibre to provide compensation of raw material variation.

There are two passages of drawing are uses

- Breaker drawing and
- Finisher drawing
The main difference between them, like on the card, there are also autolevelers on the finisher drawframes, whose job it is to correct the draft in function of variations in the fibrous mass, to maintain the section of sliver as even as possible and therefore reduce the frequency of breaking threads in spinning and in successive operations.

![Diagram of Draw Frame Auto Leveler]

1. Autoleveller module
2. On-board computer
3. Measurement unit
4. Servomotor
5. Main motor
6. Monitoring sensor
7. Web condenser
8. Delivery rollers
9. Pre drawing
10. Main draft

**Combing section:**

**The Lap former:**

The lap former has, furthermore, the task of forming the interfacing or lap, which is employed to feed the combing machine. The lap is obtained by doubling a certain number of slivers (from 16 to 32) previously subject to a drawing passage. The slivers are fed side by side, passing through rollers and stop motion. The slivers enter the drafting section and then calendar section to produce a compact lap. Finally the lap is wound on to bobbin. In the lap former, the material undergoes a light draft of around 1.5 to 2 times one a drawing aggregate of the type 2 on top of 3 cylinders.
Combing:

The combing process is carried out in order to improve the quality of the sliver coming out of the card. The process eliminates a controlled proportion of the shortest fibres, it achieves better parallelization of fibres, it straightens curls, and it removes neps and residue impurities. It is clear from these functions that the combing process is essentially aimed at obtaining excellent quality yarns and to fulfil this objective raw materials with above average physical and mechanical features must be used from the very beginning of the spinning process. Depending on what is being produced, waste from combing varies from 12% to 25%, and this can be employed to obtain yarns with a medium-coarse count using the open-end process. So combing may be defined as straightening and parallelising of fibres and removing of short fibres, neps and impurities by using comb (combs) associated by knives, brushes and rollers.

For the production of fine and very good quality yarns combing process is essential. Fine tooth combs continue straightening the fibres until they are arranged with a high degree of parallelization that the short fibres, called noils are combed out up to 25%. Combing operation is not done when man-made fibres are processing. Finally a sliver is formed by necessary drafting.

The main objects of the combing are below:

- To remove short fibres below a pre-selected length so that the spinner enable to produce finer yarn / better yarn that cannot be possible in carding state.
- To remove neps and foreign matter from the cotton.
- More straighten and parallelisation of the fibres.

Contribution of combing to yarn quality:

- Improve the uniformity and strength
- Improve the spinning value of fibre
- Reduce the neps in the yarn.
  
  \[ \frac{1}{8} \text{" staple length} \quad = \text{30Ne carded yarn} \]
  
  \[ \quad = \text{60Ne combed yarn} \]

- Improve yarn smoothness and lusture
- Produce much clearer yarn
- Improve/Increase efficiency of the next process
- Reduce the hairiness of yarn
- Improve better twist distribution in the yarn

**Simplex or Roving frame:**

The task of this machine is to transform the sliver coming from the drawframe into roving. It is present in the carded ring spinning cycle and in the combed ring spinning cycle, in the first case it is found following the post-carding drawframe (one or two drawing steps), while in the second case after the post-combing drawframe. Further drafting of the slivers and twisting take place until the cotton stock is about to a very small diameter which is called roving. Roving is the final product of the preparatory process. For the rotor spinning system this process can be eliminated. Roving has no tensile strength; it will break apart easily with any slight pull.

Transform the sliver into roving occurs in a continuous manner through three stages:

- Drawing
- Twisting
- Winding

Drawing is generally carried out by a draft system with 3-cylinder weighing arm with double apron capable of working with entering sliver counts of 0.12 N_e to 0.24 N_e and counts of the delivered roving of 0.27 N_e to 3 N_e.
The twist is given by the rotation of the flyer located on the spindles, in fact the exit roving coming from the draft cylinders enters in the higher hole of the flyer, passing through the hollow arm and then winding on the bobbin. The twist value is given by the following equation:

\[
\text{No. twists} = \frac{\text{Revolutions of the spindle (flyer)}}{\text{Exit length 1st cylinder}}
\]

The number of revolutions of the spindle can reach up to a maximum value of 1500 rpm. The twist rate given by the roving has a value of between 10 to 100 T/m (0.25 T/inch). It should be noted that the twist value to give the roving, this being an intermediate product, has a fundamental practical importance for the next processing stage.

The thread is wound by the action of the bobbin rotating at a higher speed than the flyer (spindle), in order that on every turn the bobbin makes in addition to the spindle, a coil of roving is wound on the bobbin. The length of coil is shorter for the first layers and longer for the last.

**Objects or functions of speed frame:**

- Attenuation of drawframe, sliver to form roving of required hank by drafting.
- Insert small amount of twist to give required strength of roving.
- Winding the twist roving on to the bobbin
- Build the roving in bobbin such a form, which will facilitate handling with drawing and transfer to the next process.

**Operations involved:**

- Creeling
- Drafting
- Twisting
- Winding
- Building
- Doffing

**Cotton spinning system:**

In the cotton spinning system one differentiates between two kinds of yarns:

a) **Carded yarn:**

After the fibre material has been opened (loosened), cleaned and, if necessary also blended in the first stage, it is resolved into the state of individual fibres on a card and deposited in the form of a sliver (carded sliver). In the next stage several carded slivers are presented to a
drafting unit on a draw frame. Drafting leads to a reduction of the fibre mass per sliver. Subsequently the individual slivers, now with a lower mass, are collected together to form a draw frame sliver. Compared to the carded sliver the drawn sliver displays

- a better fibre alignment towards the longitudinal axis of the sliver and
- a higher degree of parallelization between the fibres.

A yarn finally spun out of this sliver is called a carded yarn.

b) Combed yarn:

In the cotton spinning system a combing of fibres out of draw frame slivers is basically an additional processing stage. Combing leads to the following results:

- A pre-determined portion of short fibres is combed out (comber waste). This is significant in the case of cotton, which as a natural fibre contains fibres in varying lengths. Comber waste can amount to as much as 20% to 30% of the original weight of the fibre lot being processed on the comber. The portion of longer fibres is increased in the combed material. With regard to the spinning limits the following rule is valid:

  The longer the fibres are, the finer one can spin
  The shorter the fibres are, the lower is the spinning limit.

  Thus one can spin finer yarns from the fibre lot (sliver) after combing

- Combing leads to a higher degree of cleanliness in the fibre material.

  Compared to carded yarns a combed yarn has a softer handle. This property is also transferred to fabrics made out of it.

Spinning machine

This is the final stage of yarn manufacturing. The goal of this manufacturing process to get yarn is achieved by this machine. There are different types of spinning machine. Ring frame is a conventional spinning machine. This machine has very wide scope, because it can produce coarse to very fine yarn. Till now this ring spinning machine is widely used whole over the world.

There are also some modern spinning systems too. Rotor spinning system is one of them. This system is also very famous, but it has some limitation. It is mainly used for coarse yarn.

In the following section the currently most important spinning techniques are described in some detail.
**Ring Spinning machine:**

This is comparatively the oldest spinning technique and is therefore also referred to as the classical or conventional process.

Fibre material supply to the ring spinning machine is in the form of a roving. Its fibre mass is reduced in a drafting unit. The twist inserted moves backwards and reaches the fibres leaving the drafting unit. The fibres lay around one another in a heliocoidal manner. The normal forces generated here enlarge the adhesive forces between the fibres and prevent the fibres from “flying off” under tensile strain.

---

![Diagram of Ring Spinning](image)

**Principle of Ring Spinning**

A driven spindle, on which the yarn package (tapered bobbin tube with yarn) firmly sits, is responsible for twist. Around the spindle is a stationary ring. Yarn from the drafting unit is drawn under a traveler (a small metal piece), freely moving on the ring, and then led to the yarn package. This traveler, lagging because of the yarn drag on it, is responsible for winding-on the yarn. A controlled up and down movement of the ring determines the shape of the yarn package, called a cop or spinning bobbin.

With the ring spinning technique all known yarn counts can be spun and thus the entire count range is covered (0.3 Ne to 148 Ne or 4 tex to 2000 tex)

Compared to other spinning methods the ring spinning technique, however, has the lowest performance with a maximum of about 20 m/min. One significant reason for this is that the entire yarn package must insert the full amount of twist into the yarn; it therefore cannot become too large. Twist insertion and yarn wind-on take place in one continuous process. The method used for this leads to large yarn tensions and tension fluctuations with increasing package diameters and prevents the productions of large packages. **Thus the running length of yarn on a cop is relatively short.**
OE Rotor Spinning machine:

One common aim of unconventional spinning techniques is to exceed the performance of ring spinning. This is mainly achieved by separating the process of yarn formation from that of yarn winding-on. One result is that the yarn can be wound on at higher speeds.

As a rule the spinning machine is supplied with fibres from the drawn sliver. Fibres processed on short staple spinning can also be present in combed slivers. The production of a roving (needed for ring spinning) is superfluous.

With many of these techniques the fibres from the draw frame sliver are resolved into individual fibres in a processing stage prior to actual yarn spinning. In such cases the technique is generally denoted as Open End Spinning (OE Spinning).

Out of this segment OE Rotor spinning (rotor spun yarns) is currently of special significance to circular knitting, besides ring spun yarns.
In this process fibres from the draw frame sliver supply are separated from one another on an opening roller, taken over by an air stream, led through a fibre guide channel and fed to the rotor. In the revolving rotor housing the fibres lay themselves and form a ring. Out of this rotating ring the fibres are withdrawn in a plane more or less perpendicular to that of the fibre ring. The rotation of the rotor acts on the fibres in the form of twist when they just leave the fibre ring plane. This leads to a consolidation of the fibres amongst one another, i.e., to the formation of a yarn. This yarn is led away from the rotor area and is subsequently wound on a cylindrical bobbin to form a cross-wound package. The yarn obtains “real” twist. As a result of the fibre-yarn geometry during twist insertion the fibres do not have the idealized heliocoidal configuration as in a ring yarn. Every now and then fibres also coil themselves on the yarn across the longitudinal yarn axis. These places are called wrappers. A further reference is made to them later in a direct comparison between rotor and ring yarns.

Rotor spinning has established itself so far in short staple spinning. The accent lies here in the coarse count range (3 N_e to 30 N_e or 20 tex to 200 tex). Due to improvements in the technique and machine construction, combined with the use of combed slivers, count up to 42 N_e are available in good quality. Even finer counts are not only being aimed at, but are also being presented to some extent.

In short staple spinning OE rotor spinning raises performance at this stage by about 5 to 6 times as compared to ring spinning.

**Autoconer**

The quantity of yarn on spinning bobbins or cops is small compared to the package needed for efficient at knitting and weaving. The primary purpose of the winding process is to transfer yarn from small spinning packages to large packages, which yield more efficient downstream processing.

Autoconer is a modern winding system. It is an auto coning system. By this machine we can produce a cone with required length or weight from a number of small size spinning bobbins those are produced by the ring-spinning machine without any knot. Splicing system is used in this machine. It is a fully automatic winding machine. The knitted yarn is also lubricated (waxing by paraffin wax) in this machine. In addition, all types of faults even thick places, colour materials etc. of the yarn are cleaned by this machine.
Yarn conditioning or Heat setting and Packing

Heat setting is doing in one kind of chamber. This chamber is heated at a certain temperature (60°C) normally by steam. The yarn is conditioned in this heated chamber at a certain time (40 to 50 min.) to set the yarn twist. After heat setting these cones are packed by the polythene paper in a cartoon with a certain number normally 24 cones of 2.08 kg each for knitted yarn. Total weight of the package is 50kg. But for woven yarn total weight of the package is 100lbs. Finally these cartoons are shifted to produce fabric and so on.

Cones those are ready for heat setting

Heat setting chamber
Yarn Numbering System
(Yarn Count)

**Definition:**

Count is a numerical value, which express the coarseness or fineness (diameter) of the yarn and also indicate the relationship between length and weight (the mass per unit length or the length per unit mass) of that yarn. Therefore, the concept of yarn count has been introduced which specifies a certain ratio of length to weight.

**Types of Yarn Count:**

One distinguishes between two systems:

1. **Direct Count System:**
   
   The weight of a fixed length of yarn is determined. The weight per unit length is the yarn count!
   
   The common features of all direct count systems are the length of yarn is fixed and the weight of yarn varies according to its fineness.

   The following formula is used to calculate the yarn count:

   \[
   N = \frac{W \times l}{L}
   \]

   Where, 
   
   - \(N\) = Yarn count or numbering system
   - \(W\) = Weight of the sample at the official regain in the unit of the system
   - \(L\) = Length of the sample
   - \(l\) = Unit of length of the sample

<table>
<thead>
<tr>
<th>Numbering System</th>
<th>Unit of Length (l)</th>
<th>Unit of Weight (w)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Tex system, Tt</strong></td>
<td>1000 metres</td>
<td>No. of Grams</td>
</tr>
<tr>
<td><strong>Denier, D or Td</strong></td>
<td>9000 metres</td>
<td>No. of Grams</td>
</tr>
<tr>
<td><strong>DeciTex, dtex</strong></td>
<td>10 000 metres</td>
<td>No. of Grams</td>
</tr>
<tr>
<td><strong>Millitex, mtex</strong></td>
<td>1000 metres</td>
<td>No. of Milligrams</td>
</tr>
<tr>
<td><strong>Kilotex, ktex</strong></td>
<td>1000 metres</td>
<td>No. of Kilograms</td>
</tr>
<tr>
<td><strong>Jute count</strong></td>
<td>14, 400 yards</td>
<td>No. of Pounds (lb)</td>
</tr>
</tbody>
</table>
In brief, definition of the above systems is as follows:

- Tex system: No. of grams per 1000 metres.
- Denier: No. of grams per 9000 metres.
- DeciTex: No. of grams per 10,000 metres.
- Millitex: No. of milligrams per 1000 metres.
- Kilotex: No. of kilograms per 1000 metres.
- Jute count: No. of lb per 14,400 yds.

- The Tex of a yarn indicates the weight in grammes of 1000 metres yarn. So that 40 Tex means 1000 metres of yarn weigh 40 gm.
- The Denier of a yarn indicates the weight in grammes of 9000 metres yarn. So that 150 D means 9000 metres of yarn weigh 150 gm and 100 D means 9000 metres of yarn weigh 100 gm.

From above discussion it is concluded that, higher the yarn number (count) coarser the yarn and lower the number finer the yarn.

2. Indirect Count System:

The length of a fixed weight of yarn is measured. The length per unit weight is the yarn count!

The common features of all indirect count systems are the weight of yarn is fixed and the length of yarn varies according to its fineness.

The following formula is used to calculate the yarn count:

\[ N = \frac{L \times w}{W \times I} \]

Where, 
- \( N \) = Yarn count or numbering system
- \( W \) = Weight of the sample at the official regain in the unit of the system
- \( L \) = Length of the sample
- \( w \) = Unit of weight of the sample.
- \( I \) = Unit of length of the sample.

<table>
<thead>
<tr>
<th>Numbering System</th>
<th>Unit of Length (l)</th>
<th>Unit of Weigt (w)</th>
</tr>
</thead>
<tbody>
<tr>
<td>English cotton count, ( N_e ) (( N_eB ))</td>
<td>840 yards (yds)</td>
<td>1 pound (lb)</td>
</tr>
<tr>
<td>Metric count, ( N_m )</td>
<td>1000 metres / 1km</td>
<td>1 kg</td>
</tr>
<tr>
<td>Woollen count (YSW)</td>
<td>256 yards</td>
<td>1 pound (lb)</td>
</tr>
<tr>
<td>Woollen count (Dewsbury)</td>
<td>1 yard</td>
<td>1 ounce (oz)</td>
</tr>
<tr>
<td>Worsted count, ( N_eK )</td>
<td>560 yards</td>
<td>1 pound (lb)</td>
</tr>
<tr>
<td>Linen count, ( N_eL )</td>
<td>300 yards</td>
<td>1 pound (lb)</td>
</tr>
</tbody>
</table>
In brief, definition of the above systems is as follows:

- **English count system**: No. of 840yd lengths per pound.
- **Metric count**: No. of kilometers per kilogram.
- **Woollen count (YSW)**: No. of 256yd lengths per pound.
- **Woollen count (Dewsbury)**: No. of yd lengths per oz.
- **Worsted count, N_eK**: No. of 560yd lengths per pound.
- **Linen count, N_eL**: No. of 300yd lengths per pound.

- The $N_e$ indicates how many hanks of 840 yards length weigh one English pound. So that $32N_e$ means 32 hanks of 840 yards i.e. $32 \times 840$ yards length weigh one pound.
- The $N_m$ indicates how many hanks of 1000 metres length weigh one kg. So that $50N_m$ means 50 hanks of 1000 metres i.e. $50 \times 1000$ metres length weigh one kg and $100N_m$ means 100 hanks of 1000 metres i.e. $100 \times 1000$ metres length weigh one kg.

From above discussion it is concluded that, higher the yarn number (count) finer the yarn and lower the number coarser the yarn.

**Some important conversion factors:**

1 yard = 0.9144 metre
1 metre = 1.0936 yard
1 metre = 39.37 inch
1 cm = 0.3937 inch
1 gm = 0.0353 oz
1 oz = 28.350 gm
1 pound = 453.6 gram
1 kg = 2.2046 pound
1 m/kg = 0.4961 yd/lb

1 inch = 2.54 cm
1 m² = 1.1960 yd²
1 yd² = 0.8361 m²
1 gm/m² = 0.0295 oz/yd²
1 oz/yd² = 33.91 gm/m²
1 pound = 0.4536 kg
1 yd/lb = 2.0159 m/k
Calculations concerning count:

In practice, three problems may have to be solved in yarn calculations:
- Count to be found, length and weight must be known.
- Weight to be found, count and length must be known.
- Length to be found, count and weight must be known.

Example 1:

On a cone, there are 9800 m yarn which weigh 490 gm. What is the N_e, N_m, Tex and Denier of the yarn?

Solution:

For N_e:

We know that, \( N_e = \frac{L \times w}{W \times l} \)

Here, \( L = 9800 \) m
\( W = 490 \) gm
\( w = 1 \) lb = 453.6 gm
\( l = 840 \) yds = 840 \times 0.91 m

\[ N_e = \frac{(9800 \times 453.6)}{(840 \times 0.91 \times 490)} \]
\[ N_e = 11.87 \]
\[ N_e \approx 12 \]

For N_m:

We know that, \( N_m = \frac{L \times w}{W \times l} \)

Here, \( L = 9800 \) m
\( W = 490 \) gm
\( w = 1 \) kg = 1000 gm
\( l = 1000 \) m

\[ N_m = \frac{(9800 \times 1000)}{(1000 \times 490)} \]
\[ N_m = 20 \]

For Tex:

We know that, \( Tex = \frac{W \times l}{L} \)

Here, \( L = 9800 \) m
\( W = 490 \) gm
\( l = 1000 \) m

\[ Tex = \frac{(490 \times 1000)}{9800} \]
\[ Tex = 50 \]
For Denier:

We know that, \( \text{Denier} = \frac{W \times I}{L} \)

Here, \( L = 9800 \text{m} \)
\( W = 490 \text{gm} \)
\( I = 9000 \text{m} \)

\[ \therefore \text{Denier} = \frac{(490 \times 9000)}{9800} \]

\[ \therefore \text{Denier} = 450 \]

Example 2:

What length of yarn is contained in 1.2 kg of a yarn of \( N_e 30 \)?

Solution:

We know that, \( N_e = \frac{L \times w}{W \times I} \)

\[ \therefore L = \frac{N_e \times I \times W}{w} \]

Here, \( N_e = 30 \)
\( W = 1.2 \text{ kg} = 1200 \text{gm} \)
\( w = 1 \text{lb} = 453.6 \text{gm} \)
\( l = 840 \text{yds} = 840 \times 0.91 \text{m} \)

\[ \therefore L = \frac{(30 \times 840 \times 0.91 \times 1200)}{453.6} \]

\[ \therefore L = 60666.67 \text{m} \]

Example 3:

How many kg do 700 000 m of a yarn of \( N_e 30 \) weigh?

Solution:

We know that, \( N_e = \frac{L \times w}{W \times I} \)

\[ \therefore W = \frac{L \times w}{N_e \times I} \]

Here, \( N_e = 30 \)
\( L = 700 \text{ 000 m} \)
\( w = 1 \text{lb} = 453.6 \text{ gm} \)
\( l = 840 \text{yds} = 840 \times 0.91 \text{m} \)

\[ \therefore W = \frac{(700 \text{ 000} \times 453.6)}{(840 \times 0.91 \times 30)} \]

\[ \therefore W = 13846.15 \text{ gm} \]

\[ \therefore W = 13.85 \text{ kg} \]
### Formulae for count conversion

<table>
<thead>
<tr>
<th>Known value</th>
<th>Direct system</th>
<th>Indirect system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit</td>
<td>Abbr</td>
<td>den</td>
</tr>
<tr>
<td>Td</td>
<td>den</td>
<td>----</td>
</tr>
<tr>
<td>Tt</td>
<td>ktex</td>
<td>9000</td>
</tr>
<tr>
<td></td>
<td>tex</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>dtex</td>
<td>0.9</td>
</tr>
<tr>
<td></td>
<td>mtex</td>
<td>0.009</td>
</tr>
<tr>
<td>Metr. No</td>
<td>Nm</td>
<td>9000</td>
</tr>
<tr>
<td>Cotton</td>
<td>Ne</td>
<td>5315</td>
</tr>
<tr>
<td>Linen</td>
<td>Nel</td>
<td>14882</td>
</tr>
<tr>
<td>Worsted</td>
<td>NeK</td>
<td>7972</td>
</tr>
<tr>
<td>Woollen</td>
<td>NeW</td>
<td>17440</td>
</tr>
<tr>
<td>(Yorkshire)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Application:**

Multiply or divide the known value by the factor given under needed value to obtain the desired value.

From the above chart the following count conversion formulae those are very important for practical field:

\[
Ne = \frac{5315}{D} \quad D = \frac{5315}{Ne}
\]

\[
Ne = \frac{590.5}{T} \quad \text{Tex} = \frac{590.5}{Ne}
\]

\[
Ne = 0.59 \times Nm \quad Nm = 1.693 \times Ne
\]

\[
Nm = \frac{9000}{D} \quad D = \frac{9000}{Nm}
\]

\[
Nm = \frac{1000}{T} \quad \text{Tex} = \frac{1000}{Nm}
\]

\[
D = 9 \times \text{Tex} \quad \text{Tex} = 0.111 \times D
\]
Example 1: Known value: 32 Ne Needed value: Nm, Tex, Denier?

\[
\begin{align*}
Nm &= 1.693 \times Ne = 1.693 \times 32 = 54.176 \approx 54 \\
Tex &= 590 / Ne = 590 / 32 = 18.44 \\
Denier &= 5315 / Ne = 5315 / 32 = 166.09
\end{align*}
\]

Example 2: Known value: 150D Needed value: Ne, Nm, Tex?

\[
\begin{align*}
Ne &= 5315 / \text{den} = 5315 / 150 = 35.433 \\
Nm &= 9000 / \text{den} = 9000 / 150 = 60 \\
Tex &= 0.111 \times \text{den} = 0.111 \times 150 = 16.65
\end{align*}
\]

Count calculation and denotation (Designation) for ply or doubled (folded) yarn:

Ply yarns are produced by twisting two or more singles yarns together. This increases the strength of the yarn. The singles yarns may be of equal or different count and they may be twisted together in one or several stages. Yarns of different count are twisted together in fancy yarns, for instance.

Designation of ply yarns:

In the designation of ply yarns, three different options are commonly used:

The commercial count, which is designed primarily to give information about the composition of the ply yarn, i.e. the number of constituent yarns, their count, twist and direction of twist (S or Z) and the folding twist.

The nominal (resultant) count, which is the count of a singles yarn of the same fineness as the folded or ply yarn. This is used mainly in calculations.

The effective count, which is the nominal count, corrected for the shortening of the yarn during doubling (twist contraction). Twist contraction results in a somewhat shorter and coarser yarn.

The following examples quoted from Tentative Textile Standard No. 62 will illustrate the method.

1. 40/1 Z 16 ring-spun American cotton

This describes a single yarn of linear density 40 tex (approx. 15s cotton count), having 16 tpi. Z twist, spun on a ring frame from American cotton. Traditional methods of describing the same yarn include the following: 15s ring-spun American cotton, 16 Z; 1/15s, 16 Z American cotton, ring-spun; or simply 15s cotton.
II. 15/2 S 18; 7/1 S 27 cotton

This describes a two-fold cotton yarn of resultant linear density 15 tex having 18 tpi. (S-direction) folding twist, made from two single yarns, each of linear density 7 tex and having 27 tpi. (S-direction). Traditional methods of describing the same yarn include the following:
2/80s cotton; 27 S x 18 S: or simply 2/80s cotton.

Note that 15 tex is approximately equivalent to 40s cotton count, and that the resultant count of a 2/80s cotton yarn, which is produced by twisting together two singles each approximately 80s cotton count, is 40s cotton count.

III. 45/3 Z 20; 15/2 S 18; 7/1 S 27 cotton

This describes a cotton-sewing thread of resultant linear density 45 tex made by twisting together, with 20 tpi. Z-twist, three two-fold yarn similar to that described in (II) above.

The first figure in yarn descriptions set out according to Tentative Textile Standard No. 62 always refers to the resultant tex number of the final yarn. In example (III), the groups of figures have the following meanings:

45/3 Z 20 indicates that the linear density of the final yarn is 45 tex, that it consists of 3 plies twisted together with a twist of 20 tpi., Z.

15/2 S 18 indicates that each of the 3 plies comprising the final yarn consists of a two-fold thread having a resultant linear density of 15 tex, and a doubling twist of 18 tpi., S.

7/1 S 27 indicates that each of the single yarns comprising the two-fold plies consists of a cotton yarn having a linear density of 7 tex, and a spinning twist of 27 tpi., S.

- With regard to a plain ply one must differentiate between two possibilities. Such a ply can consist of
  yarns with the same count
  yarns having different counts.

**Ply with yarns of the same count:**
This is the most commonly used plain ply.

**Calculation of count on the indirect system:**

\[ N_R = \frac{N}{n} \]

Where, \( N_R = \) Ply or resultant count (e.g. \( N_m \) or \( N_e \))
\( N = \) Single yarn count (e.g. \( N_m \) or \( N_e \))
\( n = \) Number of yarns in the ply
Example 1: A ply consists of 2 single yarns, each having a count of $N_m 50$.

Solution: 

\[ N_R = \frac{N}{n} \]
\[ = \frac{50}{2} = 25 N_m \]

Example 2: A ply consists of 2 single yarns, each having a count of $N_e 40$.

Solution: 

\[ N_R = \frac{N}{n} \]
\[ = \frac{40}{2} = 20 N_e \]

Denotation or designation based on the indirect system:

\[ N / n \]

The ply in the example is denoted as follows:

$N_m 50 / 2; N_m 30 / 2 / 3; N_m 40 / 2 / 3 / 4; N_e 40 / 2; N_e 40 / 3; N_e 60 / 2 / 3$ etc.

Calculation of count on the direct system:

\[ N_R = N \times n \]

Where, $N_R$ = Ply or resultant count (e.g. tex or den)
\[ N = \text{Single yarn count (e.g. tex or den)} \]
\[ n = \text{Number of yarns in the ply} \]

Example 1: A ply consists of 2 single yarns, each having a count of 20 tex.

Solution: 

Ply count \[ N_R = N \times n \]
\[ = 20 \times 2 = 40 \text{ tex} \]

Example 2: A ply consists of 3 single yarns, each having a count of 50 den.

Solution: 

Ply count \[ N_R = 50 \times 3 \]
\[ = 50 \times 3 = 150 \text{ den} \]

Denotation or designation based on the direct system:

\[ N \times n \]

The ply in the example is denoted as follows:

20 tex $\times 2; 50 \text{ den} \times 3; 330 \text{ dtex} \times 2 \times 3$ etc.

- Thus the ply denotation always contains the single yarn counts, written in a prescribed manner. A knitted fabric is often produced by feeding-in two (very seldom three) yarns at each feeder without their being twisted previously. It is important to note that in spite of this the same nomenclature is used for denotation as in the case of a ply.
Length calculation of a cone of sewing thread:

Example 1: What length of yarn is contained in 95gm of a yarn of Ne 50/2?

Solution:

We know that, \[ N_e = \frac{L \times W}{W \times l} \]
\[ \therefore L = \frac{N_e \times l \times W}{w} \]

Here, \( N_e = 50/2 = 25 \)
\( W = 95gm \)
\( w = 1lb = 453.6gm \)
\( l = 840yds = 840 \times 0.91m \)
\[ \therefore L = \frac{(25 \times 840 \times 0.91 \times 95)}{453.6} \]
\[ \therefore L = 4002.31m \]

From the above calculation, the formula can be developed to calculate the length of sewing thread from a cone as follows:

For \( N_e \) system: \[ L = (N_R \times W) \times (840 \times 0.9144) / 453.6 \]
\[ \therefore L = (N_R \times W) \times 1.6933 \]
Where,
\( L = \) Length of the yarn in metre (m)
\( N_R = \) Resultant or ply count of yarn in \( N_e \) system
\( W = \) Weight of the yarn in grammes (gm)
1.6933 = Constant value (Only for \( N_e \) system)

For \( N_m \) system: \[ L = (N_R \times W) \times 1000 / 1000 \]
\[ \therefore L = N_R \times W \]
Where,
\( L = \) Length of the yarn in metre (m)
\( N_R = \) Resultant or ply count of yarn
\( W = \) Weight of the yarn in grammes (gm)
Fancy yarns

In the design of textile products, yarns are first selected on the basis of their mechanical properties such as strength, extensibility, elasticity, etc. Choices may also be made on the basis of the so-called physiological properties such as vapour permeability and moisture transport. Mechanical and physiological properties are governed mainly by the type of fibre, the fibre length, and the spinning system.

However, yarns may also be selected for their appearance. Special types of yarns, both single and folded, can be created to give particular optical effects.

A. Colour effects:
   I. Mixture or Ingrain: These yarns are made by mixing fibres of different colours during spinning. This results in a heather effect. Fabric example: marengeo.

   II. Melange or Vigoureux: These yarns are spun from combed sliver or top which has been printed with stripes. The appearance is somewhat like mixture.

   III. Jaspe’ or Mouline’: These yarns are made by folding two or more differently coloured yarns, or yarns made from different fibres with different dyeing behaviour. They give a mottled appearance. Fabric example: fresco.

   IV. Mottle or Marl: These yarns are made by spinning from two-colour rovings or from two rovings of different colours. The appearance is like mouline’ but with less sharp contrast.

B. Structure effects:
   I. Slub: These yarns are single or folded yarns having long thick places, regularly or irregularly disposed. The slub effect is made either in spinning or in folding. Fabrics may have the character of linen or wild silk which is favoured in furnishings.
II. **Chenille:** This is a cut pile yarn, it is soft and voluminous. These yarns are made by cutting special fabrics into strips. They are used in furnishing fabrics and knitwear.

III. **Crepe:** These yarns are used to make fabrics with a wrinkled surface and a sandy handle. They are made from highly twisted yarns. Fabric examples: crepe de chine, georgette, crepon, marocain.

IV. **Bourette or knop:** These yarns are folded yarns containing short, often coloured bunches of fibres or yarn at regular or irregular intervals. The knops may be formed during carding, during spinning, or during folding. Fabrics have a structured surface. Example: Donegal tweed.

V. **Boucle’ or loop:** These yarns are compound yarns made by a special folding process which results in wavy or looped projections. Fabrics have a more or less grainy handle and a textured surface. Examples: boucle’, frise’, frotte’.

C. **Lustre effects:**

**Matt or lustre** effects are obtained by mixing matt and bright fibres. Lustre and glitter effects can also be obtained by the use of metal fibres or metallised plastic films (e.g. Lurex), or clear films, or man-made fibres with special cross-sections. Fabric examples: brocade, lame’.
Fabric:

Fabric is a flexible planar substance constructed from solutions, fibres, yarns, or fabrics, in any combination. Textile fabrics can be produced directly from webs of fibres by bonding, fusing or interlocking to make non-woven fabrics and felts, but their physical properties tend to restrict their potential end-usage. The mechanical manipulation of yarn into fabric is the most versatile method of manufacturing textile fabrics for a wide range of end-uses.

Types of Fabric:

There are three principal methods of mechanically manipulating yarn into textile fabrics: interweaving (interlacing or interlacement), interlooping and intertwining. All three methods have evolved from hand-manipulated techniques through their application on primitive frames into sophisticated manufacturing operations on automated machinery.

a. Interweaving:

It is the intersection or interlacement of two sets of straight threads, warp (ends) and weft (picks or filling), which cross and interweave at right angles to each other. Weaving is by far the oldest and most common method of producing continuous lengths of straight-edged fabric.

![Woven fabric (Interlacing)](image)

b. Interlooping:

It consists of forming yarn(s) into loops, each of which is typically only released after a succeeding loop has been formed and intermeshed with it so that a secure ground
loop structure is achieved. The loops are also held together by the yarn passing from one to the next. Knitting is the most common method of interloping and is second only to weaving as a method of manufacturing textile products. It is estimated that over seven million tons of knitted goods are produced annually throughout the world. Although the unique capability of knitting to manufacture shaped and form-fitting articles has been utilized for centuries, modern technology has enabled knitted constructions in shaped and unshaped fabric form to expand into a wide range of apparel, domestic and industrial end-uses.

![Warp knitted fabric](image1)

![Weft knitted fabric](image2)

Knitted fabric (Interlooping / Intermeshing)

C. Intertwining and twisting:

It includes a number of techniques, such as braiding and knotting, where threads are caused to intertwine with each other at right angles or some other angles. These techniques tend to produce special constructions whose uses are limited to very specific purposes.

![Braid fabric (Intertwining)](image3)

There is another method of manipulating directly fibre into textile fabrics is so called nonwoven process. This relatively young branch of the textile industry has expanded enormously after the second world-war because of the high production rates and the resulting cost savings.
Nonwovens are flexible, porous products consisting of one or more fibre layers. The separate fibres may either be preferentially oriented in one direction or may be deposited in a random manner. They are bonded by chemical, thermal or mechanical processes into textile products. Nonwovens are mainly planar structures.

Fabric classification at a glance:

I. Woven Fabric
   Weaving machine / Loom
   Weaving Process ← Two sets of yarn:
   (Interlacing / Interlacement)
   a. Warp/Ends → vertical yarn
      & parallel to the selvedge
   b. Weft/Picks → horizontal yarn

II. Knitted Fabric
    Knitting machine
    Knitting Process ← One or one set of yarn
    (Intermeshing / Interlooping)

III. Nonwoven Fabric
     Nonwoven Process ← Fibre web
     (Mechanical / Chemical / Thermal bonding)

IV. Braided Fabric
    Braiding machine
    Braiding Process ← At least three group of yarn from a set
    (Intertwining / Diagonal interlacement)
WOVEN FABRICS AND WEAVING TECHNOLOGY
Woven Fabrics:

Woven fabrics are composed of longitudinal or warp threads and transverse or weft threads, interlaced with one another according to the class of structure and form of design that are desired.

Process Flow To Manufacturing Woven Fabric:

Weaving preparation:

Yarn is the basic building block in weaving. Therefore, after yarn manufacturing, the next successive steps would be to weave the yarn into a fabric. However, in practice, the condition of yarn produced on the spinning machine is not always good enough to be used directly for fabric formation. Package size, yarn surface characteristics, and other factors make it necessary for both weft yarn and warp yarn to be further processed for efficient fabric formation. These preparatory processes are called weaving preparation.
Warp and weft yarns are subjected to different conditions and requirements during weaving. Therefore, the preparation of warp and weft yarns is different. Warp yarn is subjected to higher stresses which requires extra preparation. The weft yarns are not subjected to the same type of stresses as the warp yarns and thus are easily prepared for the weaving process. Depending on the spinning method, the weft yarns may not be prepared at all, but rather taken straight off the spinning process and transported to the weaving process. This is the case with open-end (rotor), air-jet and friction spinning systems which provide a large single-end package suitable for insertion during weaving. However, ring spun yarns need to go through a winding process for several reasons that are explained below. The process used to prepare yarns for weaving depend on yarn type as well.

Winding is the major preparation process for weft yarn. Warp preparation includes winding, warping, sizing and drawing-in or tying-in.

Spun yarn quality characteristics that are most important for good weaving performance include short and long-term weight uniformity, imperfections, tensile properties and hairiness. It should be noted that variation in a property is almost always more important than the average value of that property. Regardless of the processes employed, a second concept of quality has to be embraced. Not only must the quality of the yarn itself be maintained and enhanced, but also the quality of yarn packages is extremely important to further processing.

The cost of repair a yarn failure is much less if it occurs prior to the weaving process. In addition, a yarn failure during weaving also increases the chances for off quality fabric. Many if not most of the quality problems encountered during fabric forming are directly related to mistakes made during yarn manufacturing or yarn preparation for weaving.

Since winding is common for both weft and warp preparation, it will be discussed first for both yarn systems. The weaving process is particularly abusive to lengthwise yarns in a woven fabric; therefore, the technology surrounding the preparation of warp yarn for weaving is given special attention.

**Winding:**

Winding is basically transferring a yarn from one type of package to another. This simple definition may make the winding sound like a trivial process; however, it is an important and necessary process that performs the following functions especially for ring spun yarns.

- Winding produces a yarn package that is suitable for further processing. Ring spinning produces small packages of yarn (called spinner's packages or bobbins) which would be depleted relatively quick during weft insertion or warping. Therefore, the amount of yarn on several small packages is combined by splicing or knotting onto a single package. Knotting has been replaced by splicing in modern winding machines.
The winding process provides an opportunity to clear yarn defects. Thin and thick places, slubs, neps or loose fibres on the yarn are cleared during winding and, thus, the overall quality of the yarn is improved. Staple yarns require this clearing operation most because they may have these kinds of faults more often.

The increasing use of newer spinning technologies resulted in a situation where the old concept of yarn clearing and package quality now has become a part of the spinning process rather than part of a separate winding process. Properly formed packages of defect-free spun yarn are an even more critical factor. Package considerations include condition of the package core, the proper provision of yarn transfer tails; properly formed splices or knots; elimination of internal defects such as slubs, sloughs, tangles, wild yarn, scuffs and ribbon wind; and elimination of external defects such as over-end winding, cobwebs, abrasion scuffs, poor package shape or build, proper density (hardness) and unwindability.

**Winding Process:**

There are three main regions in winding; those are shown in the following figure.

a) **Region 1:**

Unwinding of yarn from the spinning package – The yarn package is held in the creel in an optimum position for unwinding. Yarn withdrawal can be done in two ways:

- **Side withdrawal:** In this method the spool is rotated and therefore the yarn does not rotate during withdrawal. As a result, the yarn twist does not change, which is an advantage.
Since the yarn does not rotate, the spool must rotate for side withdrawal. This requires additional energy and equipment, which is a disadvantage. At high winding speeds, due to inertia, the rotation of the spool can cause yarn tension variations. Upon start-up, higher tensions may be developed because the winder must overcome spool inertia.

**Over-end withdrawal:** In this system, the spool does not rotate. Therefore, the problems associated with rotating a spool are avoided. The method is simple and does not require driving the spool.

The disadvantage of this system is ballooning which is due to the way the yarn is withdrawn and unwound from the package at high speeds. Centrifugal force causes the yarn to follow a curved path leading to ballooning upon rotation of the yarn. Ballooning leads to uneven tensions in the yarn. Each time one complete wrap of yarn is removed from the supply package, the twist in that length changes by one turn. This change may be insignificant for regular round yarns, but in cases where flat yarns of metal, polymer or rubber are used, even one twist is not allowed since yarns must remain flat. These yarns cannot be unwound using the over-end method; therefore, the side withdrawal method must be used.
b) Region 2:

The tensioning and clearing region – In this region, proper tension is given to the yarn for a desired package density and body. The typical components of this region are a tension device, a device to detect thick and thin spots in the yarn (clearing device) and a stop motion. The stop motion causes the winding to stop in case of yarn breakage or the depletion of a supply package. The yarn is directed into this region by a guide.

There are two types of guides: closed and open. Closed guides require a yarn end to thread, and open guides do not. Open guides, however, give less positive guiding. Engineering issues here are guide smoothness, abrasion between yarn and guide causing yarn damage. If the guide is too rough, damage of yarn due to abrasion will occur. On the other hand, if the guide is too smooth, friction may develop. Guides are usually made from hard stainless steels or from ceramics.

Wire guides are easier to manufacture to any shape. The chromium layer can be satin finished or mirror polished depending on the need. Ceramic-coated metal guides are especially good for synthetic fibres. These guides combine wear resistance of ceramic compounds with ductility of metals while allowing complex shapes to be made. As a result, there is no need for inserts, clamps or gluing. Alumina sintered yarn guides with mat surfaces are recommended for synthetic and mixed yarns (nylon, polyester, etc.) while alumina sintered yarn guides with polished surfaces or ground polished surfaces are generally used for natural fibres (silk, wool, cotton, etc.). Porcelain yarn guides are produced with mat or mirror glazes. They are resistant to wear of natural or synthetic fibres and yarns.
Tension Device:

The tension device maintains a proper tension in the yarn to achieve a uniform package density. It also serves as a detector for excessively weak spots in the yarn that break under the added tension induced by the tension device.

There are three major types of tension devices; those are shown in the following figure.

- **Capstan (or multiplicative):**

  The output tension depends on the input tension, coefficient of friction between the yarn and the post ($\mu$), and the total angle of warp ($\alpha$):
  \[ T_{out} = T_{in} e^{\mu \alpha} \]

  Since $\mu$, $\alpha$, and $e$ are constants, $T_{out}$ is a constant multiple of the incoming tension $T_{in}$ (this is the reason why Capstan is called multiplicative). If $T_{in}$ is zero, so is the $T_{out}$.

  Changing $\mu$, $\alpha$, the number of guides and/or $T_{in}$ changes the output tension. $\mu$ can be changed by changing the post material or yarn surface characteristics.

---

Principles of basic tensioning devices
• **Additive tensioner:**

In this system, a dead weight or spring is used to apply a normal force (N) to change the tension. The output tension is calculated by:

\[
T_{out} = T_{in} + 2\mu N
\]

Since \(\mu\) and N are approximately constants for a given system, \(T_{out}\) is obtained by simply adding a constant to \(T_{in}\). If \(T_{in}\) is zero, there is still an output tension \(T_{out} = 2\mu N\). \(T_{out}\) may be changed simply by changing the normal force N.

![Roller tensioner](image1)

![Tension roller unit](image2)

![Capstan tensioner (for fine yarn)](image3)

![Disc tensioner](image4)

• **Combined tensioner:**

This is the most common type, which consists of at least a disc, and Capstan type tensioner. Tension is changed by normal force and/or wrap angle.

\[
T_{out} = T_{in} + T_{in} e^{\mu t} + 2\mu N
\]

\[
= T_{in} (1 + e^{\mu t}) + 2\mu N
\]
Yarn Clearers:

The purpose of a yarn detector is to remove thin and thick places. Yarn detectors are usually two types: mechanical and electronic.

A mechanical clearer may be as simple as two parallel blades. The distance between the plates is adjustable to allow only a predetermined yarn diameter to pass through. A thicker spot on the yarn (slub) will cause the tension on the yarn to build up and eventually break the yarn. Consequently, this type of device can only detect thick places in the yarn.

The clearers of today's technology are more sophisticated and contain electronics which continuously monitor the yarn to detect thin and thick places. Electronic detectors are mainly two types: capacitive and photo-electric. In a capacitive type detector, the variation in the mass of the yarn passing through the plates changes the capacitance of the unit. It should be emphasized that the system measures the mass of the yarn. The signal is not based on the physical dimensions of the yarn. When the generated signal reaches a certain value, the yarn is cut.
In a photo-electric detector, the yarn passes between a light source and a photocell. Any fluctuation in yarn thickness causes the fluctuation of light coming to the photocell, which changes the resistance of the photocell. This resistance change is detected by a signal conditioning amplifier which can be set to send a signal to cut the yarn and stop the winding process.

Principle of mechanical yarn clearer

Principles of electronic yarn clearers

The latest yarn clearing systems can also detect foreign fibres. These fibres are classified and eliminated during the winding process. As a result, the quality of the yarn can be improved during the winding process.

Stop Motion:

The purpose of a stop motion is to stop winding when the yarn breaks or runs out. Stop motions vary from machine to machine. In general, a mechanical stop motion consists of a counter weighted or spring loaded sensing device which is held in an inactive position if the yarn is present. Breakage or running out causes the absence of this restraining yarn and allows the sensing device to activate. Electronic stop motions simply sense the existence of the yarn without mechanical contact.

c) Region 3:

The winding region – in this region, the yarn package which is suitable for further processing is wound. Many types of package configurations can be obtained
including cone, tube or cheese, dye tube or spool depending on the next stage of processing.

The basic requirement of winding is uniform tension on the yarn. Uniform tension is necessary for consistent winding and yarn uniformity with respect to properties that are functions of tension. If the tension on yarn passing the tension device is constant, the tension in the package should be constant provided that the yarn speed is constant, i.e., the tension on the package is only a function of the yarn speed.

The yarn is wound on the package by only rotating the package. Consider a disc of radius $R$, rotating at an angular velocity $\omega$. Then, the linear velocity (or the tangential speed) of any point on the circumference of the package is:

$$V = \omega R = \text{the yarn linear velocity}$$

Therefore $V = f (\omega \text{ and } R)$

The rotation of the package may be accomplished in two ways: Spindle drive and Friction drive.

- **Spindle drive winder:**

  In this system, the spindle, which holds the package, is driven directly. There are two variations of this system: constant speed winders and variable speed winders.

  **Constant speed winders:**

  The spindle is driven at a constant speed, i.e., $\omega = \text{constant}$. Since $\omega = 2\pi n$, then $n \text{ (rpm)}$ is constant.
Therefore, \( V = \omega R = f(R) \)

As more yarn is wound on the package, \( R \) increases, hence \( V \) increases. This is not a desired situation, as explained below.

Since \( T = \text{tension} = f(V) \), a change in yarn velocity causes a change in tension. Therefore, the tension will vary throughout the package. This problem can be overcome by using the second type of the spindle drive systems in which the spindle speed is varied.

**Variable speed winder:**

In the equation \( V = \omega R \), this time \( \omega \) is variable. As \( R \) increases (i.e. more yarn on the package), \( \omega \) will change to keep \( V = \text{constant} \). Although \( R \) and \( \omega \) are variables, the product \( \omega R = V = \text{yarn velocity} = \text{constant} \).

Change \( \omega \), a variable speed motor or a variable speed connection is needed which increases the cost. Therefore, this system can be justified only for very delicate yarns. A simple way to achieve this is to use the second type of winder.

- **Friction drive winder:**

  In this system, the spindle, that carries the package, is free to rotate and the package is driven through surface friction between the package and a driven drum or roller.

  At the point of contact \( A \) (assuming no slippage), yarn, friction drum and package have the same velocity, i.e.

  \[ V_y = V_d = \omega_d R_d = \text{constant} \quad (\omega_d, R_d \text{ are constants}) \]

  Thus, a constant surface speed on the package and therefore an almost constant yarn winding speed are obtained. This system is widely used for staple yarns.

**Traversing Mechanisms:**

A traversing mechanism is used to distribute the yarn axially along the package. The distribution of the yarn should be done evenly on the package.

In the friction drive winder (only), a traversing groove cut into the friction drum is used, which is shown in the following figure. The yarn will fit into the groove and travel back and forth along the length of the package as the drum rotates.
In the spindle drive winder (also in some friction drive), a reciprocating traverse is used, i.e. an externally driven guide carries the yarn back and forth across the package.

**Types of Packages:**

Based on the winding pattern, yarn packages can be grouped under three categories: parallel, near-parallel and cross-wound packages.

- **Parallel wound packages:**

  These packages are similar to warp beams; there are many yarns, which are parallel to each other. For these packages, flanges or shoulders are necessary to prevent yarn instabilities. The application of this type of package is limited.

- **Near-parallel packages:**

  In this type of package, there is usually one yarn end that is wound on the package. A near parallel wound package is not self-supported. Therefore, for stability, the ends of the package need tapering, flanges or shoulders.
• **Cross-wound packages:**

A single yarn end is wound on the package at a considerable helix angle, which is generally less than 80°. This type of winding provides package stability and, therefore, there is no need to taper or flange the edges. Thus, a cone or tube could be used in the winding process.

The ratio of winding speed ($V_w$) and traversing speed ($V_t$) determines the package type for near-parallel and cross-wound packages. If $V_t$ is very large, relatively fast successive layers of yarn will be laid at distinct angles to each other, producing a cross-wound package. If $V_t$ is slow, successive layers will be very close to parallel to each other, producing a near parallel-wound package. Sloughing-off is a condition where many coils of yarn unwind from the package at a time. It depends on what is called a critical winding angle. The package forms can be conical or cylindrical, as required by the subsequent processes.
Pirn Winding:

A pirn or quill is a weft bobbin that is placed inside a shuttle in shuttle weaving. As the shuttle travels back and forth across the width of the shuttle loom, the weft yarn is unwound from the pirn through the eye (for ordinary shuttle) or slot (for automatic shuttle) of the shuttle and laid in the shed. The yarn on the pirn is tapered at one end such that the yarn withdrawal takes place continuously without entanglement.

Winding of a pirn is different from the regular winding process. In quilling, the yarn is transferred from a larger package to the smaller pirn, which is shown in the following figure. Also, the inspection of yarn is not part of the process, therefore, there is no yarn clearing zone.

The traverse mechanism is also different because of the different geometry of the pirn. The traverse here does not go back and forth along the package. It only builds yarn on one part of the package at a time, which is shown in the following figure. Therefore, pirn building is somewhat similar to the building of a bobbin on a ring spinning frame. This type of winding helps reduce ballooning effects, maintain uniform tension, and reduce the possibility of slough-off.

The machines that are used to wind pirn are called "quillers" or pirn winding machines. These machines are automatic, which means that when the pirn is filled, it is doffed and an empty pirn is placed on the spindle automatically. With the elimination of shuttle looms, the pirn winding process is also disappearing.
Winding Machine:

Cross winding machines are used for cross winding of tubes, cones and bobbins with one or two flanges. Yarn laying and package drive are achieved by a grooved drum. In cross-winding, the stability of the package is provided by the acute crossing angle. The package ends can be tapered as well. A near parallel winding machine with four winding positions and automatic doffing also available. The yarn traverse is controlled by a cam driven gear. Today’s winding machines allow use of different size bobbins with different flange diameters, overall lengths and winding widths on the same machine. For winding of industrial yarns such as aramid, carbon or glass yarns and monofilaments, specially designed yarn guide elements are used. A spindle speed of 5000 rpm is possible.

Today yarn singeing machine with gas burners of stainless steel, traveling blower and gas / air mixing station with variable mixing ratio is also available.

Precision Winding:

In precision winding, the position of the yarn as it is laid on the package is controlled very precisely to increase the density of the package. The following figure shows a precision winding machine. In this particular machine, the yarn positioning system is all-electronic. With the electronic system, freely programmable package building is possible, which is shown in the following figure.
Problem:

How long will it take for a winder to wind 3.00 lbs of 16 N\textsubscript{e} yarn if the winder operates at 745 yd/min. with the efficiency 95%?

We know that,

\[
\text{Time, } t = \frac{L}{V}
\]

Here, \( L \) = Length of yarn in the package

Speed, \( V \) = 745 yd/min.

Weight of the yarn in the package, \( W \) = 3.00 lbs

Yarn count, \( N\text{e} \) = 16

We know that, Yarn count, \( N\text{e} \) = \( \frac{L \times w}{W \times l} \)

Therefore, \( L = \frac{N\text{e} \times W \times l}{w} \)

\[
= \frac{16 \times 3.00 \times 840}{1}
\]

\[
= 40,320 \text{ yds}
\]

\[
\therefore t = \frac{40320}{745}
\]

\[
= 54.12 \text{ minutes (assuming no breaks or stops)}
\]

To consider the effect of efficiency,

Therefore, \( t = \frac{54.12}{0.95} \)

\[
\approx 56.97 \text{ minutes.}
\]
WARP PREPARATION

The preparation of warp yarn is more demanding and complicated than that of the weft or filling yarn. Each spot in a warp yarn must undergo several thousand cycles of various stresses applied by the weaving machine. Weaving stresses include dynamic extension / contraction, rotation (twist / untwist), and clinging of hairs. Additionally, there are metal-to-yarn and yarn-to-yarn flexing and metal-to-yarn and yarn-to-yarn abrasion stresses. Modern weaving machines have placed increased demands on warp preparation due to faster weaving speeds and the use of insertion devices other than the shuttle. Warp yarn must have uniform properties with sufficient strength to withstand stress and frictional abrasion during weaving. The number of knots should be kept to a minimum. The knots should be standard type and size such that they fit through the heddle eyes and reed dents. Sizing agent must be applied uniformly on the surface of the yarn. The yarns on the warp sheet must be parallel to each other with equal tension.

Warp preparation involves winding, warping, sizing and drawing-in or tying-in. The purpose of warp winding is to form a package of good quality yarn that is large enough to be used in the creel of a warping machine. Winding of yarn for warping is usually done at relatively high tension.

Warping:

Warping section for warp yarn preparation:

In general terms, warping is transferring many yarns from a creel of single-end packages forming a parallel sheet of yarns wound onto a beam or a section beam. Today's warping machines can process all kinds of materials including coarse and fine filament and staple yarns, monofilaments, textured and smooth yarns, silk and other synthetic yarns such as glass. Usually a static eliminator device is recommended for yarns that can generate static electricity.

The warp beam that is installed on a weaving machine is called a weaver's beam. A weaver's beam can contain several thousand ends and for different reasons it is rarely produced in one operation. There are several types of warping processes depending on the purpose. It should be noted that the warping terminology is quite different in different regions and sometimes the same term may be used to identify different processes in different regions or industries.
Warping is aimed at preparing the weaver's beam to be set up on the weaving machine. Warping carries out following operations:

- Creation, out of a limited number of warp threads (creel load), of a warp composed of any number of threads with the desired length;
- Arrangement of above-mentioned threads according to the desired sequence;
- Manufacturing of a warp beam with said characteristics.
- If the creeling capacity is equal or higher than the number of warp threads, the warping would simply entail the direct winding on the warp beam of the threads coming from the creel. Generally this condition does not take place and, even with creels of high capacity, the number of creeling positions never corresponds to the number of threads, which is always by far higher than the number of bobbins, which the creel can contain.
- This problem has been solved by dividing the warping operation into two phases:
  - 1st phase: unwinding of the threads from the bobbins and their winding on intermediate carriers, till attainment of the required total number of warp threads;
  - 2nd phase: simultaneous rewinding of all these threads and subsequent winding on the weaver's beam; the contemporaneity of these two operations is the prerequisite to produce a beam where all threads show same tension and length.

Depending on the kind of intermediate carrier used, the industrial warping process can be carried out according to two different technologies:

- Sectional warping (Indirect or conical drum or dresser warping)
- Beam warping or direct warping (preparatory beam warping).
Direct Warping or High speed warping:

In direct warping, the yarns are withdrawn from the single-end yarn packages on the creel and directly wound on a beam.

Direct warping is used in two ways:

- I. Direct warping can be used to directly produce the weaver’s beam in a single operation. This is especially suitable for strong yarns that do not require sizing such as continuous filaments or monofilaments and when the number of warp ends on the warp beam is relatively small. This is also called direct beaming.

- II. Direct warping is used to make smaller, intermediate beams called warper’s beams. These smaller beams are combined later at the sizing stage to produce the weaver’s beam. This process is called beaming. Therefore, for example, if the weaver’s beam contains 9000 warp ends, then there would be – say – 9 warper’s beams of 1000 ends each. If this weaver’s beam were to be made at one stage, the creel would have to have 9000 yarn packages, which is hardly possible to manage and accommodate. Usually 8 to 10 ends per inch are recommended on section beams for sizing purposes. Beam hardness is recommended to be 50 – 60; hardness should be achieved with tension, not from packing roll pressure.

Direct warpers are used to warp all conventional staple fibres, regenerated fibres and filaments. In direct warping, a flange beam is used. Since all the yarns are wound at the same time, the flanges provide sufficient yarn stability on the beam. The typical beam flange diameters are 800, 1000, 1250 and 1400 mm with working widths of 1400 to 2800 mm. Machine specific options include tape applicator, static eliminator, windscreen, comb blowing and dust extraction devices, yarn storage and inspection units, oiler, tension roller unit, beam removal unit and control platform. An expanding zigzag comb which is used to control the width of the beam and keep the yarns parallel and straight.
Indirect or Section Warping:

In indirect warping, a section beam is produced first as shown in figure. Other names used for section warping are pattern warping, band warping or drum warping. The section beam is tapered at one end. Warp yarn is wound on the beam in sections, starting with the tapered end of the beam. Each section has multiple ends that are traversed together slowly during winding along the length of the section to form the angle. Due to the geometry of the yarn sections, the last section on the beam will have a tapered end that will make the whole yarn on the beam stable. It is important that each layer on the beam contain the same number of yarns. The same length of yarn is wound on each section which is measured by a measuring roller. The warping speed can be adjusted in the range of 20 to 800 m/min; however, residual elongation will be reduced at high speeds.

After all the sections on the beam are wound completely, then the yarn on the beam is wound onto a regular beam with flanges, before sizing. This process is called beaming. Sometimes a section beam is also used in the sizing stage.
With today's computerized sectional warping systems, once the basic style information is entered, the computer automatically calculates the following:

- number of sections on the beam and width of each section
- carrier lateral movement speed and automatic positioning of each section start point
- automatic stops for leasing
- calculation of the correct feed speed irrespective of the material and warp density.

The computer can also monitor the following:

- automatic stops for predetermined length
- operating speed regulation of +/- 0.5% between warping and beaming
- beaming traverse motion
- memory of yarn breakage during warping for beaming

Other typical features of a modern sectional warper are:
- feeler roller to apply material specific pressure to obtain exact cylindrical warp buildup
- lease and sizing band magazines
- constant warp tension over the full warp width
- automatic section positioning with photo-optical section width measurement
- pneumatic stop brakes
- warp tension regulation for uniform buildup
- automatic warp beam loading, doffing and chucking
Warping Machines:
A typical warping machine has three major components: creel, headstock and control devices.

I. Creel:

There are various types of creels. The most common creel types are:

- parallel standard creel with fixed package frame (single end creel)
- parallel creel with package trucks
- parallel creel with swiveling package frame sections (for cotton, viscose, polyester/cotton, wool colored)
- parallel creel with reserve packages (magazine creel, for synthetic filaments)
- parallel creel with unrolling draw-off for polypropylene, monofilaments
- V – creel with reversible frames
- V – creel with reversible frames and automatic knotter (for cotton, viscose, polyester/cotton)
- V – creel with traveling packages.

Parallel creels are used for sectional warping and direct warping; V – creels are used for direct warping.

In single end creel, there is only one package for each warp end. Since creeling takes a considerable time, the package size should be such that a number of beams can be made from one creel. Also, usually more than one creel is used such that once a creel is depleted; the next one would be readily available to continue warping. Depending on the space requirements, this is done either by moving the headstock or by moving the creels. If the headstock is movable, then usually two creels are used which are called duplicated creels. If the headstock is fixed, again two creels will be enough but a third creel place is needed in which to move the empty creel. This is known as a truck creel or trolley creel.
Trolley creels are suitable for both sectional and direct warping. The creel generally has a rectangular tube construction. The trolley creels have wheels for easy maneuvering; however, they are stabilized to prevent tipping over.

In a magazine creel, usually a two-package creel is used. The tail end of the running package is attached to the leading end of the reserve package. This allows continuous warping operation. With a yarn splicer, the undesirable effects of knots can be avoided. Normally a magazine creel with two pivoting spindles: a working spindle and a reserve spindle. When one set of spindles is in operation, the empty packages are removed from the reserve set, which is then filled with new packages. The creel can be loaded from the center aisle or from the outside. They are ideal if long yarn lengths are to be unwound, if the packages do not have measured yarn lengths or if residual packages are used.

In the swivel frame creel, empty packages can be replaced on either side from the center aisle. This creel is suitable for confined spaces. A foot pedal is used to swivel the frame 180° to allow the empty side to be reccreeled. Swivel creels can have a V shape as well.

In traveling package creels, the creel is like a continuous belt. Usually two creels form a V shape. When the full packages are being used for warping on the outside position (active or run position), the empty inner side can be filled with packages. When the full packages are emptied, the side with the full packages is brought to the warping area (outside) by rotation and the warping continues without much interruption except for threading of the warp ends. After rotating the creel, the groups of yarn from the vertical rows are threaded and pulled to the warper where each yarn is positioned in the designated comb dent. The V configuration is especially suitable for warping of staple yarns at high speeds. Other advantages of V - creel are:

- no need for yarn guide
- uniform yarn tension across the whole beam
- free yarn run from the creel to the warping machine
- low yarn tension

In cases where overhead unwinding cannot be tolerated, a roller creel is used. In the roller creel, the package rotates and side withdrawal of yarn takes place. This type of creel is used especially for carbon filaments, aramid fibres, tape yarns and monofilaments.

II. Headstock:

The yarn speed should be kept as constant as possible during warping. In indirect (sectional) warping, a constant speed drive is generally sufficient in providing approximately uniform yarn speed on the surface of the beam. This is because the thickness of the yarn built on the beam is relatively small compared to the beam diameter such that the surface speed does not change much. In direct warping, the change due to yarn buildup on the beam is
significant. Therefore, in direct warping, mechanisms that are similar to the ones used in winding are utilized to attain uniform yarn speed; surface friction drive and variable speed drive are commonly used. For some filament yarns, variable speed drive is chosen since friction drive would cause problems.

Today's headstocks are equipped with advanced design features such as precision direct drive, advanced electronics, smooth doffing and programmable breaking. Automatic hydraulic doffing is accomplished with the operation of one button. Programmable pneumatic braking provides a constant stopping distance regardless of the operating speed or beam diameter. The length of the yarn wound on the beam is controlled with a measuring roller and counter device. The density of the yarn can be controlled by tension, pressure or both. Frictional drive usually results in higher yarn density. In spindle drive, yarn tension and a hydraulically activated pressure roller are used to control density. Some headstocks are designed to run more than one beam width.

III. Control Devices

Similar to winding, warp yarns are threaded through tension devices, stop motions, leasing rods and the reed. Uniform tension is necessary so that all the warp ends behave the same way. The tension on the warp yarns is kept relatively low. Every end requires a tension controller which is usually located close to the package.

A quick response, advanced stop motion is necessary for warping. Due to the high inertia of the beam, it is difficult to stop the beam suddenly once an end is broken. However, the beam must be stopped before the broken end reaches the beam. The stop motion
electrically links each warp end to the warper braking system; when a warp end breaks, the warper stops. *Powerful brakes are used for this purpose.* A light indicates the location of the broken end. The warping process is generally irreversible, unwinding of the beam would cause yarn entanglement. The stop motion device, which can be mechanical or electronic for quick response, is usually located near the creel.

In an electronic, motion sensitive stop motion device; the electronic eye detects movement of individual ends to trigger a warp stop when there is no yarn movement.

To avoid static buildup, especially with manmade fibres, different methods can be used including chemicals, ionization of air or humidification of air. Fans are used to prevent lint accumulation when warping staple yarns.
SIZING OR SLASHING

Sizing section also for warp yarn preparation

Although the quality and characteristics of the warp yarns coming out of the winding and warping processes are quite good, they are still not good enough for the weaving process for most of the yarns. The weaving process requires the warp yarn to be strong, smooth and elastic or extensible to a certain degree. To achieve these properties on the warp yarns, a protective coating of a polymeric film forming agent (size) is applied to the warp yarns prior to weaving; this process is called sizing or slashing. Sizing is not a value added process in woven fabric manufacturing. This is because, after the fabric is woven, the size materials will be removed from the fabric during the finishing operation, which is called desizing.

The main purposes of sizing are as follows:

- to increase the strength of the yarns
- to reduce the yarn hairiness that would cause problems in weaving process
- to increase the abrasion resistance of the yarns against other yarns and various weaving machine elements
- to reduce fluff and fly during the weaving process for high speed weaving machines.
- To increase the weaveability of the warp yarn, this is the main goal of sizing.

The ultimate goal of sizing is to eliminate or reduce warp breaks during weaving. Warp breaks are caused either by high tension or by low strength in the yarn. High tensions in the warp are caused by large shed openings, lack of proper tension compensation, high beat-up force and inadequate let-off. Knots, yarn entanglement and high friction also cause tension buildup.

Sizing is a complementary operation which is carried out on warps formed by spun yarns with insufficient tenacity or by continuous filament yarns with zero twist. In general, when sizing is necessary, the yarn is beam warped, therefore all beams corresponding to the beams are fed, as soon as warping is completed, to the sizing machine where they are assembled. Sizing consists of impregnating the yarn with particular substances which form on the yarn surface a film with the aim of improving yarn smoothness and tenacity during the subsequent weaving stage. Thanks to its improved tenacity and elasticity, the yarn can stand without problems the tensions and the rubbing caused by weaving.

There is not just one sizing ‘recipe’ which is valid for all processes, on the contrary the sizing methods change depending on the type of weaving machine used, on the yarn type and count, on the technician’s experience and skill, but above all on the kind of material in progress. The
only common denominator of the various sizing materials is that they have to be easily removable after weaving in order to allow carrying out without problems the selected finishing cycle. The substances used as sizing material are potato flour, starches, glues, fats but also talc and kaolin, when a particularly thick size is requested.

It should be noted that only warp yarns need to be sized. This is because, as mentioned earlier, warp yarns are subject to harsher treatments than filling yarns during the weaving process on the weaving machine. Therefore, the filling yarns will be free of size and no special finishing considerations are necessary for these yarns in the fabric. Often, around 80% of yarn failures in weaving are caused by 20% or less of the yarns in a warp which are called repeater ends. The slashing process deals with enhancing individual warp yarn properties not with improving the characteristics of the warp sheet. If done improperly, slashing can worsen yarn sheet characteristics.

Several spun yarn properties are positively affected by sizing. Figure shows the effect of sizing on a typical staple yarn sheet. Good sizing should reduce hairiness, improve strength and abrasion resistance while keeping the yarns separated. Elongation is reduced in a controlled manner. Flexibility is reduced but reasonably maintained. If the sizing is not done correctly, the long hair fibres protruding from one yarn will be glued together with the fibres from the other yarns. This will cause damage of the size film when the yarn sheets are separated back into individual yarns at the separator rods on the slasher which will reduce the strength and cause a yarn break. The fibres should be kept to the body of the yarn such that hairs and fibrils do not interfere with the weaving process.

Factors influencing yarn hairiness include hairiness generated by the winding process, spinning tensions, location of the yarn on the spinning package, yarn balloon shape, yarn twist, spindle speed, yarn count, percentage synthetics in a blend, end spacing at slashing, size add-on, slasher creep speed and bottom squeeze roll cover.

Control of yarn hairiness with sizing,

- top: unsized; middle: improperly sized; bottom: properly sized.
A practical understanding of the importance of size penetration, size encapsulation, yarn hairiness, residual yarn elongation and yarn abrasion resistance is essential to good sizing practice. It is important that the size film must coat the yarn surface without excessive penetration into the body of the yarn, because if the size material is penetrated deep in the yarn, complete desizing would not be possible. Therefore, only enough penetration should occur to achieve bonding of the size film to prevent removal during weaving.

The following terms are used related to sizing:

- **Size Concentration**: the mass of oven dry solid matter in size paste
- **Size Take-up (size add-on)**: the mass of paste taken up in the size box per unit weight of oven dry unsized yarn
- **Size Percentage**: the mass of oven dry size per unit weight of oven dry unsized yarn.

There is an optimum level of size add-on that gives the minimum warp end breakage. Excessive size makes the yarn stiffer and less extensible; yarns with too little size will not be strong and smooth enough for weaving. Therefore, too little or too much sizing causes an increase in warp end break. Optimum size add-on gives the best results for weaving.

Although sizing is done mainly to increase the strength of the yarn, some strong yarns such as continuous filaments still need sizing. This is because sizing keeps the slack and broken filaments together in low twist yarns which otherwise would protrude from the body and rub against the machine elements, leading to entanglement, development of fuzz balls and end breaks.

**Other points to consider in sizing:**

- Slasher creel tension control is critical especially with MJS and open-end yarns. Maximum tension should not exceed 5% of breaking strength (15 – 20g for ring spun yarns and 12 – 15g for open-end, MJS and MVS yarns). With coarse yarns, sometimes 30g is allowable.
- The amount of size picked up is affected by the viscosity of the size mix as well as the yarn structure. The viscosity of the mix is controlled by the recipe, amount of solid content in the size liquor and the type of sizing product, mechanical mixing level, temperature and time of boiling. Flat filaments, textured and spun yarns pick up size differently.
- Yarn spacing at the slasher size box and on the drying cylinders is very important.
- The choice of size for staple yarns is usually based on cost. For filament yarns, the size material is chosen based on the compatibility with the fibre.
- Running the slasher at creep speed, which is sometimes necessary, generates a very undesirable condition for proper sizing and should be minimized in every way possible.
- Stretch of warp yarns during sizing should be controlled accurately to maintain residual elongation in the yarn which is needed for good weaving. Back beam – size box stretch should not exceed 0.5%.
- Water-soluble sizes can cause problems in water jet weaving.
- Process studies to determine causes for inefficiency should be conducted with strict cause analysis techniques by an experienced practitioner and not as part of a typical stop frequency study for job assignments.
- Guide rollers should be kept free from nicks, burrs and sharp edges, especially for MJS yarns. They should be sanded / polished frequently.
- Pre-wetting yarns prior to sizing can reduce the amount of required size add-on for the same performance, especially for cotton yarns.

**Sizing machine:**

A sizing machine is used to apply the size material to the warp yarns. The first sizing machine was built in 1803 in England. The major parts of the sizing machine are the creel, size box, drying units, separation unit, beaming and various control devices.

![Warp sizing (simplified)](image)

The size box is probably the most important section of the sizing machine. During the sizing process, the sheet of yarns is passed through the size box which contains the hot water solution or mixtures of sizing agents. The yarns pick up the required quantity of size solution in the size box, any excess size is squeezed off as the yarns pass through squeeze rolls. Depending on the size material, warp quality and density, single and double immersion rolls and single squeeze and double squeeze configurations are used. Multiple size boxes can also be employed. In general, single box sizing machines have two squeezing rollers and two box machines have a single roller in each box. It is important that the rollers provide uniform squeezing pressure. The squeezing system determines the degree of size pick up to a large extent. While providing size consistency, the roll pressure should be adjusted to get around 125 to 130% wet pick up for cotton yarns, 110 to 115% for poly/cotton and 95 to 105% for polyester. On average, MJS and open-end yarns pick up around 10 to 15% more wet size than a comparable ring spun yarn. Therefore, about 10% more water should be added to get the same add-on. The bottom rollers are usually made of steel and the top rollers are rubber coated.
Temperature of the size box is important for proper size pick up. For 100% polyvinyl alcohol (PVA) sizing, a temperature of 160 to 170°F (70°C) is recommended. Constant size temperature can be obtained in two ways:

1. Direct heating in which steam is injected into the size.
2. Indirect heating in which steam flows in pipes around the double walled size box.

A cooker is used to prepare the size and the shearing action in the cooker is important for uniform mixing. Powdered size from silos, big-bags or sacks is metered into weighing stations and then transferred to the cooker.

After the size box, the yarns go through the dryer section. The wet yarns are dried by using hot air, infrared radiation or cylinder drying. Cylinder drying is done using steam heated hot rolls which are called drying cylinders. Some-times, a combination of drying methods is used on the same machine. Quite often, the wet yarns (usually filament) are predried using hot air or infrared and drying is completed with drying cylinders.

Due to the nature of sizing, the yarns in the sheet may be stuck together at the exit of the dryer section. Therefore, they are separated into individual ends by using bust rods. First, the
individual sheets of yarns from each section beam are separated followed by pins in the expansion comb to separate the yarns within each sheet. Then the yarns are wound onto a loom beam for weaving (weaver's beam).

Beam arrangements in the creel are usually two types:

1. Groups of 2, 4, 6 or 8, one to four tiers
2. Staggered, two-tier arrangement

Some sizing machines can have up to 24 beam positions. The beams can be controlled in groups or individually. The let-off can be individual let-off, single group let-off or wrap-round let-off.
**DRAWING-IN AND TYING-IN**

**Drawing-in:**

After sizing, the sized warp beam is prepared to be placed on the weaving machine. High fashion fabrics generally have high density which increases the demand on the quality of shed opening. As a result, warp leasing is becoming more popular. Different lease combinations can be selected with the automated leasing machines.

Drawing-in is the entering of yarns from a new warp into the weaving elements of a weaving machine, namely drop wires, heddles and reed, when starting up a new fabric style. Tying-in the new warp ends to the depleted warp is done when a new pattern is not required.

A drop wire is a narrow metal sheet that is hung in the air by the tensioned warp yarn. If the warp yarn is broken or slacken (loose), then the drop wire drops and touches a metal bar that extends along the width of the machine. This contact between the drop wire and metal bar closes an electrical circuit and shuts down the machine immediately. There is a drop wire for each warp yarn.

Pinning machines are used to pin open drop wires on warps. Since the pinning speed is high (up to 200 wires per minute), these machines are economical for more than 3000 warp ends.

After drop wire, the warp yarn goes through the heddle eye (there is only one warp yarn per heddle eye). This is done according to a plan called drawing-in-draft. Then the yarn is threaded through the reed spaces. A reed space is the opening between two dents (metal) in a reed. In general, one, two or three warp yarns are passed through one reed space. The reed plan
specifies the number of yarns per reed space. The number of yarns depends on the diameter of the yarns and the dent opening; each yarn should be able to move freely up and down in the reed space independent of the other yarns.

In the manual mode of drawing-in, one person sorts the warp yarn and the other draws it through from the other side. The sorting step can be automated by a reaching machine.

Today, the drawing-in and tying-in processes are fully automated. Drawing-in is done using robot-like machines. A special type of heddle is needed for automated drawing-in. The warp ends, taken from the warp sheet, are fed individually to the drawing-in element; heddles are separated from the stack and brought to the drawing-in position; a plastic knife opens a gap in the reed and a hook draws-in the warp end through the heddle and reed in one step.
Automatic drawing-in increases speed, flexibility and quality in weaving preparation compared to manual drawing-in. A drawing rate of 50,000 warp ends per 8 hours (200 ends per minute) is possible.

Changing style means producing a new fabric style, weaver’s beam changing means going on weaving the same fabric style just replacing the empty beam with a full beam of same type.

Drawing-in consists of threading the warp yarns through the drop wires, the healds and the reed. Depending on the styles of the produced fabrics and on the company’s size, this operation can be carried out manually, by drawing-in male or female workers.

**Tying-in:**

After the depletion of a warp beam on the weaving machine, if there will be no change in design, then the drawing-in process needs not be repeated. The ends of the old warp beam (now a fabric beam) are cut and the ends of the new warp beam are tied to the corresponding ends of the old beam which is called tying-in process. Then, the warp ends are pulled through the heddle eyes and reed until the knots are cleared.
A small portable robot is used on or off the weaving machine for tying-in. A typical warp tying machine can knot single or ply yarns from 1.7 to 80 N (340 – 7 tex). They can knot cotton, wool, synthetic and blend warp yarns as well as yarns of different thicknesses. Typical knotting speed of a knotter is from 60 to 600 knots per minute.

With continuous filaments and bulky yarns, a non-slip double knot is recommended which can be handled by knotting machines. Some automatic tying machines can knot extremely short tails of yarns (5mm). Tape yarns and monofilaments require a slightly different tying machine. Tape yarns of up to 8 mm width can be tied. The knotting speed is typically 60 to 450 knots per minute. The number of warp ends to be tied together can be preprogrammed; once this number is reached, the knotter stops automatically. A dual knotting system is used on a double beam weaving machine; the knotters work from left to right and from right to left simultaneously.

The warp welding machine is used to weld the warp end layer with a plastic foil after drawing-in which provides simple insertion through the weaving machine. This results in time saving at the machine startup. After drawing-in with a brush beam the ends protruding from the reed are aligned parallel and stretched evenly. An approximately 5cm wide plastic foil is placed on top of the lower welding bar and a longer piece of plastic foil is placed on the warp yarns above the lower piece of plastic foil. By moving the upper welding bar down, the plastic foils are welded together with the warp yarns in between.

Several points should be considered during drawing-in and tying-in. Improper splicing and / or knotting can become critical to good weaving performance. The straightness of individual warp yarns and their freedom to act independently as they pass through a weaving machine are important for quality weaving. Yarns that are crossed and tangled cannot proceed without excessive stress and yarns that are restricted or influenced by drop-wire activity, heddle spacing, harness interference or reed spacing will not weave at top performance.
FUNDAMENTALS OF WEAVING

Weaving Principle:

The following figures show a schematic of weaving. The warp yarns are stored on a beam called a weaver's beam or warp beam (also called a loom beam) and they flow to the front of the machine where the fabric beam is located. The filling yarn is withdrawn from a single package and inserted between the sheets of warp yarns, which are perpendicular to the filling yarn.

The warp beam, which holds the lengthwise yarns, is located at the back of the machine and is controlled so that it releases yarn to the weaving area of the loom as needed. This function is the let-off motion, the first of four primary loom motions. The heald wires or heddles are wire or metal strips that allow control of the individual ends; an end is pulled through the eye located in the center of each heald. The individual heddles are mounted in a harness or heald shaft that allows the warp yarns to be controlled in groups. A loom has at least two harnesses or heald shafts, and most have more. The number of harnesses on a loom helps determine the complexity of the fabric design that can be produced.

In a two-harness loom, every other warp yarn across the width of the fabric is in one harness. When that harness is raised, half of the warp yarns rise to produce an opening between the two
sheets of warp yarns. This opening, known as the shed, produces a path through which the filling is inserted. The loom motion is called shedding, and the order in which harnesses are raised and lowered produces a pattern in the fabric. In looms containing more than two harnesses, the sequence for drawing ends through heddles and mounting heddles in harnesses becomes more intricate. In many cases, groups of harnesses are raised and lowered together. A very good fabric designer is needed to plan the drawing-in of a warp and the sequencing of harness movements in a 32-harness loom.

The third basic loom motion is picking or weft insertion. For many years, weft yarn was laid across the shed with a shuttle. In today's weaving machines, another device, such as a jet of air or water, a rapier, or a small projectile, is used to place the pick. Then each filling yarn must be packed against the previously placed pick. This is accomplished by using a reed, which is parallel to the harness, to press the pick into position. This is the beat-up motion, the fourth and final primary loom motion. The three motions such as shedding, picking and beat-up is called weaving cycle or loom cycle.

The cloth beam, or cloth roll, located at the front of the loom, holds the completed fabric; as each pick is beaten into position, the fabric just produced is rolled onto the take-up beam. This take-up motion is the final loom motion; because let-off and take-up occur simultaneously, the loom motion is usually referred to as “let-off and take-up”.

Most fabrics are produced on weaving machines with eight or fewer harnesses; elaborate fabrics, however, require many harnesses and the special attachments required to control groups of harnesses, or they have mechanisms similar to computer controls that move each individual warp yarn to produce complex patterns. These more elaborate shedding mechanisms such as dobbby and jacquard shedding mechanism.
Basic weaving motions:

Although there are many mechanisms on a modern weaving machine for various purposes, there are five basic mechanisms that are essential for continuous weaving as follows:

Warp let-off, shedding, pick insertion or picking, beat-up and fabric take-up.

1. **Warp Let-off:**

Warp let-off mechanism releases the warp yarn from the warp beam as the warp yarn is woven into the fabric. The let-off mechanism applies tension to the warp yarns by controlling the rate of flow of warp yarns. The mechanism should keep the proper tension on the warp yarns which controls the crimp rates of warp and weft yarns. Uniform tension is essential in weaving. Increasing the warp tension decreases the warp crimp and increases the filling crimp in the fabric. The crimp ratio of warp and weft affects the fabric thickness. Yarn diameters being the same, equal warp and weft crimps result in the lowest thickness of the fabric.

Let-off mechanisms can be classified as negative and positive. In negative let-off mechanism, the tension on the warp yarns provides the driving force against friction forces in the let-off motion. The tension of the warp is regulated by the friction between the chain or rope and the beam ruffle. The negative friction type of let-off mechanisms were mainly used for non-automatic weaving. In positive let-off mechanisms, the warp beam is turned at a rate which depends on the yarn length between the warp beam and cloth fell. A separate mechanism is used to apply constant tension on the warp yarns as the warp is depleted.
and controlled release of warp yarn from full to empty beam which results in a consistent warp tension. It is good for preventing fabric defects such as pick density variation and stop marks. Weaving tensions should be maintained at minimum levels for best weaving performance.

The electronic let-off system can be equipped with a pulley mechanism or a reduction gear mechanism. The linear and positive letting off of the warp beam can be provided by a magnetic reading of the whip roll position. Electronic warp let-off systems have programmable movements with a tenth of pick accuracy to eliminate stop marks. They have the capability to release the yarn tension at the stop of the weaving machine and recover it at the starting of the machine by a number of picks ranging 1/10 of a pick to 50 picks. This way, the overstretching of the yarn, which is the major cause of defects during the standstill time, is prevented. The system can follow any movement of the machine, such as the forward slow motion (jogging) and pick finding motion. With the electronic let-off mechanism, since brake and coupling linings are no longer needed, spare parts cost is reduced.

2. Warp Shedding:

Shedding is the movement of some warp yarns up and some down to make an angled opening for the weft yarn to be inserted through. This opening is called “shed”. Before the insertion of the next weft yarn, the warp sheet has to be rearranged according to the fabric design pattern so that the required fabric structure is produced.

3. Weft Insertion or Picking:

After each shed change, the weft yarn is inserted through the shed as shown in the following figure. It is possible to select and insert different weft yarns one after another. These weft yarns can be of different colour, weight, etc., and a selection mechanism is used for this purpose. Depending on the machine type, several different weft yarns can be used in the same fabric. The selection mechanism presents the proper weft yarn to the yarn carrier for insertion of each yarn.

Weaving machines are usually classified according to the weft insertion mechanism. The major weft insertion systems that are used today are air-jet, rapier, projectile and water-jet, which are called shuttleless weaving machines.

Shuttle with a pirn
A gripper projectile transports a single weft yarn into the shed. Energy required for picking is built up by twisting a torsion rod. On release, the rod immediately returns to its initial position, smoothly accelerating the projectile through a picking lever. The projectile glides through the shed in a rake-shaped guide, braked in the receiving unit, the projectile is then conveyed to its original position by a transport device installed under the shed. The projectile's small size makes shedding motions shorter which increases operating speeds over wide widths of fabric, often weaving more than one panel of fabric with one insertion mechanism.

The above figure illustrates weft insertion by two flexible rapiers with weft carriers, a giver and a taker. The weft is inserted half way into the shed by one carrier and
taken over in the center by the other carrier and drawn out to the opposite side of the fabric. A special crank gear drives the oscillating tape wheels to which the rapier tapes are attached. In the shed, the tapes move without guides. The grippers assume the correct clamping position automatically. Different versions of rapier insertion systems are also available.

The most popular method of weft insertion is illustrated in the following figure where a jet of air is used to “blow” the weft yarn into the shed. This small mass of insertion fluid enables the mechanism to operate at extremely high insertion rates. The picks are continuously measured and drawn from a supply package, given their initial acceleration by the main air nozzle and boosted or assisted across the fabric width by timed groups of relay air nozzles. The other fluid system uses water as the insertion medium, but the use of a water-jet is generally limited to hydrophobic yarns such as nylon or polyester filament.

A shuttle loom uses a shuttle to store and carry the yarn back and forth across the loom. Shuttle looms have become obsolete in manufacturing of traditional woven fabrics due to several reasons, including low production rate, high noise, safety concerns, limited capabilities, etc. Nevertheless, the shuttle loom is still used as a reference point for the modern shuttleless weaving machines. Besides, some industrial woven fabrics are still being made on specially designed shuttle looms.

Yarn Accumulators or Feeders:

Yarn feeders or accumulators are used to wind a predetermined yarn length to make it ready for insertion. Their main purpose is to supply weft yarn to the weaving machine smoothly and at a constant and proper tension. There are various types of feeders used. The selection of a feeder depends on several factors:
Maximum speed depends on the yarn count range. Reserve control can be done mechanically or electronically by means of photocells. The threading through the feeder can be done manually or pneumatically. The tensioning of the yarn is controlled by a breaking device which can be of different types including bristle, metal lamella, flex brake and coaxial output tensioner. The figure (flex brake) shows the membrane and the endless beryllium copper tensioning strip. The flex is used to replace the brush ring and output tensioner in conventional brake systems. The figure (Coaxial output tensioner) shows the yarn travels through two tensioning discs mounted in the feeder nose. An adjustable tensioning spring regulates the base force exerted by the discs, which allow the setting, and maintaining of tension levels. During the weft insertion process, the “Coaxial output tensioner” compensates yarn tension fluctuations. Weft breakage at the feeder entry is detected electronically to stop the weaving machine. For heavy yarns, a balloon breaker can be fitted in front of the feeder instead of the normal eyelet.
During weaving of fine woolens and linen yarns, usually a lubricant is used which is supplied by a liquid dispenser. The purpose of the lubricant is to reduce weft breakages and increase weaving machine speed and weaving efficiency. A liquid dispenser is placed between weft yarn package and feeder, which allows an even distribution of liquids, wax, oil, moisturizers and anti-static lubricants on weft yarns during weaving. The weft yarn is coated when it passes over a motor driven rotating cylinder that is immersed in a liquid reservoir.

To improve the fabric appearance, i.e., to compensate yarn count fluctuations and colour irregularities, a one-one-weft insertion from two bobbins instead of weft insertion from only one bobbin is recommended.

4. Beat-up:

When the weft yarn is inserted through the shed, it lies relatively far from its final position. This is because the insertion device (air-jet, projectile, rapier, etc.) cannot physically fit at the acute angle of the shed opening. This final position is called fell, which is the imaginary line where the fabric starts. Therefore, the newly inserted
weft yarn needs to be brought to its final position by pushing through the warp sheet. Beat-up is the process of pushing the last inserted weft yarn to the cloth fell by using a device called reed as shown in the above figure. For all practical purposes, the fabric is not formed until beat-up occurs.

Reed is a closed comb of flat metal strips (wires). These metal strips are uniformly spaced at intervals that correspond to the spacing of warp ends in the fabric; therefore, the reed is also used to control warp yarn density (closeness) in the fabric. Warp density is expressed as either ends per inch (epi) or ends per centimeter (epc), which affects the weight of the fabric. The spaces between the metal strips are called “dents”. The reed holds one or more warp yarns in each dent and pushes them to the cloth fell. After beating up the weft yarn, the reed is withdrawn to its original rest position before the insertion of the next pick. The following figure shows a regular reed and a profiled reed. Profiled reed is used in air-jet weaving machines. In shuttle looms, the reed also guides the shuttle.

Regular Reed (bottom) and Profiled Reed (top)

The shape and thickness of the metal wires used in the reed are important. Reed selection depends on several considerations including fabric appearance, fabric weight (ends per unit width), beat-up force, air space requirement and weave design.

Reeds are identified by a “reed number” which is the number of dents per unit width. Specifying the number of ends per dent with a certain reed number dictates the construction (density) of ends per inch in the fabric on the loom. It should be noted that interlacing causes a natural contraction of yarns in the fabric such that
density of warp ends off the loom will be higher than in the reed; generally about 5% higher depending on the weave, tensions and yarn sizes involved.

5. Take-up:

As the fabric is woven, it should be removed from the weaving area. This is achieved by the take-up motion. The fabric take-up removes cloth at a rate that controls weft density (picks per inch i.e. ppi or picks per centimeter i.e. ppc). Two factors determine weft density: weaving machine speed and rate of fabric take-up. Generally, the pick insertion rate of a weaving machine is fixed at the time of purchase based on the range of fabrics it is intended to produce, the type of insertion mechanism and the weaving machine width. There is two types of take-up mechanism, such as positive take-up mechanism and negative take-up mechanism. Following figure shows the positive fabric take-up mechanism on a typical Air-jet weaving machine. Weaving machine speed is expressed as picks per minute (ppm) and rate of take-up as inches per minute (ipm) or centimeter per minute (cm/min). Warp density and weft density together are referred to as the “construction” of the fabric.

![Schematic of fabric take-up mechanism on a typical Air-jet weaving machine](image)

1 Spreading roller
2 Cloth take-up roller
3 Press roller

The following relations exist:

- Reed number = Number of dents / inch or number of dents / cm
- Weft density (ppi or ppc) = \(
\frac{Machine \ speed(picks/ min)}{Take-up \ speed(inch/min \ or \ cm/min)}\)
- Warp density (epi or epc) = Reed number × ends / dent
- Fabric Construction = Warp density × Weft density
It should be emphasized that both the ends and picks contract because of interlacing causing construction on the loom and off the loom to be different. Subsequent fabric finishing steps also introduce changes in the fabric construction, which must be considered in setting up loom specifications.

**Auxiliary weaving motions or functions:**

In addition to the five basic motions of a loom, there are many other mechanisms on typical weaving machines to accomplish other functions. These include:

- A drop wire assembly, one wire for each warp yarn, to stop the machine when a warp end is slack or broken.
- A tension sensing and compensating whip roll assembly to maintain tension in the warp sheet.
- A mechanism to stop the machine when a weft yarn breaks
- Automatic pick finding device reduces machine downtimes in case of weft yarn breakages.
- Weft feeders to control tension on each pick.
- Pick mixers to blend alternate picks from two or more packages
- Weft selection mechanism for feeding multi-type weft patterns.
- Weft selvedge devices such as trimmers, tuckers, holders and special weave harnesses for selvedge warp ends.
- Weft replenishment system to provide uninterrupted weft insertion by switching from a depleted to a full package.
- A temple assembly on each selvedge to keep fabric width at the beat-up as near the width of the warp in the reed as possible.
- Sensors to stop the machine in the event of mechanical failure.
- A centralized lubrication control and dispensing system.
- A reversing mechanism to avoid bad start-ups after a machine stop.
- A colour coded light signal device to indicate the type of machine stop from a distance.
- A production recording system.

**Fabric width:**

At the moment it is woven, the fabric width is equal to the reed width as shown in the following figure. However, as the weaving continues and fabric gets away from the reed, the fabric starts narrowing due to several factors (it should be noted that there are certain fabrics which do not get narrower, e.g. glass fabrics). These are weaving design, fabric construction and weaving tensions. The interlacing pattern of the weave design affects the crimp level in the fabric and crimp on the weft yarn causes the fabric to contract in width direction. Fabric construction, i.e., the number of weft and warp yarns per unit length, also affects fabric crimp and therefore fabric width. High weaving
tensions, especially in the warp yarns, cause fabric to shrink. Warp yarns closest to the selvedges of the fabric undergo more stress due to widthwise contraction of the fabric toward the center, causing linear angular displacement of these outermost yarns.

![Diagram showing function of temple in weaving](image)

**Function of Temple in weaving**

The narrowing of fabric width should be prevented, by using a temple on each side of the machine. Control of fabric contraction by the temples of the machine is another critical aspect of good weaving performance. A temple is a metallic device that keeps the fabric stretched by applying a force along the weft direction. There are various temple types as shown in the following figure. It is also possible to have a temple across the full width of the fabric. Full width temples ensure uniform fabric quality over the entire weaving width with delicate fabrics and easier operation. The full temple has the following advantages:

- Uniform warp and weft tension over the entire width.
- Uniform fabric characteristics over the entire width.

![Different temples used in weaving machine](image)

**Different Temples used in weaving machine**

- No fabric drawing defect.
- No damage to fabric by needle rings.
- Rapid changeover from full width to cylindrical temples.
Weaving machine or Loom:

Weaving is done on a machine called a loom. All the weaves that are known today have been made for thousands of years. The loom has undergone significant modifications, but the basic principles and operations remain the same. Warp yarns are held taut within the loom, and weft yarns are inserted and pushed into place to make the fabric.

In primitive looms, the warp yarns were kept upright or horizontal. Backstrap looms, used for hand weaving in many countries, keep the warp yarns taut by attaching one beam to a tree or post and the other beam to a strap that fits around the weaver’s hips as the weaver stands, squats, or sits. Weft yarns are inserted by a shuttle batted through raised warp yarns. To separate the warp yarns and weave faster, alternate warp yarns were attached to bars that raised the alternate warp yarns. A toothed device similar to a fine comb pushed the filling yarns in place. Eventually, the bar developed into heddles and harnesses attached to foot pedals so the weaver could separate the warp yarns by stepping on the pedals, leaving the hands free for inserting the weft yarns.

During the Industrial Revolution, mass-production high-speed looms were developed. The modern loom consists of two beams, a warp beam and a cloth or fabric beam, holding the warp yarns between them. Warp yarns that are sufficient for the length, width, and density of the fabric to be woven are wound carefully onto a warp beam. The warp will be raised and lowered by a harnessshedle arrangement. A harness is a frame to hold the heddles. The harness position, the number of harnesses, and the warp yarns that are controlled by each harness determine the weave pattern or interlacing. A heddle is a wire with a hole or eye in its center through which a warp yarn is threaded. There are as many heddles as there are warp yarns in the cloth, and the heddles are held in two or more harnesses. Each warp yarn passes through the eye of only one heddle. The selection of the specific heddle and harness is a major factor in determining
the structure of the fabric. The above figure (basic structure of a weaving machine) illustrates how a simple two-harness loom is used to raise one harness while the other harness remains in its original position. With this arrangement, the yarns from a shed through which the weft is inserted.

The carrier used for transporting the weft yarn may differ from one kind of loom to another. The different devices used form the basis for classifying different types of looms. The name of the loom often refers to the carrier used to insert the weft yarn. Originally, these carriers were fairly large, somewhat oval wooden shuttles with a bobbin of yarn in the center. Within the industry many people refer to newer equipment as weaving machines rather than looms. Weaving machines vary from older, shuttle looms to modern shuttleless machines with sophisticated electronic controls.

A. Shuttle Weaving Machines:

For centuries, the basic loom operated with a shuttle to lay the weft yarn. By the middle of the twentieth century, shuttle looms had developed to a high level of efficiency, allowing them to make fabric rapidly with reduced numbers of flaws. These shuttle weaving machines depend on a shuttle, a boat-shaped, metal-tipped carrier, to supply a continuous length of weft yarn for the weaving operation. The yarn is actually wound on a small spindle or bobbin known as a pirn or quill, which is placed in an opening in the shuttle. The shuttle enters the shed and moves across the width of the fabric to lay the pick; it stops at the opposite side of the fabric; and, after that pick is beaten into place, a new shed is formed and the shuttle returns across the loom, releasing yarn from the pirn to produce another pick. As this operation is repeated, the weft yarn is alternately woven over and under the warp yarns at the sides of the fabric to form the selvedge.

The width of the fabric is controlled by the number and spacing of the warp yarns across the loom. The yarn supply on each pirn is fairly small; it is enough to produce several inches of fabric length. Pirn in the shuttle must be replaced when the yarn supply is exhausted. The frequency with which a pirn has to be replaced depends on the fineness of the weft yarn. Coarse yarns require more frequent replacement; finer yarns need to be replaced less often.

In the mechanical changer, full pirns are kept ready in a revolving case. The machine rams them into the shuttle when the shuttle comes to rest briefly after crossing the yarn. The pressure of the full pirn crowds the empty quill out of the shuttle. It falls through a slot into a container under the loom. The new pirn is pushed mechanically into place in the shuttle, which has a self-threading device that automatically picks up the yarn when the new pirn is inserted. This allows the weaving to continue without a stop.
A specialized process has been developed that allows winding of pirns to take place at the loom. In the Unifil system, empty pirns are carried on a conveyor belt to a point where yarn from a large package is wound onto an empty pirn that is then returned to a position where it can be placed in the shuttle. This system requires that fewer wound pirns be supplied, but it has several limitations. It is useful only for single-colour picks, and because the cost of the system is high, it is most economical for coarse yarns that would require especially frequent pirn replacement. Picking when two or more different colours or types of weft yarn are used requires two or more shuttles and a more complex and costly type of loom arrangement. A conventional shuttle loom has one shuttle box on each side of the machine.

To insert yarns of different colours or types, a number of shuttle boxes must be moved up and down to bring shuttles into position to create the pattern. Such looms are often called pick-and-pick looms. Among the advantages of most shuttleless looms is that they draw yarn for each pick directly from yarn packages, making it easier and less costly to insert a number of different colours or types of yarn.

The length of fabric produced by a single weaving machine is determined by the length of the individual warp yarns wound on the warp beams. If a 500-yards length of fabric is needed, each end on the warp beam will be longer than 500 yards to provide enough yarn for the fabric length, plus an additional amount for certain allowances. The amount of fabric produced in a given time period is governed by the speed at which the picks are inserted.

The speed with which weaving machines operate has traditionally been expressed in picks per minute, or ppm. It operates at speeds ranging from about 110 to 225 picks per minute (ppm). As shuttle equipment was operated at higher speeds to increase mill productivity, the noise level in weave rooms became intense. Shuttle looms are extremely noisy because the picker stick, or bar that hits the shuttle across the shed, and the bar that catches it on the other side make loud clacking noises each time they make contact with the shuttle. The shuttle loom is the oldest kind of loom. It is effective and versatile, but it has other disadvantages. The shuttle sometimes causes abrasion on the warp yarns as it passes over them and sometimes causes thread breaks. This, in turn, results in machine stoppage in order to tie the broken yarns. Shuttle looms operate more slowly than some new types of looms.

**B. Shuttleless Weaving Machines:**

Shuttleless weaving machines were invented to increase the speed of weaving, reduce the literally deafening noise and overcome the other disadvantages of the shuttle loom. The modern loom with a shuttle, although much faster in operation than the earliest automatic looms, is not susceptible to further increases in speed because of the variety of operations that the machine must perform. Time is required for stopping the shuttle and accelerating it in the other direction and the
weight of yarn on the pirn that must be carried across the shed limits the speed. For this reason, future loom developments are likely to be in the area of shuttleless weaving.

Shuttleless weaving machines wove 17 percent more fabric in 1987 than they did in 1982, and Textile World predicts that shuttle looms will be outnumbered by shuttleless weaving machines in the early 1990s.

Shuttleless machines may be classified as to the method used in inserting the weft yarns. Four basic types have been developed:

- Machines with grippers or projectiles (throw across)
- Machines with mechanically operated gripper arms or rapiers (reach across)
- Machines employing air or water jets to carry the weft (spit or blow across)
- Machines that form multiple sheds (multiphase)

In hand weaving and automatic shuttle weaving, the weft yarn is continuous and runs back and forth across the fabric, but in most shuttleless weaving, the weft yarn extends only from selvedge to selvedge, as it is cut off before it passes across the shed. In all shuttleless weaving, the yarn for the pick is unwound from large, stationary packages of yarn that are sometimes set on one side and at other times set on both sides of the loom. Since weaving speed depends on fabric width, there is every incentive to build wider machines for more efficient weft insertion.

**Projectile, Missile, or Gripper Weaving Machine:**

These weaving machines were developed in the 1950s in Switzerland and represent the first proven shuttleless weaving machine. In the gripper or projectile type of weaving machine, a small bullet-shaped or hooklike device grips the end of the weft yarn, which is shown in the following figure. As the gripper is projected across the warp shed, it tows the weft behind it. The projectile can move more quickly than a conventional shuttle because of its decreased size; it can travel farther more easily, thereby making possible the weaving of wider fabrics, and it does not require the step of weft the shuttle; it pulls the yarn directly from a prepared yarn package.

 Projectile looms with one or more projectiles are available; the multiple-projectile type is more common. Two types of projectile looms are used. In one, the projectile travels only in one directiis returned to the starting point by a conveyor belt. To maintain the weaving speed, each machin must have several projectiles, although only one is in use at any one time. It is called multiple-projectile systems. They can be used in machines with a wide weaving bed so the projectile grippers can transfer the pick across the fabric in a relay fashion. In other multiple-projectile
systems, the gripper from the first projectile picks up yarn from the supply source and moves across the shed to lay that length of yarn; then, as beat-up occurs, the projectile drops into a conveyor system that returns it to the supply side to pick up new yarn. In the meantime, the second gripper has pulled a pick to repeat the process.

In the other type of gripper machine, a single gripper inserts one weft yarn alternately from the right- and left-hand sides of the loom. It is called single-projectile system. This system picks up yarn on the supply side and carries it the entire width of the shed. After beat-up has occurred, the projectile picks up yarn from a second supply source on the other side and returns across the shed to place the next pick. The gripper serves the same function as a conventional shuttle, but instead of holding a pirn, it carries the yarn behind it. Packages of yarn must, therefore, be placed on both sides of the machine.

Each pick is individually cut, so there is not a continuously woven selvage like that produced by a shuttle machine. Instead, the edges are fringed. To finish them, a tucking device is used on both sides to interlace the fringe with the last few warp yarns along each edge.

Such machines may be wide or narrow; they are available in weaving widths up to approximately 508cm (200 inch). In addition to being quiet, machines are popular because they can deliver weft yarns from larger packages, which increases productivity reduces some faults in weaving.
The projectile machine not only weaves fabric more quickly than does the shuttle loom, but it runs with less noise, making it possible for manufacturers to comply more easily with government regulations that restrict noise levels.

There is also a saving in power costs for wide-width fabrics. Narrow fabrics are not economically woven on this loom since too much time is spent in periods of acceleration of the gripper. Wide fabric widths are quite productive, as the power consumed is less than that for a conventional shuttle loom of the same size. Sheets are woven side by side on some of these machines to take advantage of these savings. According to data from producers of these machines, the looms can reach speeds slightly over 1,200 meters of weft yarn per minute.

The projectile loom has good versatility and is used for a wide variety of basic fabrics ranging from cotton-type goods such as percale and printcloth to worsted-type material. It does require a smooth, uniform yarn that is properly sized to reduce friction. The projectile loom has speeds of up to 300 ppm.

Rapier weaving machine:

As in the projectile loom, a stationary package of yarn is used to supply the weft yarns in the rapier machine. One end of a rapier, a rod or steel tape, carries the weft yarn. The other end of the rapier is connected to the control system. The rapier moves across the width of the fabric, carrying the weft yarn across through the shed to the opposite side. The rapier is then retracted, leaving the new filling in place.

In some versions of the machine, two rapiers are used, each half the width of the fabric in size. One rapier carries the yarn to the center of the shed, where the opposing rapier picks up the yarn and carries it the remainder of the way across the shed. A disadvantage of both these techniques is the space required for the machine if a rigid rapier is used. The housing for the rapiers must take up as much space as the width of the machine. To overcome this problem, looms with flexible rapiers have been devised. The flexible rapier can be coiled as it is withdrawn and will therefore require less space. However, if the rapier is too stiff, it will not coil; if it is too flexible, it will buckle. The double rapier is used more frequently than the single rapier. Rigid and flexible rapier machines operate at speeds of up to 1,300 meters of weft per minute. These rapier looms are efficient. They operate at speeds ranging from about 200 to 260 ppm at about the noise level of projectile looms. They can produce a wide variety of fabrics ranging from muslin to drapery and upholstery materials.
Newer rapier machines are built with two distinct weaving areas for two separate fabrics. On such machines, one rapier picks up the yarn from the center, between the two fabrics, and carries it across one weaving area; as it finishes laying that pick, the opposite end of the rapier picks up another yarn from the center, and the rapier moves in the other direction to lay a pick for the second weaving area, on the other half of the machine. The above figure shows the action on a single width of fabric for a single rigid rapier system, a double rigid rapier system, and a double flexible rapier system.

Rapier machines weave more rapidly than most shuttle machines but more slowly than most projectile machines. An important advantage of rapier machines is their flexibility, which permits the laying of picks of different colours. They also weave yarns of any type of fibre and can weave fabrics up to 110 inches in width without modification.

**Air-jet Weaving Machine:**

These weaving machines, invented in Czechoslovakia and later refined by the Swiss, Dutch, and Japanese were designed to retain the tensionless aspect of the picking action of the water jet while eliminating the problems caused by the use of water.

The above figure depicts the basic steps in air-jet weaving. The yarn is pulled from the supply package at a constant speed, which is regulated by the rollers, located with the measuring disk just in front of the yarn package. The measuring disk removes a length of yarn appropriate to the width of the fabric being woven. A clamp holds the yarn in an insertion storage area, where an auxiliary air nozzle forms it into the shape of a hairpin.
The main nozzle begins blowing air so that the yarn is set in motion as soon as the clamp opens. The hairpin shape is stretched out as the yarn is blown into the guiding channel of the reed with the shed open. The yarn is carried through the shed by the air currents emitted by the relay nozzles along the channel. The initial propulsive force is provided by a main nozzle. Electronically controlled relay nozzles provide additional booster jets to carry the yarn across the shed. The maximum effective width for air-jet weaving machines is about 355 cm (140 inch). At the end of each insertion cycle the clamp closes; the yarn is beaten in, and then cut, after the shed is closed. Again, some selvage-forming device is required to provide stability to the edges of the fabric.

These weaving machines use a jet of air to propel the weft yarn through the shed at rates of up to 600 ppm. Data from manufacturers indicate that air-jet looms operate at speeds up to 2,200 meters of pick inserted per minute. They can weave multicoloured yarns to make plaids and are available with both dobby and jacquard patterning mechanisms.

Air-jet looms require uniform weft yarns. They are more suitable for use with heavier than lightest yarns because the lighter weight yarns are more difficult to control through the shed. Yet, if the yarn is too heavy, the air jet may not be able to carry the weft across the loom. Within these restraints, the air-jet loom is effective and can produce a wide variety of fabrics. Also, the air-jet loom operates at a lower
noise level than the shuttle, projectile, or rapier looms. Air-jet weaving is more popular because the machines cost less to purchase, install, operate, and maintain than rapier or projectile weaving machines, and the air-jet can be used on a broader variety of yarns than a water jet.

Today automated flaw detectors installed on air-jet machines can inspect fabric. The unit on the batcher is programmed to stop the machine when defects that fall outside preset tolerances are detected. The batcher operator then cuts out the defect, seams the fabric, and restarts the fabric take-up. These flaw detectors are capable of inspecting fabric at 400 ppm.

**Water-jet weaving machine:**

These weaving machines were first developed in Czechoslovakia in the 1950s and subsequently refined by the Japanese in the 1960s. Water-jet weaving machines are not used as frequently as air jets, but they are preferred for some types of fabrics. The process is unsuitable for yarns of hydrophilic fibres because the fabric picks up too much moisture. Water-soluble warp sizings are used on most staple warp yarns. Therefore, the use of water-jet looms is restricted to filament yarns of acetate, nylon, polyester, and glass; yarns that are nonabsorbent, and those that do not lose strength when wet. Furthermore, these fabrics come off the loom wet and must be dried. In this technique a water jet is shot under force and, with it, a weft yarn. The force of the water as it is propelled across the shed carries the yarn to the opposite side. This machine is economical in its operation. A water jet of only 0.1 centimeter is sufficient to carry a yarn across a 48 inch shed. The amount of water required for each weft yarn is less than 2.0 cubic centimeters. Water-jet machines can reach speeds of 2,000 meters of picks per minute. The water-jet looms can produce superior high quality fabrics that have good appearance and feel.

Both air and water jet weaving machines weave rapidly, provide for laying different colours in the weft direction, and produce uniform, high quality fabrics. They are less noisy and require less space than most other types of weaving machines. They cause minimal damage to warp yarns during the weaving operation, because the air or water jets are less abrasive than moving metal parts.

The speeds of shuttleless weaving machines can be compared by measuring the picks per minute (ppm) or the yards laid per minute (ypm) in weft insertion. In 1990, the top speed for a projectile weaving machine was 420 ppm with between 1000 and 1203 ypm weft insertion. Flexible rapier machines operated at 524 ppm and rigid rapiers at 475 ppm, laying weft at up to 1404 and 930 ypm, respectively. Air jets could lay as many as 1200 ppm and water jets up to 1500 ppm, laying 2145 and 2360 ypm, respectively.
If a fabric 60 inches wide is woven on each machine at a density of 50 picks per inch, approximately 84 yards of weft yarn would be needed to produce an inch of fabric. In theory, the projectile would produce approximately 8.4 inches of fabric per minute; the flexible rapier, 10.5 inches; the rigid rapier, 9.5 inches; the air jet, 24 inches; and the water jet, 30 inches. The slowest of the new machines could produce a yard of fabric in 4.3 minutes, and the fastest would take just 1.2 minutes. Seldom do weaving machines operate at full capacity, but even at 50 percent efficiency such machines could produce a yard of fabric every 2.5 minutes.

Multiphase or multished weaving machine:

All the weaving techniques discussed thus far require that the shed be open all the way across the machine for the device carrying the filling yarns to pass through the shed. This imposes a limit on loom speed. The multiphase weaving machine overcomes this limitation by forming many different sheds at different places across the machine and forming these only as the weft yarn inserted. In this way, a number of weft yarns can be inserted, one behind the other. As a section of the shed opens, the weft passes, and the shed closes, opening again in the new pattern as the next weft yarn arrives. Speed is increased because of the number of yarns that can be inserted almost simultaneously one right after the other, but the actual speed of movement of the weft yarns is lower than in other types of machines. For this reason, weft yarns that are weaker can be used. Sultz Ruti, the manufacturer of a multiphase machine, states that its loom will insert up to 5,400 meters of pick per minute.

The process transforms weaving into a continuous process rather than a cycle of shedding, picking, and beating up. Multiphase loom continually inserts weft yarns from yarn carriers. Rotary beat-up devices press inserted yarn firmly against previously formed cloth. If the pattern changes, small groups of yarns are changed into a new shedding position after each new yarn carrier has passed.

The operation of multished weaving machines is based on a series of wavelike motions across the weaving surface. In general, fabrics woven on these looms do not have a true 90-degree angle between warp and weft; the weft yarns are slightly slanted, or skewed. Multished weaving is limited to special types of fabrics, but it can be expected to gain acceptance in the years ahead.

As many as 16 to 20 weft carriers insert the precut weft in a continuous process instead of the intermittent process of single-shed weaving. Beating up and shedding arrangements are different. In this continuous weaving process, the number of picks per minute is doubled. However, multiphase looms have never been extensively used in the industry.
Fabric selvages or selvedges:

In yard goods, the outer edges are constructed so they will not ravel. These finished edges are called the selvages (self-edges) and are often made with heavier and more closely spaced warp yarns than are used in the rest of the fabric by using more or stronger warp yarns or by using a stronger weave. Selvages (also called selvedges) provide strength to fabric for safe handling of the fabric. Selvage should not curl. The warp yarns always run parallel to the selvages. Proper use of the selvages can also prevent the bowing and bias conditions that occur in some fabrics. The weaving machines need mechanisms which through the formation of sufficiently strong selvages bind the wefts together, thus imparting to the fabric a proper appearance and solidity and preventing the breaking up of the threads on the fabric edges during the subsequent operations.

In shuttle looms, there is no need for special selvedge; since the yarn is not cut after each weft insertion, the edges of the fabric are smooth and strong. On conventional shuttle looms, it is formed when the weft yarns turns to go back across the fabric. The conventional loom makes the same kind of selvedge on both sides of the fabric. At the present time this is the only advantage of shuttle loom over shuttleless loom. In shuttleless weaving, since the weft yarn is cut after every insertion, there is fringe selvedge on both sides of the fabric. In this case, special selvedges are needed to prevent slipping of outside warp yarns out of the fabric. There are several types of selvedge designs that are used for this purpose with shuttleless looms. The kind of selvedge used depends upon economy of production and the expected use of the fabric.

- **Plain selvages:**

  These selvages are constructed of the simple plain weave with the same size yarn as the rest of the fabric, but with the threads packed more closely together. Such selvages are fairly durable and firm. Plain selvages are similar to the structure of the rest of the fabric. They do not shrink and can be used for seam edges.

- **Tape Selvages:**

  The tape selvages are sometimes constructed with the plain weave but often are made of the basket or twill weaves, which makes a flatter edge. Tape selvages are made of heavier yarns or ply yarns, which provide greater strength. They are firmer and wider than plain selvages. For towels, bed sheets, drapery and curtain fabrics, tape selvages give added strength to the edges. Selvages vary in width from one-quarter to three-eights of an inch.
• **Split selvages:**

Split selvages are made by weaving a narrow width fabric twice its ordinary width with two selvages in the center. The fabric is then cut between the selvages, and the cut edges are finished with a chain stitch or hemming. Split selvedges are used when items such as towels are woven side by side and cut apart after weaving.

• **Fused selvages:**

These selvages are made on fabrics of thermoplastic fibres, such as polypropylene, nylon, etc., by pressing a hot mechanical element on the edges of the fabric. The fibres melt and fuse together, sealing the edges. Electronically controlled thermal cutters are used to cut and fuse selvedges of synthetic fabrics on weaving machines. The temperature of the cutters is reduced when the machine is stopped. This technique is sometimes used to split wide fabrics into narrower widths.

• **Leno selvages:**

The leno selvages are obtained by binding the wefts with strong additional threads working in leno or gauze weave and by eliminating through cutting the protruding weft ends. Half cross leno weave fabrics have excellent shear resistance. They are made with special leno weaving harnesses. The leno selavage is used on some shuttleless looms. The construction utilizes a narrow leno weave, which locks the cut ends along the fabric edge. A loose weave generally requires a tight leno selavage, whereas a light weave may have a leno selavage with less tension. The leno gauze system is optimally suited for heavy fabrics, blankets, wall coverings.

• **Tucked-in selvages:**

The tucked selvedge is a technique used on some shuttleless looms. A device is used to tuck and hold the cut ends into the fabric edge. In tucked-in selavage, the fringed edges of the weft yarns are woven back into the body of the fabric using
a special tuck-in mechanism. As a result, the weft density is doubled in the selvage area. Tucked-in selvedge was being only used for projectile weaving machines in the past, however, it is now also applied to other shuttleless weaving machines. This system is generally used for light to middleweight fabrics, when weave and fabric density permits. There are also available tucked-in selvage motions, which are entirely controlled by pneumatic or mixed pneumatic and mechanical devices.

The construction of the selvage is dependent upon the particular weave and a number of other factors. A formula for weaving the tucked-in selvage considers fibre density, the diameter of the yarns (which is also affected by twist, ply, and count variation), as well as the yarn diameter balance, or ratio of the diameter of the weft yarn to that of the warp yarn – in effect, if the diameter of the weft yarn is finer than the diameter of the warp yarn, fewer wefts can be inserted in the fabric selvage, because the warp intersection requires more space between the wefts than one diameter of the weft.

When setting up for the selvages on a projectile weaving machine, the following points must be noted.

- The selvage must be drawn into the reed 15 mm wide.
- The selvage must not be thinned too much.
- The reed must be filled with yarns up to the last dent.

If possible, the selvages are always drawn-in on separate harnesses. The selvage harnesses are always behind the ground harnesses, so that the front shed is shorter. This arrangement enables the shed to be adjusted smaller.

**Grey Fabric Inspection Lines:**

After weaving, some fabrics are inspected on the weaving machine for quality purposes. Inspection speed can be varied between 0 to 100 linear meters per minute. Inspection machines have a lighted diffusion screen. Fabric alignment is controlled by a mobile trolley operated by photocells to sense the cloth.
FABRIC STRUCTURE AND DESIGN
INTRODUCTION TO FABRIC STRUCTURE AND DESIGN

Woven fabrics are composed of longitudinal or warp threads and transverse or weft threads, interlaced with one another according to the class of structure and form of design that are desired. The terms chain or twist are applied to the warp and the warp threads are known individually as ends, while the terms picks and filling are applied to the weft threads.

In the following the term threads is used in referring to warp and weft collectively, but in order to distinguish clearly one series from the other the warp threads are mostly described as ‘end’ and the weft threads as ‘picks’.

According to weave structures woven fabrics may be conveniently divided into two principal categories, as follows:

I. **Simple Structure:**
   In which the ends and the picks intersect one another at right angles and in the cloth are respectively parallel with each other. In these constructions there is only one series of ends and one series of picks and all the constituent threads are equally responsible for both the aspect of utility or performance in a fabric and the aspect of aesthetic appeal.

II. **Compound Structures:**
   In which there may be more than one series of ends or picks some of which may be responsible for the body of the fabric, such as ground yarns, whilst some may be employed entirely for ornamental purposes such as ‘figuring’, or ‘face’ yarns. In these cloths some threads may be found not to be in parallel formation one to another in either plane, and indeed, there are many pile surface constructions in which some threads may project out at right angles to the general plane of the fabric.
Warp (End) and Weft (Pick / Filling) Yarn:

Warp and weft yarns have different demands placed on them and may differ in their structure or fibre type. Thus, a fabric may not have the same performance characteristics for warp and weft. The warp must withstand the high tensions of the loom and the abrasion of weaving, so the warp yarns are stronger and more uniform with higher twist. Filling yarns are more often fancy or special-function yarns such as high-twist crepe yarns, low-twist napping yarns, or boucle yarns.

Identification of warp and weft:

Differentiating between warp and weft is possible by carefully examining both the fabric and the length-wise and crosswise yarns.

1. The selvedge always runs in the lengthwise (warp) direction of all fabrics.
2. Most fabrics have lower elongation in the warp direction.
3. The warp yarns lie straighter and are more parallel in the fabric because of loom tension.
4. Fancy or special-function yarns are usually in the filling direction.
5. Fabric characteristics may differentiate between the warp and weft directions. For example, poplin has a weft rib and satin has warp floats.
6. Warp yarns tend to be smaller, are more uniform in structure and appearance, and have higher twist.
7. Fabric crimp is usually greater for weft yarns since they must bend or flex over or under warp yarns due to the way the loom operates.

Grain:

Grain refers to the geometry or position of warp yarns relative to filling yarns in the fabric. A fabric that is on-grain has warp yarns parallel to each other and perpendicular to the filling yarns that move straight across the fabric. Lengthwise grain is parallel to the warp yarns. Crosswise grain is parallel to the weft yarns. Fabrics are almost always woven on-grain. Handling, finishing, or stress due to yarn twist, weave, or other fabric aspects may cause fabrics to distort and lose their on-grain characteristic. These fabrics are off-grain. Fabric quality has increased significantly and it is rare to find fabrics as badly off-grain.

Off-grain fabrics: These create problems in production and use. During finishing, off-grain causes reruns or repeating finishing steps and lowers fabric quality. Products do not drape properly or hang evenly and printed designs are not straight.

There are two kinds of off-grain. Skew occurs when the weft yarn is at an angle other than 90 degrees to the warp. It usually occurs in finishing when one side of the fabric travels ahead of the other. Bow occurs when the weft yarns dip in the center of the fabric; it usually develops when the fabric center lags behind the two sides during finishing.

Fabrics should always be examined for grain. On-grain fabrics usually indicate high quality standards and minimize problems in matching designs or patterns, in cutting and sewing.
**Structure:**

In the manufacture of a fabric, by weaving on a loom, the technique – how the two series of thread are interlaced at right angles to each other is called structure. Or the interlacements of warp and weft threads are known as structure.

**Texture:**

A term referring to the appearance or hand of a fabric and especially such features as structure coarseness, openness. This signifies the general quality of a fabric, developed by the interlacements of yarn used weight, bulk, how it feels when handled etc. are also express by the term texture.

Materials, count of the yarns relative density of threads are its main factors.

**Sett:**

A term used to indicate the spacing of ends and/or picks in a woven cloth this is usually expressed a threads per inch, centimeter or other convenient unit. The state of the cloth of the time should be described, eg. Grey, finished woven fabric sets are commonly given in a pare

warp x weft, as for example handkerchief – 36 x 36

**Thread density in warp and weft:**

Warp (ends) density is expressed in Ends per inch (EPI) Or Ends per cm (EPC)
Weft (picks) density is expressed in Picks per inch (PPI) Or Picks per cm (PPC)

**Woven fabric Specification:**

Woven fabric construction or specification as follows:

\[
\frac{EPI \times PPI}{Warp \ count \times Weft \ count} \times Fabric \ width \quad \text{OR} \quad \frac{Warp \ count \times Weft \ count}{EPI \times PPI} \times Fabric \ Width
\]

For example:

\[
\frac{110 \times 52}{20 \times 16} \times 56" , \quad \frac{30 \times 30}{130 \times 70} \times 57 - 58"
\]

**Fabric weight calculation:**

There are two way of fabric weight calculation. One is weight per unit area such as, GSM(grams per square meter) or oz / yd\(^2\) and another way is weight in running length.
GSM calculation:

Calculate the GSM of the following fabric
\[
\frac{120 \times 70}{40 \times 30} \times 58''
\]

For warp weight calculation

Here, EPI = 120

\[\therefore \text{Total number of ends} = 120 \times 39.37\]
\[\text{Length of each end} = 1\text{m} + 1\text{m} \times 0.03 \quad \text{(warp crimp\%} = 3\%\text{)}\]
\[= 1.03\text{m}\]
\[\therefore \text{Total length of warp yarn} = 120 \times 39.37 \times 1.03 \text{ m}\]

We get from the yarn numbering system,

\[N_e = \frac{L \times w}{W \times l}\]
\[\therefore W = \frac{L \times w}{N_e \times l}\]
\[= \frac{120 \times 39.37 \times 1.03 \times 453.6}{40 \times 840 \times 0.9144} \text{ gm}\]

For Weft weight calculation

Here, PPI = 70

\[\therefore \text{Total number of picks} = 70 \times 39.37\]
\[\text{Length of each pick} = 1\text{m} + 1\text{m} \times 0.05 \quad \text{(weft crimp\%} = 5\%\text{)}\]
\[= 1.05\text{m}\]
\[\therefore \text{Total length of weft yarn} = 70 \times 39.37 \times 1.05 \text{ m}\]

We get from the yarn numbering system,

\[N_e = \frac{L \times w}{W \times l}\]
\[\therefore W = \frac{L \times w}{N_e \times l}\]
\[= \frac{70 \times 39.37 \times 1.05 \times 453.6}{30 \times 840 \times 0.9144} \text{ gm}\]

\[\therefore \text{Total weight of the fabric per square meter} = \frac{120 \times 39.37 \times 1.03 \times 453.6}{40 \times 840 \times 0.9144} + \frac{70 \times 39.37 \times 1.05 \times 453.6}{30 \times 840 \times 0.9144}\]
\[= \left( \frac{120 \times 1.03}{40} + \frac{70 \times 1.05}{30} \right) \times 39.37 \times 453.6\]
\[= \left( \frac{120 \times 1.03}{40} + \frac{70 \times 1.05}{30} \right) \times 23.25\]

\[\text{GSM} = \left( \frac{\text{EPI} \times 1.03}{N_{e_w}} + \frac{\text{PPI} \times 1.05}{N_{e_we}} \right) \times 23.25\]
Similarly oz/yd$^2$ can be calculated by the following formula:

$$\text{oz/yd}^2 = \left( \frac{\text{EPI} \times 1.03}{\text{Ne}_{warp}} + \frac{\text{PPI} \times 1.05}{\text{Ne}_{weft}} \right) \times 0.686$$

1.03 = For warp crimp (warp crimp % = 3%)
1.05 = For weft crimp (weft crimp % = 5%)

The crimp % for warp and weft can be changed. These two values normally applicable for most common fabrics, although crimp% mainly depends on fabric structure.

**Weight calculation in running length (Yarn consumption calculation):**

Calculate the weight of warp and weft yarn in kg to produce 2000 m of the following fabric

$$\frac{150 \times 100}{50 \times 50} \times 58''$$

**For warp weight calculation**

Here, EPI = 150

\[ \therefore \text{Total number of ends} = 150 \times 58 \]
\[ \text{Length of each end} = 2000m + 2000m \times 0.03 \] (warp crimp% = 3%)
\[ = 2060m \]
\[ \therefore \text{Total length of warp yarn} = 150 \times 58 \times 2060 m \]

We get from the yarn numbering system,

\[ \text{Ne} = \frac{L \times w}{W \times l} \]
\[ \therefore W = \frac{L \times w}{\text{Ne} \times l} \]
\[ = \frac{150 \times 58 \times 2060 \times 0.4536}{50 \times 840 \times 0.9144} \text{kg} + 20\% \text{ wastage of the total weight of warp.} \]

From the above system a simple formula is developed to calculate the weight of warp yarn in kg to produce a particular length of a fabric as follows:

**Weight of warp yarn in kg. =**

$$\frac{\text{EPI} \times \text{Fabric width in inch} \times \left( \text{Fabric length in m + Fabric length in m} \times \text{crimp%} \right)}{\text{Ne}_{warp}} \times 0.0005905512$$

+ Wastage % of total weight of the warp (about 20%)

**For Weft weight calculation**

Here, PPI = 100

\[ \therefore \text{Total number of picks} = 100 \times 39.37 \times 2000 \]
Length of each pick = \((58'' + 58'' \times 0.05)/39.37\) = \(1.547\ m\)

\[
\therefore \text{Total length of weft yarn} = 100 \times 39.37 \times 2000 \times 1.547 \ m
\]

We get from the yarn numbering system,

\[
Ne = \frac{L \times w}{w \times l}
\]

\[
\therefore W = \frac{L \times w}{Ne \times l} = \frac{100 \times 39.37 \times 2000 \times 1.547 \times 0.4536}{50 \times 840 \times 0.9144} \text{ kg +15% wastage of the total weight of weft.}
\]

From the above system a simple formula is developed to calculate also the weight of weft yarn in kg to produce a particular length of a fabric as follows:

**Weight of weft yarn in kg. =**

\[
PPI \times \text{Fabric length in m} \times \left(\frac{\text{Fabric width in inch} + \text{Fabric width in inch} \times \text{crimp\%}}{Ne_{\text{weft}}}\right) \times 0.0005905512
\]

+ Wastage % of total weight of the weft (about 15%, although it depends on selvedge, loom type)

Similarly weight of the warp and weft yarn in pound (lb) can be calculated by the following formula:

**Weight of warp yarn in lb. =**

\[
EPI \times \text{Fabric width in inch} \times \left(\frac{\text{Fabric length in yds} + \text{Fabric length in yds} \times \text{crimp\%}}{Ne_{\text{warp}} \times 840}\right) + \text{Wastage % of total weight of the warp (about 20%).}
\]

**Weight of weft yarn in lb. =**

\[
PPI \times \text{Fabric length in yds} \times \left(\frac{\text{Fabric width in inch} + \text{Fabric width in inch} \times \text{crimp\%}}{Ne_{\text{weft}} \times 840}\right) + \text{Wastage % of total weight of the weft (about 15%).}
\]

**Problem:**

Calculate the weight of warp and weft yarn in lb to produce 2500 yds. of the following fabric

\[
\frac{120 \times 90}{16 \times 14} \times 58''
\]

The weight of warp and weft yarn in lb. can be calculated directly from the fabric specification by using the above formula. It will be very easy and it safe lot of times.
Solution:

Weight of warp yarn in lb. =

$$\frac{\text{EPI} \times \text{Fabric width in inch} \times (\text{Fabric length in yds} + \text{Fabric length in yds} \times \text{crimp} \%) + \text{Wastage}}{\text{Ne}_{\text{warp}} \times 840} \times \% \text{ of total weight of the warp.}$$

$$= \frac{120 \times 58 \times (2500 + 2500 \times 0.03)}{16 \times 840} + 20\%$$

$$= 1333.48 + 1333.48 \times 0.2$$

$$= 1333.48 + 266.696$$

$$= 1600.176 \text{lbs. Or 725.84 kg (1600.176} \times 0.4536)$$

Weight of weft yarn in lb. =

$$\frac{\text{PPI} \times \text{Fabric length in yds} \times (\text{Fabric width in inch} + \text{Fabric width in inch} \times \text{crimp} \%) + \text{Wastage}}{\text{Ne}_{\text{weft}} \times 840} \times \% \text{ of total weight of the weft.}$$

$$= \frac{90 \times 2500 \times (58 + 58 \times 0.05)}{14 \times 840} + 15\%$$

$$= 1165.18 + 1165.18 \times 0.15$$

$$= 1339.96 \text{lbs. Or 607.804 kg (1339.96} \times 0.4536)$$

Foundation of woven cloth structure:

Variation of woven cloth structure depends on following foundational factors:

- The nature of yarns used
- The count or relative thickness of the yarns used as warp and weft
- The relative setting, or the number of ends or picks, which are placed side by side in a given width and length of the cloth
- The order of interlacing the ends and picks
- Modifications produced by finishing

Classification or parts of a complete design for a woven fabric:

A complete design for a woven fabric consists of three parts as follows:

- **The weave plan:**
  It illustrates the interlacing of ends and picks in the fabric under consideration. In the weave plan, space between two vertical lines indicates as warp yarn and space between two horizontal lines indicates as weft yarn.
• The drafting or looming plan:

A draft indicates the number of heald, used to produce a given design and the order in which the warp threads or ends are threaded through the mail eyes of the healds. In the drafting plan, space between two vertical lines indicates as warp yarn and space between two horizontal lines indicates as heald shaft.

![Drafting plan](image)

![Weave plan](image)

![Lifting plan](image)

• The lifting or peg plan:

Lifting plan defines the selection of healds to be raised or lowered on each successive insertion of the pick of weft to produce the pattern.

• Denting plan:

This indicates the order of drawing-in the warp threads or ends through the dents of reed.

Point paper diagram in textile design:

To illustrate a weave either in plan view and/or in cross-section, as the following figure, takes a lot of time, especially for more complicated weaves. A type of shorthand for depicting weave structures has therefore been evolved and the paper used for producing designs is referred to as squared paper, design paper or point paper. Generally the spaces between two vertical lines of graph or design paper represent one warp thread or end and the spaces between two horizontal lines of graph or design paper indicates one weft thread or pick. If a square is filled in it represents an end passing over a pick whilst a blank square represents a pick passing over an end. If ends and picks have to be numbered to make it easier to describe the weave, ends are counted from left to right and picks from the bottom of the point paper design to the top. The point paper design shown in the following figure (a) is the design for a plain weave fabric. To get a better impression of how a number of repeats would look, four repeats of a design (two vertically and two horizontally) are sometimes shown. When four repeats are shown the first repeat is drawn in the standard way but
for the remaining three repeats crossing diagonal lines may be placed into the squares, which in the first repeat, are filled in. This method is shown for a plain weave in following figure (b).

![One repeat](image)

Plan view - 3x3 repeats

![Point paper diagram](image)

Point paper diagram (a) 1- repeat (b) 4- repeat

**Methods of fabric representation:**

**Interlacing type ‘a’:**

In this type the warp yarn is up over the weft yarn. In the graph or design paper, it is represented by putting any type of sign such as cross, circle, or colour shade in the square space of the design paper.

![Interlacing type 'a'](image)

**Interlacing type ‘b’:**

In this type the weft yarn is up over the warp yarn. In the graph or design paper, it is normally represented as empty square space of the design paper.

![Interlacing type 'b'](image)

**One repeat of weave:**

A number of interlacings combined together in both directions produce a unit of design, or one repeat of the weave. In the above figure (a) represents one repeat of the design.
Some important factors or terms:

The weave shows the interlacing pattern of warp and weft. Each weave consists of the following parts or fields

- **Contact fields:**
  These are the contact points between warp and weft crossing at right angle. The number of contact fields always equals the product of the number of warp and weft threads. 
  Contact field = $R_{wa} \times R_{we} = 3 \times 3 = 9$

- **Interlacing field:**
  These are the points where a yarn of one system of threads changes its position in relation to the other system. A distinction is made between single and double interlacing fields.

- **Single interlacing field:**
  The yarn bends from the top of the fabric to the bottom and covers two or more yarns.

- **Double interlacing field:**
  The yarn bends, cover a following yarn, bends again and reappears at the same fabric side.

  Interlacing fields are active fields since they provide the fabric cohesion.

- **Free field:**
  These are the zones where the warp and weft yarns do not touch and do not change fabric side. Because of the free field floats are formed and the yarns in the weave may shift.
- **Open field:**
  These are zones where neither warp nor weft threads occurs. The number of open field is important, for example for air and water permeability.
  
  \[
  \text{Open field} = RN_{wa} \times RN_{we} = 3 \times 3 = 9, \text{ same as contact field}
  \]
  
  Where, \(RN\) = Repeat number
  
  \(W_a = \text{warp and } W_e = \text{weft}\)

- **Formula number:**
  It is a kind of short-hand system representing the waving of warp or weft yarn. It gives the successive floats. The number of floats always equals the number of figures in the formula number. The warp floats coming up are put above the fraction line, the warp floats going down are put under the fraction line.

  \[
  \begin{align*}
  FN_{wa} &= \frac{4}{1} \frac{2}{1} \frac{1}{1} \\
  FN_{we} &= \frac{2}{1} \frac{1}{1} \frac{1}{1} \frac{4}{1}
  \end{align*}
  \]
  
  Where, \(FN_{wa} = \text{formula number for the warp } & FN_{we} = \text{formula number for the weft.}\)

- **Repeat number:**
  It indicates the number of warp and weft yarns in the repeat. The repeat number for the warp equals the sum of the figures in the formula number for the weft and vice versa.

- **Interlacing ratio:**
  The interlacing ratio of a fabric is the ratio between the actual number of interlacing fields and the maximum number of interlacing fields. The degree of interlacing is the interlacing ratio expressed in percentage.

**Drafting:**

Various methods of indicating drafts may be employed as for instance –

a) **By ruling lines:**
  In which the horizontal lines represent the healds and the vertical lines the warp threads, while the marks placed where the lines intersect indicate the healds upon which the respective threads are drawn.
b) By numbering:
As shown by the numbers below the designs, which refer to the number of the healds (the front heald is number one). In this case the threads are successively drawn on the healds in the order indicated by the numbers.

c) By the use of design paper:
In which the horizontal spaces are taken to represent the healds, and the vertical spaces the warp threads. Marks are inserted upon the small squares to indicate the healds upon which the respective threads are drawn. This method is usually the most convenient.
1. **Straight draft (or entering):**
   The warp ends are threaded through the heddles according to their numerical order. A distinction is made between S- and Z-entering. Straight draft is the most common and can be used with any number of shafts. Each successive thread is drawn on successive shafts, the first thread on the first shaft, the second thread on the second shaft, and so on. The last thread of the warp repeat is drawn on the last shaft. Thus the number of shafts equals the warp repeat and the repeat of draft equals the warp repeat.

2. **Point draft:**
   Point entering is obtained by straight entering of a number of yarns followed by reverse entering of the same or a different number of yarns. Point drafts are used for weaves, which are symmetrical about the center, and they are frequently employed to produce waved or diamond effects. The main advantage of this system is that it allows the production of quite large effects economically, which if attempted on the straight drafts would require almost twice the number of healds. The method used to construct these drafts and it will be seen that to achieve a well defined point in the design the ends are drawn in straight order starting with heald 1 and finishing with the last heald in the number employed, where upon the order of drawing-in of the consecutive ends is reversed. The first and the last healds carry only one end each, whilst all the healds in the middle carry two ends each per repeat of the draft. As a result, using this system of drafting the number of ends per repeat of the design is: $2 \times$ number of healds – 2.
3. **Skip drafts:**
The warp ends are threaded in an irregular way. Warp ends with the same action are threaded through the same shaft. This system is particularly useful in weaving very densely set fabrics where normally a small number of healds is required. In order that the mails will not be too crowded on the shaft and to reduce friction and rubbing between the ends it is customary to use more healds than the minimum necessary for the weave. For example, in case of the plain weave, may be drawn on two healds, if the cloth is coarse; or on four healds, if the cloth is of medium fineness; or on six healds, if the cloth is very fine.

4. **Broken draft:**
It can be considered as a modified pointed draft. Again it is a combination of straight drafts with different directions of constructing. But the direction is reversed not on the last or the first shaft. When the direction is reversed the first thread of the next group is started higher or lower than the last thread of the preceding group. This small modification changes considerably the design by breaking the axis of symmetry. The order of interlacing of the last thread of the first group is opposite to that of the first thread of the preceding group. This draft is applied for producing herringbone twills, diaper design and etc.

5. **Divided draft:**
This draft is employed for derived weaves, double warp weaves, two ply weaves, pile weaves, and some others. The shafts are divided into two or more groups. A suitable type of draft is chosen for each group. The divided draft is employed for double-warp fabric. There are two systems of warp threads: the face and back ones.
6. **Grouped drafts:**
These drafts are employed for production of check and stripe designs, in which the stripes have different weaves or their combinations. A typical draft is used for producing the fabric with two different stripes containing 15 and 12 threads, respectively. The warp repeat of the first stripe equals 3 and the second 4. The weave of the first stripe requires 3 shafts, and that of the second stripe 4 shafts. All the threads of the first stripe are drawn on 3 first shafts with straight draft, and the threads of the second stripe are drawn on shafts 4, 5, 6, 7 of the second group. The repeat of the draft is 27.

7. **Curved drafts:**
These drafts are applied for fancy weaves having a large warp repeat with the purpose of reducing the number of shafts. Note, that the minimal number of shafts equals the number of threads in warp repeat with different order of interlacing. The drawing-in is done applying the rule: all warp threads which works alike are drawn on the same shaft. Curved drafts are irregular and cannot be classified.
8. **Combined draft:**

Various methods of drawing-in can be combined in one draft for producing a certain type of fabric. Two or more drafts described above can be applied simultaneously, for example, straight and skip or sateen, grouped and curved, and so on. Combined draft is the most complicated and can be chosen only if there are some technological or economical reasons.

---

**The basic weaves or structures of woven fabric:**

Woven fabric structure is defined as the interlacement of warp and weft yarn at 90° angles to each other. It is also called weave structure. The number of weave structures that can be produced is practically unlimited. Three types of weave structure form the basis of even the most complex weaves. Known as basic weaves, these are the plain weave, the twill weave, and the satin weave. In the following section basic structures, from which all other weave structures are developed, are discussed. All structures can be derived from the three basic weaves: Plain, Twill and Satin / Sateen. Most two-dimensional woven fabrics are constructed from simple weaves and of these at least 90% use plain weave.
PLAIN WEAVE

The plain weave is the simplest of the weaves and the most common. It consists of interlacing warp and weft yarns in a pattern of over one and under one. Imagine a small hand loom with the warp yarns held firmly in place. The weft yarn moves over the first warp yarn, under the second, over the third, under the fourth, and so on. In the next row, the weft yarn goes under the first warp yarn, over the second, under the third, and so on. In the third row, the weft moves over the first warp, under the second, and so on, just as it did in the first row. Plain weave is obtained by raising all even-numbered warp ends at one pick and raising all the odd numbered ones at the other pick. It means threads interlacing in alternate order.

Main features of plain weave:

- Threads interlacing in alternate order.
- The repeat contains two ends and two picks.
- Both sides of the weave are identical.
- Each thread gives maximum amount of support to the adjacent threads.
- Texture is stronger and firmer than any other ordinary cloth.
- Made from all kind of textile raw materials and yarns i.e. cotton, linen, jute, man-made fibres, both spun and continuous filament yarns.
- It comprise a high production of the total output of woven fabrics.
- Two heald shafts are sufficient to produce plain weave, when the number of ends/inch is large (more than 50), four or six heald shafts are used with skip draft.
Classification of plain cloth:

There are at least two ways of approaching such a classification. The simplest is in terms of warp and weft cover factors.

a. **Approximately square cloths:**
The cloths in which the warp and weft counts, the ends and picks per inch, and therefore the warp and weft cover factors are approximately equal, so that warp and weft are equally prominent, or nearly so, on both sides of the cloth. The crimps are also usually approximately equal.

![Approximately square cloths](image)

b. **Warp faced cloths:**
The cloths in which the warp cover factor substantially exceeds that of the weft, and in which the warp predominates on both sides of the cloth. A warp faced effect is obtained by increasing the warp count i.e. warp yarn is finer than the weft yarn.

![Warp faced cloths](image)

c. **Weft faced cloths:**
The cloths in which the weft cover factor substantially exceeds that of the warp, and in which the weft predominates on both sides of the cloth. A weft faced effect is obtained if the weft yarn is finer than the warp yarn.

![Weft faced cloths](image)

Another method of classification, more logical in some respects, distinguishes between balanced and unbalanced structures:
a. **Balanced cloths:**
The cloths in which the warp and weft counts are similar, and likewise the ends and picks per inch. The yarn crimps are usually equal.

\[
\frac{140 \times 140}{45 \times 45} \times 59''
\]

b. **Unbalanced cloths:**
The cloths include all those which do not conform to the requirements of balanced cloths. They are grouped under three headings:

I. The ends and picks per inch are similar (square sett), but the warp and weft counts are different, so the warp and weft cover factors are also different.

\[
\frac{150 \times 150}{50 \times 42} \times 58''
\]

II. The warp and weft counts are similar, but the ends and picks per inch are different, so again the warp and weft cover factors are different.

\[
\frac{150 \times 140}{42 \times 42} \times 57''
\]

III. The ends and picks per inch are different, and so are the warp and weft counts. The warp and weft cover factors will usually be different, but in a special case they may be similar.

\[
\frac{120 \times 90}{20 \times 16} \times 58''
\]

**Derivatives of Plain weave:**
Weaves developed on the basis of plain weave principle is called derivatives of plain weave. All the weaves those are based on plain weave principle are classified as follows:

- Plain weave derivatives
  - **Rib weave**
    - **Warp rib**
      - Regular warp rib
      - Irregular warp rib
    - **Weft rib**
      - Regular weft rib
      - Irregular weft rib
  - **Matt or Hopsack weave**
    - Regular matt
    - Irregular matt
    - Stitch matt
    - Fancy matt
Rib Weave:

Ribbed or corded effects are variations of the plain weave. Interesting and attractive fabrics can be obtained with the rib variation of the plain weave or by making a rib-weave construction. The rib may be produced in the warp or in the weft by alternating fine yarns with coarse yarns, or single yarns with doubled yarns. There are two types of rib weave, such as warp rib and weft rib.

Warp Rib weave:

In the warp rib, the warp ends float over two or more picks. At the change of shed which occurs simultaneously across the whole warp, the picks in the same shed are bunched together and form the rib effect which characterizes this weave. Usually, only the warp ends can be seen on the both face and back surfaces because they are very closely set and tend to cover the weft which only acts as a weft material. Thus, while one uses good quality, fine yarn for the warp, the weft can be a cheap, coarse material. So the main features of warp rib fabrics are as follows:

- Warp yarns are used as a single yarn and weft yarns are used as group or bundle yarns.
- Rib or cord effects are shown horizontally i.e. weft-way rib effects.
- The formula number of a typical warp rib weave is $\frac{2}{2}$ warp rib, $\frac{4}{1}$ warp rib etc.
- In the repeat size, the number of warp yarn is always two and the number of weft yarn is depends on the formula number, it is the sum of warp and weft floats.

There are two types of warp rib weave, such as regular warp rib and irregular warp rib.

Regular Warp rib weave:

In this weave the number of picks in the bundle should be same, i.e. in the formula number, the number above the fraction line and below the fraction line are same. The thickness of all ribs are same. So the same size of ribs are produced on the surface of the fabric. The regular warp rib weaves are shown in the following figure.
Irregular Warp rib weave:
In this case the number of weft yarns in the bundle are different, i.e. in the formula number, the number above the fraction line and below the fraction line are not same. The thickness of all ribs are not same. So the different size of ribs i.e. thick and thin ribs are produced on the surface of the fabric. The irregular warp rib weaves are shown in the following figure.

Weft Rib weave:
These are opposite to warp rib weaves, and result from extending the plain weave horizontally. This weave may be described as plain weave in which two or more ends weave together as one. In the weft rib which is frequently called cord, the picks float over several warp ends which are bunched together to form a rib in the warp direction. With these fabrics, the pick spacing is usually so close that the weft completely covers the warp. Here, one uses a fine, high-quality yarn as weft and a cheaper, coarser yarn as warp. The first following figure shows a two-end weft rib (cord). The draft is shown for four heald shafts. The short-hand or formula number used for the warp rib is inadequate for the weft rib because it only indicates the length of the warp floats. For characterizing the weft rib, the length of the float must be added. Thus, the weave shown in the first following figure is described by: $\frac{1}{1}2$. So the main features of weft rib fabrics are as follows:

- Weft yarns are used as a single yarn and warp yarns are used as group or bundle yarns.
- Rib or cord effects are formed warp-wise i.e. in the direction of warp.
- The formula number of a typical weft rib weave is $\frac{1}{1}3, \frac{1}{1}(4+2)$ etc.
- In the repeat size, the number of weft yarn is always two and the number of warp yarn is depends on the formula number, it is the sum of group yarns.
- The prominence of the ribs can be increased by suitable use of coarse and fine yarns.

There are two types of weft rib weave, such as regular weft rib and irregular weft rib.
Regular Weft rib weave:
In this weave the number of warp ends in the bundle should be same, i.e. in the formula number, there is single number at the right side of the fraction line. The thickness of all ribs is same. So the same size of ribs is produced on the surface of the fabric. The regular weft rib weaves are shown in the following figure.

Irregular Weft rib weave:
In this case the number of warp yarns in the bundle is different, i.e. in the formula number, there is two different numbers at the right side of the fraction line. The thickness of all ribs is not same. So the different size of ribs i.e. thick and thin ribs are produced on the surface of the fabric. The irregular weft rib weaves are shown in the following figure.
Hopsack, Basket or Matt Weave:
The hopsack weave, a variation of the plain weave, uses two or more warp and/or two or more weft yarns side by side as one yarn. The resultant cloth is fairly loose in weave. The hopsack weave is obtained by doubling or otherwise multiplying the interlacing points of the plain weave in both the warp and weft direction. Basket weaves are made with two or more adjacent warps controlled by the same harness, and with two or more weft yarns placed in the same shed. The interlacing pattern is similar to a plain weave, but two or more yarns follow the same parallel path. Basket weave fabrics are more flexible and wrinkle resistant because there are fewer interlacings per square inch. The fabrics look flatter than comparable regular plain weave fabrics. However, long floats snag easily. The Matt weave cloth has a greater resistance to tearing. Matt weaves tend to give smooth-surfaced fabrics. In the repeat size of the Matt weave the numbers of warp and weft yarns are equal. There are four types of hopsack or Matt weave such as regular Matt, irregular Matt, stitch Matt and fancy Matt.

Regular Matt weave:
Most regular mats are woven with the same number of ends and picks and the same yarn count. Equal warp floats exchange with equal weft floats. So the regular Matt weave is produced by the combination of regular warp and weft rib weave. The regular Matt weave is represented by the formula number of \( \frac{A}{A} \), where ‘A’ indicates the warp or weft floats. Denting plays an important part in achieving a correct Matt weave. Ends that work alike should be separated by the reed as the ends tend to roll or twist round each other when weaving. The following figures show close-up view of some regular Matt weave with drafting and lifting plan.
Irregular Matt weave:
Warp and weft floats are different in one repeat of irregular matt weave. So the irregular matt weave is produced by the combination of irregular warp and weft rib weave. The irregular matt weave is represented by the formula number of $\frac{A}{B}(A + B)$, where ‘A’ indicates the warp floats and ‘B’ indicates the weft floats. The following figures show close-up view and interlacing diagram of some irregular matt weaves with drafting and lifting plan.

![Interlacing diagram of $\frac{3}{1}(3 + 1)$ matt fabric with weave, drafting and lifting plan](image1)

$\frac{3}{2}(3 + 2)$ Weave, drafting and lifting plan of $\frac{4}{2}(4 + 2)$ with close-up view

Stitch Matt weave:
Matt or basket structures are liable to slippage, especially in coarser weaves or when woven with worsted yarns. To produce a firm cloth with lower setting, the centre ends in each square can be stitched. In case of warp float area the central warp yarn goes down and of weft float area the central warp yarn comes up. The following figures show the weave plan of some stitch matt fabric with drafting and lifting plan.
Fancy Matt weave:

Fancy matt is one kind of stitch matt. In case of stitch matt, the stitch or stitching thread is does not affect the prominence of actual regular matt effect. The stitching thread is hidden by the neighbouring threads, so it does not visible on the fabric surface. But in the fancy matt the stitching threads are not hidden, they are visible. The stitching system affects the design of the regular matt weave. They produce decorative appearance on the fabric surface. It can be compared with “katha” and “nokshi-katha”.
Ornamentation of plain cloth:

A plain weave is ornamented without deviating from the true principles of plain weave as follows:

- The threads in both warp and weft vary in colour, raw material, types of construction and in thickness.
- Threads of different colours are combined in check form.
- By using fancy slub yarns.
- By combining different orders of denting.
- By using two warp beams, which are differently tensioned, is produced seer-sucker stripe.

- By using different twisted yarns (such as hard twisted weft yarn is produced crepon effect).
- By using different Textile materials, such as wool and cotton is produced union fabric.
- By using a specially shaped reed, which rises and falls the threads are caused to form zig-zag lines in the cloth.
- By using extremely fine or coarse yarn.
End uses:

It is used for structures, which range from very heavy and coarse canvas and blankets made of thick yarns to the lightest and finest cambries and muslins made in extremely fine yarns.

Advantages and disadvantages of plain weave fabric:

Advantages:

- Wears well
- Offers appropriate background for printing, special finishes, and applied surface designs.
- Is snag-resistant
- Has good dimensional stability if of high fabric count, i.e. high thread density.
- Is reversible if not printed or finished with special effects.

Disadvantages:

- Ravels
- Appears uninteresting
- Shows wrinkling
- Has lower tear strength than some other weaves
- Shows soil readily.
TWILL WEAVE

The second basic weave pattern used in manufacturing fabrics is the twill weave. This weave is characterized by diagonal lines or ribs (twill lines) on the face, and often on the back, of the fabric. The face diagonal can vary from reclining twill, with a low 14-degree angle, to steep twill, with a 75-degree angle. A twill angle of 45-degrees is considered to be a medium diagonal or a regular twill; it is the most common.

The angle of the twill line is determined by the closeness of the warp ends, the number of yarns per inch, the diameters of the yarns used, and the actual progression forming the repeat. These twill lines are produced by letting all warp ends interlace in the same way but displacing the interlacing points of each end by one pick relative to that of the previous end. While the plain weave can only be woven in one form, there exist several options with regard to twills.

Twill lines are formed on both sides of cloth. The direction of diagonal lines on the face side of cloth is opposite to that on the wrong side coinciding respectively with the weft and warp floats on the other side. Thus, if warp floats predominate on one side of the cloth, weft floats will predominate in the same proportion on the other side.

Twills differ from plain weaves in the increased number of picks and ends needed to complete a repeat pattern. Whereas a plain weave requires two ends and two picks for a repeat, the simplest twill requires three picks and three ends. At least three heald-shafts are needed to make a twill weave. Normally straight drafting system is used to produce regular twill fabric. The smallest possible repeat for a twill weave is 3 ends x 3 picks, and there is no theoretical upper limit to the size of the repeat.
The designation of the design of a twill fabric describes the placement of the warp yarns over and under the weft yarns. In a fabric described as a $\frac{2}{2}$ twill, four warp and four weft yarns are used to form the design repeat.

**Classification of Twill weave:**

Twill weaves can be classified from four points of view:

a) According to the way of construction
   - Warp-way twill weave: $\frac{3}{1}$ warp-way twill, etc.
   - Weft-way twill weave: $\frac{2}{3}$ weft-way twill, etc.

b) According to the direction of twill lines on the face of the fabric
   - S – Twill or Left-hand twill weave: $\frac{2}{1}$ S, etc.
   - Z – Twill or Right-hand twill weave: $\frac{3}{2}$ Z, etc.

c) According to the face yarn (warp or weft)
   - Warp face twill weave: $\frac{4}{2}$ S, etc.
   - Weft face twill weave: $\frac{1}{3}$ Z, etc.
   - Double face twill weave: $\frac{3}{3}$ Z, etc.

d) According to the nature of the produced twill line
   - Simple twill weave: $\frac{1}{2}$ S, $\frac{3}{1}$ Z, etc.
   - Expanded twill weave: $\frac{4}{3}$ S, $\frac{3}{2}$ Z, etc.
   - Multiple twill weave: $\frac{2}{3}$ $\frac{3}{1}$ S, $\frac{3}{2}$ $\frac{1}{3}$ Z, etc.

**According to the way of construction:**

**Warp-way Twill weave:** In warp way twill weave warp float run in the warp direction.
Formula number of every yarn is same i.e. all warp ends interlace in the same way but displacing the interlacing points of each end by one pick relative to that of the previous end. In this case any sign or colour in the square of graph or design paper represent warp up and empty square represent weft up.

**Weft-way Twill:**

In weft way twill weave weft float run in the weft direction. Formula number of every yarn is same i.e. all weft yarn interlace in the same way but displacing the interlacing points of each pick by one end relative to that of the previous pick. In this case any sign or colour in the square of graph or design paper represent weft up and empty square represent warp up. This is exceptional than other normal system.

**According to the direction of twill lines on the face of the fabric:**

The lines created by this pattern are called twill lines or diagonal lines or wales. When the cloth is held in the position in which it was woven, the diagonal lines will be seen to run either from the lower left corner to the upper right corner or from the lower right to the upper left corner.

**S – Twill or Left-hand Twill:**

When the twill runs from the lower right to the upper left corner, the twill is known as a left-hand twill. It is produced by downward displacement of the interlacing points, if the starting point is bottom left corner or upward displacement of the interlacing points, if the starting point is bottom right corner. For example it is expressed by the formula number $\frac{3}{2}^{S}$, where $S$ – indicate the direction of twill line. The following figures show the weave plan of different left hand twill fabric. The alignment of twill line is parallel to the middle portion of ‘S’, so it is called $S$ – twill.

**Z – Twill or Right-hand Twill:**

When the diagonal line runs from the lower left corner to the upper right corner, the twill is known as a right-hand twill. About 85% of all twill-woven fabrics are right-hand twills. It is produced by upward displacement of the interlacing points. For example it is
expressed by the formula number \( \frac{2}{2} Z \), where, \( Z \)– indicate the direction of twill line.

The following figures show the weave plan, with drafting and lifting plan of different right-hand twill fabric. The alignment of twill line is parallel to the middle portion of ‘Z’, so it is called Z–twill.

**c) According to the face yarn (warp or weft):**

The description of twill weaves is notated as \( \frac{4}{2}, \frac{2}{2}, \frac{2}{3} \), and so on. The top digit of the fraction line refers to the number of weft yarns crossed over by the warp and the bottom digit to the number of weft yarns the warp passes under before returning to cross the filling again. When the crossing is over and under the same number of yarns, the fabric is called a double-face or even or even-sided twill. When warps pass over a larger or smaller number of weft yarns than they pass under, the fabric is called an uneven twill. Uneven twill fabrics have a right and a wrong side and therefore are not considered reversible. The traditional denim fabric used in blue jeans is an uneven warp-faced twill; the warp yarns are dyed blue and the weft yarns are undyed, so the fabric appears blue on the face and white on the back. There are two types of uneven twill, such as warp-face twill and weft-face twill.

**Warp-face Twill:**

Warp-faced twills have a predominance of warp yarns on the face of the fabric, with patterns of \( \frac{2}{1}, \frac{3}{1}, \frac{3}{2}, \frac{4}{2} \), and so on. The top digit of the fraction line is higher than the bottom one, so it is called warp-face twill. Since warp yarns are made with higher twist, these fabrics are stronger and more resistant to abrasion and pilling. The following figures show the weave plan and interlacing diagram of warp-face twill.
Weft-face Twill:

Weft-faced twills have a predominance of weft yarns on the surface of the fabric, with patterns of $\frac{2}{3}$, $\frac{3}{4}$, $\frac{1}{2}$, $\frac{2}{4}$, and so on. The top digit of the fraction line is smaller than the bottom one, so it is called weft-face twill. Weft yarns are generally weaker than warp yarns, so that relatively few weft-faced twills are made. The following figures show the weave plan of weft-face twill.

Double face Twill or Even-sided twill:

Even-sided twills expose an equal amount of warp and weft yarn on each side of a fabric. They are also known as reversible twills because they look alike on both sides, although the direction of the twill line differs. Better quality weft yarns are used in these fabrics as compared with warp-faced twills because both sets of yarn are exposed to wear. They are most often $\frac{2}{2}$ twills and have the best balance of all the twill weaves.
\[ \frac{3}{3}, \frac{4}{4}, \text{etc. are also the double-face twill. In this case the top and bottom both digits of the fraction line are same, so it is called double-face twill. The following figures show the weave plan of some double-face twill.} \]

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\textbf{d) According to the nature of the produced twill line:}

**Simple Twill:**

There are two types of simple twill, such as simple warp twill and simple weft twills. Each warp end is raised over or lowered under only one pick in the repeat, with pattern of \( \frac{1}{2}, \frac{1}{3}, \frac{1}{4}, \frac{2}{1}, \frac{3}{1}, \frac{4}{1} \), and so on. \( \frac{1}{2}, \frac{1}{3}, \frac{1}{4}, \text{etc. are the simple weft twill and } \frac{2}{1}, \frac{3}{1}, \frac{4}{1}, \text{etc. are the simple warp twill. The following figures show the weave plan with drafting and lifting plan of some simple warp and simple weft twill fabrics.} \)
Expanded Twill:

Each warp end is raised over or lowered under more than one adjacent pick in the repeat. If the warp and weft twill lines are of equal width, the fabric is double-faced. It is represented by the formula number of \( \frac{2}{3}, \frac{3}{2}, \frac{4}{4}, \frac{2}{4} \), and so on. The following figures show the weave plan of some expanded twill weaves.

Multiple Twill:

In each repeat, there are at least two warp twill lines or two weft twill lines of different width. If the prominence of warp yarn is more than it is called warp-face multiple twill and the prominence of weft yarn is more than it is called weft-face multiple twill. If the prominence of both warp and weft yarns are same than it is called double-face multiple twill. It is represented by the formula number of \( \frac{4}{1}, \frac{3}{1}, \frac{2}{1} \), \( \frac{1}{1}, \frac{3}{1}, \frac{1}{5} \) and
so on. The following figures show the weave plan with close-up view of some multiple twill weaves.

Derivatives of Twill weave:

Weaves are developed on the basis of principle of twill weave or from a regular twill, these are called derivatives of twill weave. The common twill derivatives are listed below:

1. Zig-zag or waved or pointed Twill weave
2. Herringbone Twill weave
3. Diamond design
4. Diaper design
5. Broken Twill weave
6. Re-arranged Twill weave or Transposed Twill weave
7. Stepped Twill weave
8. Elongated Twill weave
9. Combined Twill weave or combination of twill weave
10. Shaded Twill weave or shaded design
11. Curved Twill weave

1. Zig-zag or Pointed or Waved Twill weave:

In zig-zag twills the diagonal line proceeds either to the left or right. Where two lines meet they create a point, forming a continuous zig-zag effect in the fabric. If one takes a twill weave and reverses the drafting order in the heald shafts regularly after a certain number of ends, the twill lines will run across the width of the fabric in a zig-zag configuration. The reversing of the draft can occur after a repeat or after any number of warp ends. Each reversal produces a point.

Selecting the right twill weave when constructing zig-zag or waved effects is of great importance. Short warp or weft floats should be used so as to avoid long floats when the weave is reversed. So zig-zag weave is produced by the combination of S-twill and Z-twill weave. According to the change of twill direction there are two types of zig-zag weave, such as:

- Horizontal zig-zag, and
- Vertical zig-zag weave.

**Horizontal Zig-zag weave:**

If the direction of twill line is change depends on the warp yarn than horizontal zig-zag twill weave is produced. The repeat size of horizontal zig-zag is calculated from the regular or base twill weave. In one system, the number of warp yarn in zig-zag weave is double of the number of warp yarn of base twill and the number of weft yarn is same as base twill weave. For example, if the repeat size of basic regular twill is $4 \times 4$, than the repeat size of horizontal zig-zag is $8 \times 4$. In other system, the number of warp yarn in zig-zag weave is two less from double of the number of warp yarn of base twill and the number of weft yarn is same as base twill weave. For example, if the repeat size of basic regular twill is $4 \times 4$, than the repeat size of horizontal zig-zag is $6 \times 4$. In general, the direction of twill line is changed after the completion of repeat of regular twill weave and the point is created at the changing time. Normally warp-way twill is used as regular basic twill. Returning a straight draft in the opposite direction will create a pointed draft and does result in a horizontal waved effect if programmed with a peg plan of the twill weave. So pointed or V – draft is used to produce horizontal zig-zag weave. It is possible to produce this weave from any type of regular basic twill weave. The following figures show the weave plan with drafting and lifting plan of some horizontal zig-zag weaves.
Horizontal zig-zag twill based on \( \frac{2}{2}Z \) Twill weave
The following figures show the close-up view of some horizontal zig-zag fabric.

Zig-zag twill based on $\frac{2}{2}$, reversing after each repeat.  
Zig-zag twill based on $\frac{2}{2}$, reversing after every 10 picks.  
Zig-zag twill based on $\frac{3}{1}$, $\frac{1}{3}$.
**Vertical Zig-zag weave:**

If the direction of twill line is change depends on the weft yarn than vertical zig-zag twill weave is produced. The repeat size of vertical zig-zag is calculated from the regular or base twill weave. In one system, the number of weft yarn in zig-zag weave is double of the number of weft yarn of base twill and the number of warp yarn is same as base twill weave. For example, if the repeat size of basic regular twill is $5 \times 5$, than the repeat size of vertical zig-zag is $5 \times 10$. In other system, the number of weft yarn in zig-zag weave is two less from double of the number of weft yarn of base twill and the number of warp yarn is same as base twill weave. For example, if the repeat size of basic regular twill is $5 \times 5$, than the repeat size of horizontal zig-zag is $5 \times 8$. In general, the direction of twill line is changed after the completion of repeat of regular twill weave and the point is created at the changing time. Both weft-way and warp-way twills are used as regular basic twill. Straight draft is used to produce vertical zig-zag weave. It is possible to produce this weave from any type of regular basic twill weave. The following figures show the weave plan with drafting and lifting plan of some vertical zig-zag weaves.
Zig-zag twill is used for figured or ornamented design, upholstery, wall-covering, screen, curtain, various house hold items.
2. **Herringbone Twill weave:**

These weaves are generated by introducing a step into the design after a certain number of ends or picks. At the step, every thread changes from up to down or vice versa. If the original weave is not double-faced, this means that, at every step, a warp twill changes into a weft twill or vice versa. It is also produced by the combination of S—twill and Z—twill like zig-zag weave but it is not create a point. It is also divided into two groups depending on the change of the direction of twill line, such as:

- Horizontal herringbone twill weave, and
- Vertical herringbone twill weave.

**Horizontal Herringbone Twill weave:**

If the direction of twill line is change according to the herringbone principle depends on the warp yarn than horizontal herringbone twill weave is produced. The repeat size of horizontal herringbone is calculated from the regular or base twill weave like as horizontal zig-zag weave. In this case the number of warp yarn in herringbone weave is double of the number of warp yarn of base twill and the number of weft yarn is same as base twill weave. For example, if the repeat size of basic regular twill is $4 \times 4$, than the repeat size of horizontal herringbone is $8 \times 4$. In general, the direction of twill line is changed after the completion of repeat of regular twill weave. Normally warp-way twill is used as regular basic twill. Broken draft is used to produce horizontal herringbone weave, if double-face twill weave is used as base twill. When uneven
twill such as warp-face or weft-face twill is used as base twill then straight draft is used to produce horizontal herringbone weave.
It is possible to produce this weave from any type of regular basic twill weave. The vertical stripe effect is produced on the surface of this fabric. The just previous figures show the weave plan with drafting and lifting plan of some horizontal herringbone weaves.

**Vertical Herringbone Twill weave:**

If the direction of twill line is change according to the herringbone principle depends on the weft yarn than vertical herringbone twill weave is produced. The repeat size of vertical herringbone is calculated from the regular or base twill weave like as vertical zig-zag weave. In this case the number of weft yarn in herringbone weave is double of the number of weft yarn of base twill and the number of warp yarn is same as base twill weave. For example, if the repeat size of basic regular twill is $4 \times 4$, than the repeat size of vertical herringbone is $4 \times 8$. In general, the direction of twill line is changed after the completion of repeat of regular twill weave. Normally weft-way twill is used as regular basic twill. Straight draft is used to produce vertical herringbone weave from all type of base twill. It is possible to produce this weave from any type of regular basic twill weave. The horizontal stripe effect is produced on the surface of this fabric. The following figures show the weave plan with drafting and lifting plan of some vertical herringbone weaves.

![Vertical Herringbone Twill Weave Diagram](image)

The weave, drafting and lifting plan with Close-up view of vertical herringbone twill based on $\frac{2}{2}$ warp-way twill.
3. Diamond design:

This is a derivative of twill weave. Diamond design is developed on the basis of pointed principle. It is build-up by the combination of vertical and horizontal zig-zag weave. The repeat size of diamond design is also calculated from the regular or base twill weave. In
this case the number of both warp and weft yarns in diamond weave are double of the number of warp and weft yarn of base twill respectively. For example, if the repeat size of basic regular twill is $4 \times 4$, than the repeat size of diamond design is $8 \times 8$. Diamond is a reversible design. So it may be divided into two equal parts in both vertical and horizontal axis. Pointed or V-drafting system is used to produce diamond design.
The construction principle of diamond as follows: there is several system to build up diamond design. At first select the repeat size according to the basic twill. Then repeat size is divided into four quadrants. Now the basic twill is put in every quadrant by the change of direction of twill line in this way that the opposite twill line of every twill should be parallel and they produce an angle at the changing point. Both sides of some diamond design are equal but some diamond designs are not equal although they are developed on the same basic twill. It depends on the construction principle, which is shown in the following figures.
4. Diaper design:

This derivative of twill weave is developed on the basis of herringbone principle. It is build-up by the combination of vertical and horizontal herringbone weave. The repeat size of diaper design is also calculated from the regular or base twill weave like as diamond design. In this case the number of both warp and weft yarns in diaper weave are double of the number of warp and weft yarn of base twill respectively. For example, if the repeat size of basic regular twill is $4 \times 4$, than the repeat size of diaper design is $8 \times 8$. Diaper is not a reversible design like diamond. It may be divided into two parts in diagonal axis. Broken draft is used to produce diaper design, if double-face twill weave is used as base twill. When uneven twill such as warp-face or weft-face twill is used as base twill then straight draft is used to produce this design.
The construction principle of diaper design as follows: there is several systems to build up diaper design. At first select the repeat size according to the basic twill. Then repeat size is divided into four quadrants. Now the basic twill is put in every quadrant by changing direction of twill line on the basis of herringbone principle in this way that they do not produce point like as diamond. For every change of twill direction a warp twill changes into a weft twill or vice versa like as herringbone principle.

Towel, bedsheet, wrappers, pelow covers, table cloth, curtain, sopa cover and many other house hold fabrics can be made by this weave.
5. Broken or reversed Twill weave:

A broken twill is formed by a break in the continuation of the twill line at predetermined intervals. There is several systems to produce broken twill. Usually the break will be at the centre of the repeat, with only one reversal, but more complicated breaks can be made. One divides the original weave into two halves and copies the first half unchanged, starting from the first warp end. The second half is copied in reverse order, starting from the last end. Broken twills are also produced by dividing three or more parts. Normally straight draft is used to produce this weave. The pattern can be broken either in the warp or in the weft direction and no twill line will be generated. The following figures show the close-up view with weave, drafting and lifting plan of different types of broken twill weaves.
6. Re-arranged Twill weave or Transposed Twill weave:

Rearranging a weave means taking single thread or group of threads of the base weave and arranging them in a different order. If the rearrangement does not exceed the repeat of the base weave, the same straight draft can be used. The pattern can be rearranged either in the warp or in the weft direction. By this rearrangement the different types of novelty and attractive designs can be developed in the fabric. The appearance of some rearranged twill is same as broken twill. This twill weave is created by the following different methods.
Rearrangement of individual threads:

One can rearrange weaves by changing the sequence of the warp ends. The following figure represents 5-end expanded weft twill \( \frac{2}{3} \), rearranged as a steep or elongated twill by changing the warp sequence to every 2\(^{nd}\) end.

The following figure represents a 8-end double-faced twill \( \frac{4}{4} \), rearranged like satin with step 3. This weave is also called a “mock satin” but, unlike the real satin, is double-faced.
The following figure represents a 8-end multiple twill \( \frac{2}{3} \frac{2}{1} \) where the warp ends are rearranged in the sequence 1,5; 2,6; 3,7; 4,8; 5,1; 6,2; 7,3; 8,4.

Rearrangement of groups of threads:

With this type of rearrangement, one divides the original weave into groups of two or more ends and changes their sequence, e.g. by reversing it or arranging them in satin fashion. The following figure represents 8-end multiple twill \( \frac{2}{1} \frac{2}{3} \), divided into groups of two ends which are placed in reverse sequence. The sequence within the group remains unchanged.
The following figure represents the rearranged weave of the just previous figure is divided into groups of two picks each and these are also arranged in reverse order.

Corkscrew Weave:
Corkscrew weaves are a variety of rearranged twill. These are characterized by a some what subdued twill formation with either warp or weft face. These weaves, also called diagonal ribs. The peculiar feature of corkscrew weaves is the combination of two or more distinct twill lines, which may be of different colours. Corkscrew fabrics, which are usually made of fine worsted, should be set close in the warp, otherwise the twill will look thin and ragged.

They are used either alone or in combination with other weaves for variety of purpose. They are used for garment for which they are capable of producing firm and compact textures of greater strength, warmth and durability. They are of two kinds, such as –

- Odd number corkscrew weave, and
- Even number corkscrew weave.

Odd number corkscrew weave:
Odd number corkscrew weave is created by rearranging any type of regular twill weave in a sateen order. Both warp and weft face types are available. Warp-face – warp floats are one thread longer that weft floats. Same in the case of weft face. They are developed from odd number of ends and picks. The following figures show the odd number corkscrew weave from respective regular twill weave with drafting and lifting plan. Straight drafting system is normally used to produce this weave.
Even number Corkscrew weave:

Even number corkscrew is produced from two different regular base twill of the same repeat size. In this case the number of warp yarn in the repeat size of the resultant corkscrew weave will be the sum of the number of warp yarn of the base twill weave and the number of weft yarn is equal to the base twill. For example, if the repeat size of the base twill is $6 \times 6$ then the repeat size of the resultant even number corkscrew weave is $12 \times 6$. Straight drafting system is normally used to produce this corkscrew weave. The following figure show the even number corkscrew weave from respective regular twill weave with drafting and lifting plan.
7. Stepped Twill weave:

These weaves are generated by introducing a step into the design after a certain number of ends or picks. At the step, every thread changes from up to down or vice versa. If the original weave is not double-faced, this means that, at every step, a warp twill changes into a weft twill or vice versa. There are three types of step twill weave, such as:

- Warp-way step twill
- Weft-way step twill, and
- Both warp and weft-way step twill weave.

Warp-way step twill weave:

There are two types of warp-way step twill. One is created in the same twill direction and another one is created by reversal of the twill direction.

Same twill direction:

In the same twill direction step may be occur after the repeat or any desired number of thread. The following figure represents 4 – end double-faced twill \( \frac{2}{2} \) with step after every four ends and same twill direction.
Step after every four ends with same twill direction based on $\frac{2}{2}$ twill weave

The following figure represents 8 – end multiple twill $\frac{4}{1} \frac{1}{2}$ with a step after every four and two ends alternately and same twill direction.

Reversal of the twill direction:
Same as horizontal herringbone twill weave. It already discuss in the previous section.

Weft-way step twill weave:
There are also two types of weft-way step twill like as warp-way step twill weave. One is created in the same twill direction and another one is created by reversal of the twill direction.

Same twill direction:
In the same twill direction step may be occur after the repeat or any desired number of thread like as warp-way step twill weaveThe following figure represents 4 -end
double-faced twill $\frac{2}{2}$ with step after every four picks and same twill direction. Straight drafting system is normally used to produce this weave.

**Reversal of the twill direction:**

Same as vertical herringbone twill weave. It already discuss in the previous section.

**Both warp and weft-way step twill weave:**

Same as diaper design. These are also discussed in the previous section.

8. **Elongated or Steep Twill weave:**

A peculiar form of twill, known as an elongated or steep twill, is obtained when the warp float of each thread rises two or more picks instead of one pick above the float of the preceding thread. A steep twill can be made by drafting in succession the alternate threads of a regular twill.

This is a term applied to a regular twill which has been altered to achieve a steeper or flatter angle. The angle of elongated twill is either below $45^0$ or above $45^0$. These are based on a square sett (same number of ends and picks per one inch and an identical yarn count). Any deviation from this will automatically influence the angle. The angle of
the twill line is determined by the step number (the rate of advance from one
interlacing point to the next).

There are two types of elongated twill, such as warp way elongated twill i.e. warp-way elongation and weft way elongated twill i.e. weft-way elongation. There are two methods by which elongated twills are developed.

**Method – 1: By using step number:**

The angle of the elongated twill is determined and this also decides the step number. Assuming the step number required is two, then starting with the first end and using only odd numbered ends will automatically achieve a step of two.

**Method – 2: By selecting a base line:**

Only a base line is selected with a step number divisible through the repeat of this line. Repeat of base line: 12 ÷ 2 = 6 ends repeat, 9 ÷ 3 = 3 ends repeat, 15 ÷ 3 = 5 ends repeat, 15 ÷ 5 = 3 ends repeat, etc. This is a more efficient method, eliminating drawing out the base weave in full.

**Warp way elongation:**

Warp way elongated twill is developed from the warp-way regular twill weave. If the repeat size of regular twill is even number, then the number of warp yarn in the repeat size of the elongated twill is half of the regular twill and the number of weft yarn is same as regular twill weave, when the step number is two. When the repeat size of regular twill is odd number then the repeat size of elongated twill is same as regular twill. Straight drafting system is used to produce this weave. The following figures show the weave plan with drafting and lifting plan of some warp way elongated twill fabric.
Weft way elongation:

Weft way elongated twill is developed from the weft-way regular twill weave. If the repeat size of regular twill is even number, then the number of weft yarn in the repeat size of the elongated twill is half of the regular twill and the number of warp yarn is same as regular twill weave, when the step number is two. When the repeat size of regular twill is odd number then the repeat size of elongated twill is same as regular twill. Straight drafting system is used to produce this weave. The following figures show the weave plan with drafting and lifting plan of some weft way elongated twill fabric.
Elongated twill (weft-way elongation) based on \( \frac{4}{2} \) \( \frac{1}{2} \) \( \frac{1}{2} \) multiple twill weave

Close-up view of a weft-way elongated twill, based on \( \frac{4}{4} \) weft-way twill weave

Elongated twill (weft-way elongation) based on \( \frac{5}{2} \) \( \frac{2}{2} \) weft-way multiple twill weave
The object of combined twill is to produce useful and new weaves of greater variety and interest. Combined twills are those produced by arranging the threads of two continuous regular twill weaves alternately with each other. The repeat size of two regular twill weaves may be equal or different. This combination may occur in warp direction or weft direction. According to this combination, there are two types of combined twill, such as warp-way combined twill and weft-way combined twill.

For the construction of combined twill, the repeat sizes of two regular base twills play an important role. The repeat size of the combined twill depends on the repeat size of the regular base twill. If the repeat sizes of two base twills are same, then the number of warp yarn in the repeat size of the warp-way combined twill is twice of regular base twill and the number of weft yarn is same as regular twill. Similarly for the weft-way combined twill, the number of weft yarn in the repeat size is twice of regular base twill and the number of warp yarn is same as regular twill. But if the repeat sizes of the base twills are not same, then it is important to calculate their (repeat sizes of the base twills) lowest common multiple (LCM). In this case the selection of repeat size depends on this LCM value. For warp-way combined twill, the number of warp yarn in the repeat size is twice of LCM value and the number of weft yarn is same as LCM value. Similarly for weft-way combined twill, the number of weft yarn in the repeat size is twice of LCM value and the number of warp yarn is same as LCM value.

**Warp-way combination:**

When the repeat sizes of the base twills are same then the construction principle as follows:

- At first select base twills, such as \(\frac{2}{3}Z\) and \(\frac{4}{1}Z\).
- Mark the repeat of twice the number of ends of the base twills and same as the number of picks of the base twills. In this case the calculated repeat size will be \(10 \times 5\).
- Transfer all ends of the base twill \(\frac{2}{3}Z\) to the odd numbered ends and transfer all ends of base twill \(\frac{4}{1}Z\) to the even numbered ends.

The following figure show the weave plan of the above mentioned warp-way combined twill with drafting and lifting plan. Divided drafting system is normally used to produce warp-way combined twill fabric.
When the repeat sizes of the base twills are different then the construction principle as follows:

- At first select base twills, such as $\frac{2}{3}Z$ and $\frac{3}{3}Z$.
- Calculate the LCM value of the repeat sizes ($4 \times 4$ and $6 \times 6$) of base twills. In this case the LCM value of the mentioned base twills is 12 (LCM of 4 and 6).
- Mark the repeat of twice the number of ends of the LCM value and same as the number of picks of the LCM value. In this case the calculated repeat size will be $24 \times 12$.
- Transfer all ends of the base twill $\frac{2}{2}Z$ to the odd numbered ends and transfer all ends of base twill $\frac{3}{3}Z$ to the even numbered ends.

The following figure show the weave plan of the above mentioned warp-way combined twill with drafting and lifting plan. Divided drafting system is also used to produce this weave.
Weft-way combination:

Weft-way combined twill normally developed from the weft-way twill. When the repeat sizes of the base twills are same then the construction principle as follows:

- At first select base twills, such as $\frac{3}{2}Z$ and $\frac{2}{3}Z$ weft-way twill.
- Mark the repeat of twice the number of picks of the base twills and same as the number of ends of the base twills. In this case the calculated repeat size will be $5 \times 10$.
- Transfer all picks of the base twill $\frac{3}{2}Z$ to the odd numbered picks and transfer all picks of base twill $\frac{2}{3}Z$ to the even numbered picks.

The following figure show the weave plan of the above mentioned weft-way combined twill with drafting and lifting plan. Straight drafting system is normally used to produce weft-way combined twill fabric.
When the repeat sizes of the base twills are different then the construction principle as follows:

- At first select base twills, such as $\frac{3}{1} Z$ and $\frac{2}{1} Z$ weft-way twill.
- Calculate the LCM value of the repeat sizes (4 x 4 and 6 x 6) of base twills. In this case the LCM value of the mentioned base twills is 12 (LCM of 4 and 6).
- Mark the repeat of twice the number of picks of the LCM value and same as the number of ends of the LCM value. In this case the calculated repeat size will be 12 x 24.
- Transfer all picks of the base twill $\frac{3}{1} Z$ to the odd numbered picks and transfer all picks of base twill $\frac{2}{1} Z$ to the even numbered picks.

The following figure shows the weave plan of the weft-way combined twill with drafting and lifting plan. Straight drafting system is also used to produce this weave.
Shade effect can be produce in different way on the surface of the fabric. This shade effect can be introduced in any type of cross-over or stripe or figure design. There are mainly two types of shading effects, such as single shading and double shading effect. When these shading effects are produce by the use of twill weave, then it is called shaded twill weave. The base twill may be either warp-way or weft-way twill. So there are two types of shaded twill, such as single shaded twill and double shaded twill weave.
**Single Shaded Twill weave:**

In this case the shade effect is gradually decreasing from deep to light by decreasing the number of warp or weft floats and vice versa. These effects are produced from the regular multiple twill. In these multiple twills, the warp and weft floats are arranged in a regular order. Such as

\[
\begin{array}{ccccccc}
6 & 5 & 4 & 3 & 2 & 1 \\
1 & 2 & 3 & 4 & 5 & 6
\end{array}
\quad
\begin{array}{ccccccc}
5 & 4 & 3 & 2 & 1 \\
1 & 2 & 3 & 4 & 5
\end{array}
\quad
\begin{array}{ccccccc}
4 & 3 & 2 & 1 \\
1 & 2 & 3 & 4 & 5 & 6
\end{array}
\quad
\begin{array}{ccccccc}
3 & 2 & 1 \\
1 & 2 & 3 & 4 & 5 & 6
\end{array}
\]

etc.

The following figure shows the weave plan of the single shaded twill fabric.

---

**Double Shaded Twill weave:**

In this case the shade effect is gradually increasing from light to deep by increasing the number of warp or weft floats and again gradually decreasing from deep to light by decreasing the number of warp or weft floats. These effects are produced from the regular multiple twill. In these multiple twills, the warp and weft floats are arranged in a typical order. Such as

\[
\begin{array}{ccccccc}
1 & 2 & 3 & 4 & 5 & 6 \\
5 & 4 & 3 & 2 & 1 & 2
\end{array}
\quad
\begin{array}{ccccccc}
2 & 1 & 3 & 4 & 5 & 6 \\
4 & 3 & 2 & 1 & 2 & 3
\end{array}
\quad
\begin{array}{ccccccc}
3 & 1 & 4 & 5 & 6 & 1 \\
1 & 2 & 3 & 4 & 5 & 6
\end{array}
\quad
\begin{array}{ccccccc}
4 & 1 & 3 & 5 & 6 & 2 \\
2 & 1 & 3 & 4 & 5 & 6
\end{array}
\quad
\begin{array}{ccccccc}
5 & 1 & 2 & 4 & 6 & 3 \\
3 & 2 & 1 & 4 & 5 & 6
\end{array}
\quad
\begin{array}{ccccccc}
6 & 1 & 2 & 3 & 5 & 4 \\
4 & 3 & 2 & 1 & 5 & 6
\end{array}
\]

etc.
The following figure shows the weave plan of the double shaded twill fabric.

For the construction of shaded twill, there is no special system; it is same as regular twill construction. Only specialty is that, the arrangement of warp and weft floats in the formula number.
Advantages and disadvantages of twill weaves:

Twill weaves usually make fabrics closer in texture, heavier, and stronger than do plain weaves. This is why twills are so suitable for men’s clothing fabrics. Also, it is possible to produce more fancy designs in twills than in plain weaves. In addition to their distinctive appearance and high strength, twill fabrics tend to show soil less readily than plain-weave fabrics. However, twills are more expensive to produce than plain-weave fabrics because loom productivity is frequently reduced by the increased complexity of shed formation with additional heald-shafts.

The major advantages of a twill fabric are that it is durable and wears well, resists soiling, and has good resistance to wrinkling. Its disadvantages are that, once soiled, it is more difficult to clean than plain weave fabrics and it usually has a right and wrong side, which may make garment design difficult. Unless given special treatments, some uneven twill fabrics produce garments that are prone to twisting or skewing on the body after laundering.
**SATIN WEAVE**

**Introduction:**

Satin is the third basic weave of the woven fabrics. In basic construction, the satin weave is similar to the twill weave but generally uses from five to as many as twelve harnesses, producing a five to twelve-shaft construction. It differs in appearance from the twill weave because the diagonal of the satin weave is not visible; it is purposely interrupted in order to contribute to the flat, smooth, lustrous surface desired. There is no visible design on the face of the fabric because the yarns that are to be thrown to the surface are greater in number and finer in count than the yarns that form the reverse of the fabric.

Satin weaves produce a smooth, even and glossy fabric surface. This is due to the interlacing points being covered up by the floats of the neighbouring threads. The smoothness of the fabric surface can be improved by:

- High thread density
- Smooth yarn with low twist
- Filament yarn from man-made fibre.

Each end and each pick makes one, and only one intersection and the intersections are distributed in an orderly manner. Uniformly separated from each other, and nowhere adjacent. Satin is more loose structure fabric, when compare with plain and twill fabrics. Satin is widely used for the foundation of jacquard design.
Classification of satin weave:

One distinguishes between warp and weft satins depending on whether the fabric face shows the warp or the weft. Weft satins are also called sateens. With the most common simple warp satin, each warp end is lowered only on one pick in the repeat while, with the weft satin, it is only raised on one pick. The smallest regular satin weave is the 5 – end satin which can be represented either by \( \frac{1}{4}(2) \) or by \( \frac{4}{1}(3) \) where the figure in the bracket shows the size of the step.

So the warp satin is denoted by the formula number \( \frac{A}{1}(B) \), where ‘A’ indicates the number of warp floats and ‘B’ indicates the step value of satin weave. Similarly the weft satin is denoted by the formula number \( \frac{1}{A}(B) \), where ‘A’ indicates the number of weft floats and ‘B’ indicates the step value of satin weave. It is important to note that when the face side of a fabric composed by the warp satin weave then the reverse side of this fabric should be composed by the weft satin weave.

Both warp and weft satins are divided into two groups, such as

- Regular warp satin and irregular warp satin
- Regular weft satin and irregular weft satin.

There is a step value or move number for regular warp or weft satin weave but there is no step value for the irregular warp or weft satin weave. In general 4 – end and 6 – end satin weaves are irregular, because they have no step value. Other 5 – end to 16 – end satins are regular, because they have step values.

Move number or Step value selection for Satin weave:

With the satin weave, the distance between consecutive interlacing points is always the same and is referred to as the step or step values or move numbers of the satin. The weaves are developed with the help of this move or count number. To establish this number certain rules have to be considered. The number must be larger than one and must not be one less than the number of threads in the repeat, as this would create a twill. The number must not be a factor. The move number can be applied by counting warp-ways or weft-ways.

The value of the step indicates by how many picks the interlacing point on the next warp end to the right moves upward. One obtains the value of the step by dividing the repeat number (i.e. the number of ends or picks in the weave repeat) into pairs of numbers. Of the two numbers of a pair, either both or none can be used as a step value. Usable steps must meet the following conditions:
Neither number must be unity.
- None of the numbers must be a factor of either the other number or of the repeat number.
- The two numbers must not have a common factor.

For example, in case of 8 – end satin, 1 and (8 – 1) or 7 does not accepted as step value. Consider any two numbers but the sum of this two numbers should be equal to 8 and 8 is not divided by this selected number i.e. there is no common factors of 8. So 3 or 5 can be choosing as a step value.

Usable step values for satin weaves:

<table>
<thead>
<tr>
<th>Repeat size of the weave</th>
<th>Usable step values</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 – end 4 x 4</td>
<td>No</td>
</tr>
<tr>
<td>5 – end 5 x 5</td>
<td>2, 3</td>
</tr>
<tr>
<td>6 – end 6 x 6</td>
<td>No</td>
</tr>
<tr>
<td>7 – end 7 x 7</td>
<td>2, 3, 4, and 5</td>
</tr>
<tr>
<td>8 – end 8 x 8</td>
<td>3 and 5</td>
</tr>
<tr>
<td>9 – end 9 x 9</td>
<td>2, 4, 5, and 7</td>
</tr>
<tr>
<td>10 – end 10 x 10</td>
<td>3 and 7</td>
</tr>
<tr>
<td>11 – end 11 x 11</td>
<td>2, 3, 4, 5, 6, 7, 8, and 9</td>
</tr>
<tr>
<td>12 – end 12 x 12</td>
<td>5 and 7</td>
</tr>
<tr>
<td>13 – end 13 x 13</td>
<td>2, 3, 4, 5, 6, 7, 8, 9, 10, and 11</td>
</tr>
<tr>
<td>14 – end 14 x 14</td>
<td>3, 5, 9, and 11</td>
</tr>
<tr>
<td>15 – end 15 x 15</td>
<td>2, 4, 7, 8, 11, and 13</td>
</tr>
<tr>
<td>16 – end 16 x 16</td>
<td>3, 5, 7, 9, 11, and 13</td>
</tr>
<tr>
<td>etc.</td>
<td></td>
</tr>
</tbody>
</table>

Construction Principle of Satin Weave:

Weft satin (sateen weave):

In this construction, the weft yarn lies on the surface of the fabric as it passes regularly over and under the warp yarns. For instance, a weft yarn may pass over four warp yarns and under one. The floats are consequently made up of the weft yarns, and the luster appears in the weft direction. There are two types of weft satin, such as regular and irregular sateen weaves.

Regular Weft satin (sateen weave):

Designing a weft satin construction – An eight-shaft construction i.e. 8 – end sateen illustrates here the rules that must be followed to select a suitable interval.
• Arrange in pairs the numbers that will add up to the desired repeat number. For an eight-end weft satin, the shaft or repeat number is 8. The pairs are 1 and 7, 2 and 6, 3 and 5, 4 and 4.

• Eliminate the pair that contains the number 1 and the number below the repeat number, which is 7 (8-1) in this case. A contiguous diagonal would result if these intervals were used, producing the conventional twill weave.

• Next, eliminate the pairs that have a common divisor and those that are divisible into the shaft or repeat number. This step eliminates 2 and 6, 4 and 4. The pair 3 and 5 remains. These numbers are the only intervals that can be used in an 8 – end construction. If any of the eliminated numbers were used as an interval, the fabric would show no interlacing whatever for one or more warp yarns; in fact, there would be no fabric because it would fall apart.

• Now that the only possible interlacings have been worked out, the design can be constructed (in above figure). For convenience, here the interlacing begins in the lower left square. The horizontal rows of squares represent weft yarns – that is, the successive picks on the weaving machine. The vertical columns represent the warp yarns.

• The interval to be used for this particular design could be 3 or 5; in this case 3 has been selected. As this is to be an 8 – end construction, the interlacing on the first pick will be 7 squares (warp yarns).

• To find the warp yarn that will interlace on the second pick, count 3 to the right, beginning with the square above the interlacing that is already started at the starting point. Adjacent interlacing on the same line will be similarly 7 squares apart.
To find the warp yarn that will interlace on the third pick, start with the square above interlacing point of previous pick. Count 3 to the right, and interlacing point is plotted. Adjacent interlacings will be 7 squares apart.

This same procedure determines the interlacing points on successive picks, additional interlacings always being 7 squares apart.

On the ninth pick, the design starts to repeat, which proves the accuracy of the construction of an 8-end weave.

Where it is not possible to plot subsequent interlacing by continuing to count to the right, because of the small area of the design, interlacings on successive picks can be determined by counting 5 to the left instead of 3 to the right. If the interval 5 had been used to count to the right, 3 would have been used to count to the left.

The following figures show the weave plan, drafting plan, lifting plan, interlacing diagram and close-up view of different regular sateen fabrics.
Irregular Weft satin (sateen weave):

There is no step value or move number to construct the irregular sateen. So the above mentioned rule is not applicable for the construction of irregular sateen. Only 4-end and 6-end sateens are irregular. The following figures show the weave plan with drafting and lifting plan of these two irregular sateen fabrics. Straight drafting system is used to produce this weave.

Regular Warp Satin (Satin weave):

Warp satin is woven so that the warp may be seen on the surface of the fabric. For example, in a five-end construction, the warp may pass over four weft yarns and under one; in a 12-end construction, the warp may pass over 11 weft yarns and under 1. Since the warp lies on the surface and interlaces only 1 weft yarn at a time, the lengths of warp between the weft yarn are called floats. These floats lie compactly on the surface with very little interruption from the yarns going at right angles to them. Reflection of light on the floats gives satin fabric its primary characteristic of luster, which appears in the direction of the warp.

Designing a satin construction – When making a design for a satin construction, the interlacings on successive lines must be separated by a proper interval to avoid forming the contiguous diagonal. When the proper interval for any shaft or repeat construction is selected, the design will not repeat itself until the number of successive picks that make up the desired shaft have been interlaced. In a five-end construction, for example, the design begins to repeat on the sixth line; in an eight-end, on the ninth line; in a nine-end, on the tenth line.

The following figures show the weave plan, drafting plan, lifting plan, interlacing diagram and close-up view of different regular satin fabrics.
8 - end satin move number 5

5 - end satin move number 3 with Close-up view
5 - end satin move number 2

7 - end satin move number 5
9 - end satin move number 4
Irregular Warp satin (satin weave):
There is no step value or move number to construct the irregular satin like as sateen. So the above mentioned rule is not applicable for the construction of irregular satin. Only 4 – end and 6 – end satins are irregular. The following figures show the weave plan with drafting and lifting plan of these two irregular satin fabrics. Straight drafting system is used to produce this weave.

Advantages and disadvantages of satin weave:
These constructions produce smooth, lustrous, rich-looking fabrics that give reasonably good service if they are not subjected to excessive hard wear. Short-float fabrics are more durable than long-float fabrics, for the former have less exposed yarn to catch on rough objects; long floats, although they increase the sheen of a fabric, snag and pull if there are any protrusions or splinters on furniture.

When style calls for luxurious fabrics for formal wear, satin is often chosen. It is an especially suitable fabric for coat linings because its smooth surface allows coats to be slipped on and off very easily. In general, it sheds dirt well, but a bright rayon in a long-float satin weave will often have a metallic sheen that may appear greasy after continuous wear.

Satin weave usually requires more shafts in the weaving than do the plain or twill weaves, thereby increasing the cost of production.

Materials that are made in the satin weave include antique satin (millions of yards per year), bridal satin, charmeuse, cotton satin, dress satin, satin bengaline, satin crepe, satin faille, slipper satin, and Venetian satin.

Derivatives of Satin Weave:
Weaves are produced on the satin base is called derivatives of satin weave. Lot of jacquard designs based on this satin weave. In this case the following simple structures those are based on satin weave will be discussed.
1. Crepe Weaves:

The characteristic feature of crepe fabrics is one of texture. Their surface exhibits an all-over, random, small-scale pattern in low relief. There are two ways of obtaining this kind of texture:

- By using a special ‘crepe’ or ‘oatmeal’ weave in conjunction with ordinary, normal-twist spun or filament yarns, and
- High-twist crepe yarns in conjunction with plain or other simple weaves such as twill or satin.

The fabric should have a rough irregular surface without any prominent features. This is generally achieved by having approximately equal disposition of warp and weft on the surface of the cloth, and also by avoiding any floats which exceed three.

The characteristics of crepe-weave fabrics depend largely upon the kind of yarn used. If ordinary yarns are used and the crepe weave is employed to give a crepe appearance, then the fabric will have little drapability, low strength, and limited durability. Some crepe fabrics tend to stretch, and some may shrink when subjected to wetting. On the other hand, combinations of yarns and weave construction can produce fabrics of interesting appearance and texture that have good drapability, resilience, stretch, and serviceability.

There are four basic methods of producing crepe weaves:

a. On a sateen base  
b. By reversing  
c. By superimposing  
d. On a plain weave base

The methods of construction are:

a. Sateen base:

- Construct a sateen weave  
- Construct a twill weave on the same repeat size  
- Using the sateen base as the starting point of each lift of the twill, rearrange the twill weave on the sateen base. This new weave is called sateen base crepe weave.

The following figures show the weave plan with drafting and lifting plan of different sateen base crepe fabric. Normally straight drafting system is used to produce this weave.
Sateen base crepe weave

\[
\begin{align*}
\frac{1}{6} (m \rightarrow 3) & & \frac{2}{1} \frac{1}{3} z \\
7 \times 7 & & 7 \times 7 & & 7 \times 7
\end{align*}
\]
b. Reversing:

- Make a small motif, as at ‘a’;
- Reverse ‘a’ by turning it over, so that the warp lifts of the 4th end become the weft lifts of the 5th end and those of the 4th end become the warp lifts of the 5th end; similarly the 6th, 7th, and 8th ends are the converse of the 3rd, 2nd and 1st, respectively, and the design is now on 8 ends × 4 picks;
- Reverse this by turning it over in the weft direction and using the same technique as described. The final design is thus produced, which is called crepe weave.

The method of constructing this weave may lead to a tendency to create grouping of threads, which is generally undesirable in crepe weaves. The following figures show the weave plan with drafting and lifting plan of different crepe fabric. Normally straight drafting system is used to produce this weave.
BY Reversing or Transposing

8X8

BY Reversing or Transposing

8X8

BY Reversing or Transposing
c. Superimposing:

- Construct two different weaves with same repeat size. As sateen weaves are mainly used in this method, there is always a predominance of weft over warp.
- Superimpose one weave on the other to give the final weave.

The following figures show the weave plan with drafting and lifting plan of different crepe fabric. Normally straight drafting system is used to produce this weave.

d. Plain base:

- Design a sateen on half the number of ends and picks required in the final design – a 6-end sateen will be used for a design to be produced on 12 ends x 12 picks;
- Expand this weave so that the sateen base appears on alternate ends and picks only, and use this base as the starting point of each lift of a twill, in this case $\frac{1}{3} 1 3 \ 1 \ 1 1 \ 1$, as shown in the following figure;

- On the remaining ends insert alternate ends of plain weave, i.e. all of these ends will weave the same tabby; care should be taken to lift the warp on the picks opposite to those on which the sateen base appears;

- Now combine these to give the final design, which is repeated in the following figure.

This method provides the most successful attempt to cover pattern formation, but it is always difficult to give an allover effect when the repeat size is small.
2. Corkscrew Weaves:

There are two types of corkscrew weave, such as odd number corkscrew weave and even number corkscrew weave. Both are discussed in previous chapter. In this case only odd number corkscrew weave will be discussed, because this is a sateen derivatives.

Odd number corkscrew weave:
The construction principle of odd number corkscrew weave is same as satin base crepe weave. For the construction of this weave it is important to select odd number repeat size. Then construct a sateen and a twill weave with the same selected repeat size. Using the sateen base as the starting point of each lift of the twill, rearrange the twill weave on the sateen base. This new weave is called odd number corkscrew weave. The following figures show the weave plan with drafting and lifting plan of different odd number corkscrew fabric. Normally straight drafting system is used to produce this weave.
3. Shaded Weaves:

With a weft satin, one can gradually add interlacing points until it turns into a warp satin. The gradual change-over produces a shaded effect in the fabric, particularly if warp and weft have different colours. There are two types of shaded design like shaded twill weave, such as – Single shaded design, and Double shaded design.

**Single Shaded design or weaves:**

In this case numbers of weft satins are developed side by side at first. Then these sateen units are divided into the number of groups. With each group of sateen one can gradually add warp floats with the interlacing points until it turns into a warp satin. After this the resultant weave will be a single shaded design. The following figures show the different single shaded design.

---

![Single shaded design based on 5-end sateen](image1)

![Single shaded design based on 5-end sateen](image2)
Double Shaded design or weaves:

Like as single shaded design at first numbers of weft satins are developed side by side. Then these sateen units are divided into the number of groups as per requirements. With each group of sateen one can gradually add warp floats with the interlacing points until it turns into a warp satin. From this warp satin with each group of sateen one can gradually minus warp floats with the interlacing points until it turns into the previous weft satin or sateen. After this the resultant weave will be a double shaded design. The following figures show the different double shaded design.
Double shaded design based on 7 – end sateen

Warp shading in an 8 – end satin which is divided into groups of six ends each. At the beginning of a new group, an interlacing point is added in the warp direction, i.e. on the picks following the warp lifts. In order to achieve adequate fabric strength, it is advisable to add plain weaving ends (after each group). These are additional to the satin ends in the denting of the front reed.

Double shaded design based on 8 – end sateen
The interlacing of the threads in a form which varies from that of the basic weaves already described, is accomplished with a view to producing a fabric which is decorative in appearance and may also utilize the characteristic features of the weave for some useful purpose. The important features and construction principle of some decorative fabrics will be discussed in this chapter.

Huckaback Weaves:

Main features:

These weaves are generally applied in the manufacture of non-pile towels. The main features of this weave are as follows:

- This weave is characterized by a rough surface, which is produced by floating threads in groups arranged on a plain weave basis.
- A more balanced huckaback is produced if the weave-repeat size is twice an odd number (i.e. $2 \times 5 = 10$; repeat size = 10 ends $\times$ 10 picks), but it is by no means impossible to produce the weave on a repeat which is complete on twice an even number of threads.

- With these constructions hardwearing and extremely thick, moisture absorbing fabrics are produced.
Groups of plain weave are exchanged with groups of one end plain weave and one end floating. To achieve a more prominent raised effect in the area where the threads are floating, correct denting plays an important part. Whenever possible, the long floating ends should be drawn into the same dent.

- $10 \times 10$ is the widely used repeat size.
- This weave can be divided diagonally into equal two parts.

**Construction principle:**

The following figure shows the stages in constructing the huckaback weave:

- Mark out the repeat size, divide into quarters and fill in plain weave in two opposite ones as shown at first;
- Fill in a motif in the other two quarters, which is preferably produced by taking plain weave and adding or removing some lifts, as at second one; care should be taken to ensure that the motif and the plain weave bind together effectively;
- The final weave is produced by combining first and second one.
Drafting system:

Different drafting systems are used to produce this fabric. The draft which is generally used is so arranged that the odd number threads are carried by the two front heald-shafts and the even number threads by the back two heald-shafts.

Uses:

Linen and cotton yarns are commonly used, and in coarser qualities they are particularly suitable for hand towels, glass cloths, roller towels and quiltings. Shirtings, dresswear and table linen are produced in the finer qualities.

The following figures show the weave plan with drafting and lifting plan of different types of huckaback fabrics:
Mock leno weaves:

Main features:

This weave is also referred to as imitation gauze weave. The main features of this weave are as follows:

- It is an open perforated weave like as leno fabrics.
- It is produced in the ordinary way without special leno shafts.
- The similarity of this weave to the huckaback is quite obvious, but the method of denting is different, as it is necessary to encourage thread grouping.
- The weave is arranged in groups of equal or unequal sizes. Threads working in plain weave alternate with threads floating on the face or back of the fabric. The ends from each individual group are whenever possible drawn into the same dent; this bunches the floating ends together and causes a slight gap or opening in the fabric giving an appearance similar to a gauze or leno weave, hence the name ‘mock leno’.
- Even number repeat size is normally used to produce this weave.
- This weave can also be divided diagonally into two equal parts.
- The smallest repeat size of this weave is $6 \times 6$.

Close-up view of Mock leno fabrics

Construction principle:

The stages in producing the weave are illustrated by the following figure:

- Mark out the repeat size, divide into quarters and fill a small motif in opposite quarters, as in first step;
- Completely reverse this motif in the two remaining quarters, by substituting warp lifts for weft lifts and vice versa, as in second step;
- Combine first and second steps to give the final weave.

The following figures show the weave plan with drafting and lifting plan of different types of mock leno fabrics:
End uses:

Because of the decorative all-over effects, the end uses range from curtains to table linen and apparel fabrics. Fabrics produced with this weave are used for embroidery cloths, canvas cloths and light-weight window curtains, but it is also popular in combination with other weaves, particularly plain, in table linen, brocades, blouses and dress-wear.

Honeycomb weave:

The term is applied to weaves which resemble honeycomb cells. The cellular formations appear square in the cloth. They are formed by some ends and picks interlacing tighter than others and therefore developing a higher tension. Usually single cloths made by progressively lengthening and shortening both warp and weft floats to form ridges and hollows on a square pattern, to give a cellular appearance. Sometimes called waffle or waffle piqué.

There are two types of honeycomb weave, such as – ordinary honeycomb and brighton honeycomb.

Ordinary Honeycomb:

Main features:

The main features of ordinary honeycomb are as follows:

- The characteristic features of this weave are alternate raised and sunk diamond-shaped areas which give the effect of a honeycomb.
- Both sides of the fabric look the same and the surface of the fabric is rough.
- It has long floats of warp and weft yarns.
• In the repeat size the number of ends and picks may be equal or unequal and multiple of two.
• In the larger repeat size, a double row of binding has been constructed by using a \(\frac{1 \times 1}{1 \times a}\) twill weave at first stage, so that a firmer structure will be produced.
• The long floats in the centre of the diamonds are not equal, and if the fabric is being produced with a square sett, this can be detrimental to the appearance of the cloth as they will produce a rectangular pattern instead of a square one. Two methods are available for improving the appearance when this occurs: adjust either the sett or the weave.

![Close-up view of Ordinary honeycomb fabric](image)

• When equal floats are required in the construction, it is necessary to construct a honeycomb in which the shorter of the two long floats is the same as the required float length in the final design. For example, the original 10 ends \(\times\) 10 picks honeycomb with the first end having a float of seven. The two indicated centre ends are removed to give the final design on 8 ends \(\times\) 10 picks, with equal longest floats of seven in both the warp and weft directions. Similarly the two indicated centre picks are removed to give the final design on 10 ends \(\times\) 8 picks, with equal longest floats of seven in both the warp and weft directions.
• Pointed drafting system is normally used to produce this weave.

**Construction principle:**

The stages of constructing an ordinary honeycomb weave are as follows:

• Construct a \(\frac{1}{a}\) Z twill starting in the bottom left-hand corner, then a similar one running in the opposite direction and starting one square in or one square down from the top left-hand corner, so that there will be a clean intersection of the twill lines, as at first stage;
• In one of the two diamonds produced, leave a row of stitching points and then lift the remainder of the diamond solid. This is the final weave.
The following figures show the weave plan with drafting and lifting plan of different equal and unequal repeat sizes of ordinary honeycomb weaves.
The following figure (left-one) shows a honeycomb produced on a larger repeat, and with the warp lift designed in the opposite diamond, whilst the right-side figure shows a honeycomb weave on an even larger repeat size; in this case, a double row of binding has been constructed by using a $\frac{1}{1}$ twill weave at first stage, so that a firmer structure will be produced.

**End uses:**

This weave particularly suitable for hand towels, glass cloths, dispensed roller towels and bath mats, where moisture absorption properties are particularly desired, but in similar coarse cotton qualities it is also used for quilts and soft furnishings, and in finer qualities for shirts and brocades. In conjunction with the newer textured yarns, it is produced in very coarse qualities for cellular blankets.
Brighton Honeycomb:

Main features:

Brighton Honeycomb is a complex structure. The main features of brighton honeycomb are as follows:

- More honeycomb cells of varying size are produce in this weave.
- The fabric surface is also rough like as ordinary honeycomb.
- When making the weave, the number of threads per repeat should always be a multiple of four (i.e. 12 ends x 12 picks), whilst the longest float should always be one less than half the number of threads in the repeat (i.e. \( \frac{12}{2} - 1 = 5 \)).
- Both sides of the fabric look the same like as ordinary honeycomb.
- Straight drafting system is used to produce this brighton honeycomb weave.

Construction principle:

The construction, more complicated than the ordinary honeycomb, is illustrated by figures below, with the following stages:

- Construct a \( \begin{array}{c}
\frac{1}{a} \\
\frac{1}{1}
\end{array} \) Z twill, starting in the bottom left-hand corner, and then construct a \( \begin{array}{c}
\frac{1}{1} \\
\frac{1}{a}
\end{array} \) S twill, starting with the first warp lifts in the squares to the right and below the square in the top left-hand corner, and indicate the points on the double row of binding which are immediately adjacent to those of intersection that will allow extensive floats in the weft direction, as illustrated in first stage;
• Using the points indicated in first stage as the extreme lift of the longest float, lift the remaining adjacent ends, as in second stage;
• Each of these warp floats now form the centre float of a diamond which can be completed. This is the final weave.

The draft of the brighton honeycomb is straight, thus producing a lifting plan which is identical with the design; therefore, there is no saving of heald-shafts as is the case with the pointed or V- draft of the ordinary honeycomb.

The following figures show the weave plan with drafting and lifting plan of different Brighton honeycomb weaves.
End uses:
Although the weave is not as popular as the ordinary honeycomb, it is used in similar qualities for more decorative end uses such as quilts and brocades and, in some cases, hand towels and glass cloths. It is also suitable for crockery towels.

Distorted Thread Effect:

Main features of distorted thread effect:

- Leno weave can also be used to create a figured appearance by causing a coarse ends to cross a number of standing ends.
- In this weave, the crossing end is made to lie at an angle to the normal direction of the warp and weft threads.
- Imitations of this effect can be produced by other weaves designed to cause certain selected threads to be distorted.
• The latter must float freely on the surface of the fabric; a firm ground weave (e.g. plain) helps to develop the effect.

Types of distorted thread effect:

There are two types of distorted thread effect. Such as – distorted warp effect and distorted weft effect. The construction principles of these weaves are described as follows:

a. Distorted Warp effect:

The frequency of the distorted threads should be decided and shown as in the following figure, where the design is constructed in stages:

- After indicating the threads in the warp and weft direction which are essential for forming the distortion, fill in plain weave on all the remaining ends and picks, as at first stage;
- For a warp distortion, lift the preselected warp threads of first stage except where they cross the preselected weft threads, and then lift all remaining ground ends over the preselected weft threads in one group on the first pick and in the other group on the second pick, as at second stage;
- The completed design, third stage, is then formed by combining first and second stage.
When the fabric is relaxed after weaving, the floating ends are distorted and assume approximately the zigzag conformation.

b. Distorted Weft effect:

The frequency of the distorted threads should be decided and shown as in the following figure, where the design is constructed in stages:

- After indicating the threads in the warp and weft direction which are essential for forming the distortion, fill in plain weave on all the remaining ends and picks, as at first stage;
- For a weft distortion, lift the preselected weft threads of first stage except where they cross the preselected warp threads, and then lift all remaining ground picks over the preselected warp threads in one group on the first end and in the other group on the second end, as at second stage;
- The completed design, third stage, is then formed by combining first and second stage.

When the fabric is relaxed after weaving, the floating picks are distorted and assume approximately the zigzag conformation.
End uses:

Fabrics produced with this characteristic are used in ornamental dresswear and shirting fabrics when produced in light-weight cotton and spun rayon qualities. In heavier qualities they serve for soft furnishings in cotton, for suitings in worsted and for coats in woolen fabrics. The above close-up view clearly shows distorted weft threads lying on the surface of a cloth which is popular for ladies’ dresswear.

Cord weave:

The main characteristic of this weave are cords running in warp or weft direction. They have some similarity in appearance to the preceding weft or warp rib weaves but they are not reversible. The end use is mainly for apparel fabrics.

Cord effect in the cloth -
- By using of thick yarns
- Weave produces cord effects
  a. Bedford cord weave,
  b. Pique weave.

a) Bedford Cord weave:

Main features:

- The Bedford cord class of weaves produces longitudinal warp lines in the cloth with fine sunken lines between the cords.
- Warp face cloth.
- In one repeat two or more cords are produced.
- Wadding or padding are used to give greater prominence of the cord effect.
- Ends and picks are always even number. In special cases ends may be odd number.
- Picks number always 4. ie. 12X4, 16X4, 20X4 etc. (for plain-face Bedford cord).
Cords running down the piece in the warp direction form the main characteristic of this weave. The face of the cloth is usually plain weave and the corded effect is produced by allowing alternate pairs of weft threads to float on the back of the fabric behind each cord. These threads interweave in plain order with the outside ends of each cord and are known as the cutting ends (sunken line).

Types of Bedford cord:

There are five types of Bedford cord design, such as -

1. Plain face Bedford cord
2. Wadded Bedford cord
3. Crepon Bedford cord
4. Bedford cords, arranged with alternate picks
5. Twill face Bedford cord.

Construction principles of plain-face Bedford cord weave:

The stages of building up a Bedford cord weave, illustrated by the following figure are:

- Indicate the width of two cords (in this example, each cord has six ends), and then show the outside ends of each cord, known as cutting ends, weaving plain throughout, as at first and second stage;
- The first pair of picks float under the warp ends in the first cord and weave plain in the second cord. The second pair of picks weave plain in the first cord but float under the warp ends, and thus on the back of the cloth on the second cord. This fourth stage is the final design.
In order to increase the prominence of the cord effect, wadding ends may be introduced, as illustrated in the following figure. In the following figure, one wadding end in each eight-end cord; it can be seen that it lies between the plain weave face and the floating weft on the back of the fabric. The weave for a Bedford cord with 12 ends in each cord and 3 extra wadding ends is also shown in the next figure (30 × 4 repeat size).

The drafting and lifting plan of these designs are shown in the figure also; it can be seen that the cutting ends are always controlled by the front shafts and the wadding ends by the back shafts. When arranging the order of denting, the cutting ends should be placed on either side of a reed wire, so that they are in adjacent dents of the reed, in order to give uniformity to the edges of the cords.
End uses:

Fabrics produced with this weave may be made in medium-weight cotton or spun rayon fabrics for ladies' blouses and dresswear, sportswear and ornamental trimmings. In heavier qualities, it is suitable for soft furnishing when produced with cotton yarns or for trouserings when made of worsted yarns.

b) Pique Weave:

Main features:

- A typical pique structure consists of a plain face fabric composed of one series of warp and one series of weft threads, and a series of back or stitching warp threads.
- Continuous sunken lines or cuts i.e. cords are run horizontally in the cloth.
- One cord produces per repeat.
- Normally skip drafting system is used to produce this weave.

Types of pique weave:

There are four types of pique weave such as –

1. Ordinary pique or welt structure / Loose back without wadding picks.
2. Weft wadded welts / Loose back wadded welt structure.
3. Fast back welt or pique structure.
4. Waved pique structure.

The special features of these welts are as follows:

Ordinary welts:

- The number of face picks in the width of a cord is varied according to requirements, but usually the number of consecutive picks that are unstitched should not exceed twelve.
- The order of the warp thread arrangement, which is always one face or ground, one stitching or back end and one ground or face end, in each split of the reed, or in the proportion of two face to one stitching end.

Construction principle of ordinary welts:

The following figure shows a cross-section of the weave through the weft and indicates the stages in the construction:
- Indicate the order of the warp thread arrangement, which is always one ground, one stitching end and one ground end, then fill in plain weave on the ground ends as at first stage;
- The stitching warp is lifted over the required number of picks, as determined by the requirements of the final fabric appearance; at second stage a two pick weave is illustrated;
- The final weave is produced by combining first and second stage.

When making the draft for pique it is preferable to control the ground ends from the front shaft (skip-draft) and back two shafts are used for stitching ends. For example, plain weave, may be drawn on two healds, if the cloth is coarse, or on four healds, if the cloth is of medium fineness, or on six healds, if the cloth is very fine. Same ground ends are arranged in different heald shafts for reducing friction.
Wadded welts:

- In order to increase the prominence of the unstitched portions of the cloth, i.e. horizontal cords and to make the cloth more substantial, it is customary to insert wadding picks between the tight back stitching ends and the slack face fabric.
- Usually the wadding weft is thicker than the ground weft, and is inserted two picks at a place, the looms being provided with changing shuttle boxes at one side only. Sometimes, however, the same kind of weft is used for both the face and the wadding, looms with a single box at each side being employed; and, in such a case, one wadding pick at a place may be inserted.

<table>
<thead>
<tr>
<th>6X8</th>
<th>6X10</th>
<th>6X14</th>
<th>6X18</th>
</tr>
</thead>
<tbody>
<tr>
<td>6 x 8 wadded welt design</td>
<td>6 x 10 wadded welt design</td>
<td>6 x 14 wadded welt design with longitudinal section</td>
<td>6 x 18 wadded welt design</td>
</tr>
</tbody>
</table>

- Again, in some cloths thick wadding picks which are inserted in pairs, are supplemented by single wadding picks of the face weft. All the face ends are raised when the wadding picks are inserted, as indicated by the different colour in the designs, while the stitching ends are left down.
- The stitching ends are placed on a separate beam which is very heavily weighted, whereas the face ends are kept at moderate tension.
- At intervals the tight stitching ends are interwoven into the plain face texture, with the result that the latter is pulled down and an indentation is formed on the surface.

Fast – back welts:

- In each of the foregoing designs, the stitching ends are only lifted to form the indentations, the term “loose-back” being applied to this type of structure.
- The term “fast-back” is applied to cloths in which the stitching ends are interwoven in plain order with all, or some wadding picks. The reduction of the float length of the stitching ends on the back of the fabric which results from this interlacing helps to produce a more serviceable cloth less liable to accidental damage.
Waved piques:

- A waved pique is a simple modification of the welt structure in which the indentations are not in a horizontal line but are arranged in alternate groups, as shown at first in the following figure, the marks in which indicate the lifts of the stitching ends on the face picks.
- The group of marks does not overlap horizontally, as one commences on a face pick immediately following that on which the other has finished.
- Between succeeding groups two wadding picks are inserted, as indicated by the arrows at the side of first figure.
- The complete design to correspond with first figure is given at second figure, in which the ends are arranged in the same order as in a welt, while there are ten face picks to two wadding picks. The lifts of the tight stitching ends force the wadding picks first in one direction and then in the other, so that waved lines are formed across the cloth. The following figures show the weave plan with drafting and lifting plan of a typical waved pique or welt design.

Close-up view of waved pique (face side)  Close-up view of waved pique (back side)
End uses:

It is now used only to a very limited degree, mainly for trimmings and other ornamental uses. It is also used for neckties, ladies light summer holding costume etc.

Sponge Weave:

Any one of a variety of weave arrangements that groups ends and picks together in order to form a cellular structure and to create a soft spongy effect in the fabric. Examples include spot weaves, diamond effects, honeycombs and sateen-based structures with lifts added.

Sponge weave considered as the result of honeycomb effect and also form the cell like honeycomb weave. The characteristics features of this weave are as follows:

- The number of ends and picks are always equal;
- 10 x 10 is the smallest repeat size of this weave;
- Straight drafting system is used to produce this weave;
- Low twisted and coarser yarns are used to produce this fabric. So the fabric produced by this weave is very soft and absorbent;
- For the construction of this weave it is important to calculate the longest float of diamond. This float is depends on the repeat size of the design. The following formula is used to calculate this longest float:

\[
\text{Longest float of diamond} = \sqrt{\text{Number of ends or picks in the repeat-1}}
\]

- It is a reversible cloth like honeycomb;
- Honeycomb weave produce one cell on both sides but in this case number of produced cell on both sides of the weave depends on the number of repeat size;
- This weave produce on the sateen base.

End uses:
Uses include fancy woolen shawls, bed-sheet, towel, counterpanes, drapes, bathing wraps and dress fabrics. It is also used as ground of jacquard design.
Simple weaves such as $\frac{1}{1}$ plain, $\frac{2}{2}$ matt and $\frac{2}{2}$ twill may be used in conjunction with two-colour warp and weft patterns to produce small geometrical designs in two colours. The particular design which results depends both on the weave and on the arrangement of the two colours in the warp and weft. These patterns are called colour-and-weave effects. They are very frequently used in woolen and worsted fabrics for costumes, sports jackets and ladies’ coats.

There are two types of colour and weave effects, such as –

- Simple colour and weave effects, and

- Compound colour and weave effects.

**Order of colouring / Arrangement of threads:**

There are two types of order of colouring, such as –

- Simple order of colouring, and

- Compound order of colouring.

Both simple and compound order of colouring again divided into two types, such as- regular order of colouring and irregular order of colouring.

**Simple order of colouring:**

In this order of colouring, only one ratio of colour is used either for warp or weft, such as -

- Regular order of colouring –
  4 dark, 4 light; 3 dark, 3 medium, 3 light etc. same for both warp and weft.

- Irregular order of colouring –
  2 dark, 1 light; 3 dark, 2 medium, 1 light etc. same for both warp and weft.

- By arranging the weft in a different order from the warp, for example – 2 and 2 warping crossed with 1 and 1 wefting

**Compound order of colouring:**

In this case more than one ratio of colour is used either for warp or weft, such as -

- 2 dark – 2 light and 4 dark – 4 light; 6 dark – 6 light and 3 dark – 3 light etc. same for both warp and weft.
• In the combination of compound order of colouring, it also may be regular or irregular order like as simple order of colouring.

Order of colouring for warp yarn is called warping and order of colouring for weft yarn is called wefting.

A convenient classification of the orders of colouring for the threads is as follows:
• Simple warping and simple wefting
• Compound warping and simple wefting
• Simple warping and compound wefting
• Compound warping and compound wefting.

In the above combinations the order of warping may be the same or different from the order of wefting. To each order of colouring, simple, stripe and check weaves may be applied. The style of pattern which is produced by the combination of each order of colouring with each type of weave is given below:

**Pattern chart for colour and weave effects:**

<table>
<thead>
<tr>
<th>Order of colouring</th>
<th>Weave</th>
<th>Simple Weave</th>
<th>Stripe Weave</th>
<th>Check Weave</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simple warping and Simple wefting</td>
<td>Simple</td>
<td>Stripe</td>
<td>Check</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pattern</td>
<td>Pattern</td>
<td>Pattern</td>
<td></td>
</tr>
<tr>
<td>Compound warping and Simple wefting</td>
<td>Stripe</td>
<td>Stripe</td>
<td>Check</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pattern</td>
<td>Pattern</td>
<td>Pattern</td>
<td></td>
</tr>
<tr>
<td>Simple warping and Compound wefting</td>
<td>Cross-over</td>
<td>Check</td>
<td>Check</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pattern</td>
<td>Pattern</td>
<td>Pattern</td>
<td></td>
</tr>
<tr>
<td>Compound warping and Compound wefting</td>
<td>Check</td>
<td>Check</td>
<td>Check</td>
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<tr>
<td></td>
<td>Pattern</td>
<td>Pattern</td>
<td>Pattern</td>
<td></td>
</tr>
</tbody>
</table>

**Construction principle of colour and weave effect:**

Order of colouring and weave structure is fixed for a particular pattern. The stages in producing the pattern are illustrated below:
• Mark out the repeat size of pattern according to the order of colouring and repeat of the weave;
• Fill-up the repeat size by particular weave structure with crosses;
• Indicates order of colouring by shade, the shades indicate the dark yarns;
• For warp colouring, colour i.e. shade is put only warp-up position of the particular warp yarn and for weft colouring, colour i.e. shade is put only weft-up position of the particular weft yarn;
• This final pattern is produced by combining the colour and weave structure.
Simple colour and weave effects:

In what follows it is assumed that dark and light yarns are used, although any sufficiently contrasting colours are possible. The following designs are the example of simple colour and weave effects:

End and end colouring Pattern:

The effect of arranging the warp and weft end and end dark and light (i.e. 1 dark : 1 light) in a plain weave cloth is shown in the following figure; the shades indicate the dark yarns. The weave and colour arrangement produce the pattern, which consists of fine horizontal lines alternately dark and light.

![End and end colouring Pattern](image)

Weave: \(\frac{1}{1}\) plain
Order of colouring: 1:1 for both warping and wefting

Continuous line effect:

The effect of arranging the warp and weft a 2:2 order of colouring in the \(\frac{2}{2}\) twill-weave cloth is shown in the above right figure; similarly the shades indicate the dark yarns. The weave and colour arrangement produce the pattern, which consists of coarse horizontal lines alternately dark and light but it is not sharp line like previous end and end colouring pattern.

![Continuous line effect](image)

Hair lines or Pin stripe:

The effect of arranging the warp and weft a 2:2 order of colouring in the \(\frac{2}{2}\) 2 matt-weave cloth is shown in the following figure; similarly the shades indicate the dark yarns. The weave and colour arrangement produce the pattern, which consists of thick or coarse horizontal lines alternately dark and light like as previous end and end colouring pattern.

In the following right side figure the weave is same as in the left one, but the warp and weft colour arrangement has been changed: the result in vertical lines. Similarly the pattern can be changed by changing the starting of the weave with same colour arrangement of both warp and weft yarn.
The effect of arranging the warp and weft 2:2 order of colouring in the $\frac{1}{1}$ plain-weave cloth is shown in the following left figure; similarly the shades indicate the dark yarns. The weave and colour arrangement produce the pattern, which is the well-known crowsfoot design.

A similar but larger crowsfoot pattern results from using a 4:4 colouring with a $\frac{2}{2}$ 2 matt-weave represent in the following middle figure. The close-up view of a fabric using this weave and colouring is shown in the following right side figure.

Other, less useful, patterns result if the footing i.e. the starting point of the $\frac{2}{2}$ 2 matt-weave is altered, the order of colouring remaining the same. The reader might work these out for himself.

The most popular weave for colour-and-weave effects is $\frac{2}{2}$ twill. With a 4:4 colouring, arranged as in the following figure, it gives a distinctive and decorative pattern known as dog’s tooth when a relatively fine construction gives a small, and as hound’s tooth when a coarser construction gives a larger pattern. A fabric made with this weave and colouring is shown actual size in the following right side figure.
Altering the footing of the weave changes the character of the effect produced, but none of the alternatives are as effective or as useful as the one shown. Here again the reader may experiment with alternative arrangements.

**Shepherd’s Check Pattern:**

A 6:6 order of colouring with a $\frac{2}{2}$ twill weave gives an effect similar to, but bolder than, dog’s tooth. A woolen coating woven in this way from black and white yarns, known as shepherd’s check, is shown in the following figure.

**Allover effect:**

A 6:6 order of colouring with a $\frac{4}{4}$ twill weave gives an effect, known as allover effect, is shown in the following figure.
**Birdseye effect:**
A useful type of colour-and-weave effect is known as birdseye, defined as "a fabric having a pattern of very small and uniform spots, the result of a combination of weave and colour". The development of the pattern and of another pattern of the same type, but having larger spots, is given in the following figures. Both these patterns use simple fancy weaves. Other fancy weaves used with suitable orders of colouring provide a considerable range of patterns, some of which are distinctive enough to be useful.

**Stepped twill Pattern:**
A 1:1 order of colouring with a \( \frac{2}{2} \) twill weave (for finer effect) or 1:2 order of colouring with a twill weave (for finer effect) or 2:1 order of colouring with a twill \( \frac{3}{3} \) weave (for coarser effect) gives a useful effect known as stepped twill. Its development is shown in the following figures. The following right side figure shows a worsted suiting fabric made with this weave and colouring.

Fabrics such as this in which the warp and weft are end-and-end and pick-and-pick in contrasting colours require uniform yarns, accurately spaced. Yarn irregularities, or variations in yarn spacing,
show up very markedly. Even the highest-quality fabrics of this type tend to exhibit some irregularities.

**Compound colour and weave effects:**

In this case different types of check and stripe patterns are produced. The following figure shows a stripe pattern, which is produced by simple weave and simple wefting with compound warping. As a weave \( \frac{2}{2} \) 2 matt is used. For warp colouring 1:1 and 2:2 order of colouring and for weft colouring simple 1:1 colour arrangement are used here. The repeat size of this pattern is 32 × 16.
Glen check:

Distinctive patterns are often made in woolen and worsted fabrics in $\frac{2}{2}$ twill weave, with alternating blocks of ends and picks arranged 4:4 and 2:2. In those parts of the fabric where both warp and weft are coloured 4:4, we obtain a dog’s tooth effect. Where both warp and weft are coloured 2:2, either vertical or horizontal lines result. Where the warp is coloured 4:4 and the weft 2:2, and vice versa, we obtain two new effects. A woolen fabric embodying these effects is illustrated actual size in the following figure. This type of design is called glen check. The warp and weft patterns are both - 4white : 4black; 4white : 4red; 4white : 4black; 4white : 4black; 4white : 4black; 2white : 2black × 8; 4white : 4green; 4white : 4black; 4white : 4black; 4white : 4green; 2white : 2black × 8. The colour and weave effect repeats on 64 ends × 64 picks, but because of the double overcheck in red and green, the design repeats on 128 ends × 128 picks. It requires only four heald shafts to produce this fabric. The following figures show the close-up view of glen check fabric with weave plan.

Close-up view of Glen check fabric
Weave plan of Glen check fabric
Main Features:

A distinguishing feature of fabrics in which extra materials are employed is that the withdrawal of the extra threads from the cloth leaves a complete ground structure under the figure. The formation of a figure by means of extra threads thus does not detract from the strength or wearing quality of a cloth, except so far as the extra threads are liable to fray out, whereas in ordinary fabrics, in which the figure is formed by floating the weft or warp threads loosely, the strength of the cloth is reduced somewhat in proportion to the ratio of figure and ground.

One of the advantages of figuring with extra materials is that bright colours in sharp contrast with the ground may be brought to the surface of the cloth in any desired proportion. Pleasing colour combinations may thus be conveniently obtained, since the extent of surface allotted to the figuring colour may be readily proportioned in accordance with the degree of its contrast with the ground shade, without the latter being affected.

Methods of introducing extra figuring threads:

The extra threads may be introduced either as weft or warp, or the two methods may be employed in combination. When the extra material is introduced as warp then a separate beam is required for each warp on account of the different take-up rates between the extra and the ground ends. For extra weft figuring the weaving machine must have the capacity to insert more than one colour or kind of weft. The form of the design may render it necessary for the extra threads to be inserted in continuous order with the ground threads, or in intermittent order, while where they are introduced the arrangement of the figuring and ground threads may be 1-and-1, 1-and-2, 1-and-3 etc. according to the structure of the cloth and solidity of figure required. In extra weft figures, for looms with changing boxes at one side only, similar results to the 1-and-1 order may be produced by wefting 2-and-2; while the 2-and-4 order may be substituted for the 1-and-2, with, however, less satisfactory results as regards the solidity of the figure.

In this case extra warp and extra weft designs are presented by the following figures:

Comparison of extra warp with extra weft figuring:

In extra warp figuring there are two or more series of warp threads to one series of weft threads, and the method has the following advantages and disadvantages, as compared with the extra weft principle.
Advantages:

- The productivity of a loom is greater because only one series of picks is inserted, and a faster running loom can be used.
- No special picking, box, and uptake motions are required.
- There is theoretically no limit to the number of colours that can be introduced.
- In an intermittent arrangement of the extra ends either spotted or stripe patterns can be formed, whereas a similar arrangement in the weft can only be used to form spots (except in special cases) because of the objectionable appearance of horizontal lines.
Extra weft design

Disadvantages:

- Two or more warp beams may be required instead of one.
- If an ordinary jacquard and harness are employed a smaller width of repeat is produced by a given size of machine, because the sett of the harness requires to be increased in proportion to the number of extra ends that are introduced in a design.
- In dobby weaving the drafts are usually more complicated.
- Stronger yarn is required for the figure, and the threads are not so soft, full, and lustrous; extra ends are subjected to greater tension during weaving than extra picks, and as a rule, there is less contraction in length than in width, and the result is that extra warp effects usually show less prominently than extra weft figures.
- If the extra threads have to be removed from the underside of the cloth, it is more difficult and costly to cut away extra ends than extra picks.
Some cloths are produced on the double cloth principle of construction but due to the deliberate absence of stitching between the layers become single cloths upon their removal from the loom. Two such constructions, the double width and the tubular cloth are described respectively in the following stages.

**Tubular Cloth**

**Basic Principle:**

A tubular fabric consists of two distinct face and back fabrics in which selvedges are joined, because the shuttle flies from left to right, inserting the face pick and then flies in the opposite direction, inserting the back pick. When the pick is inserted into the face fabric all the threads of the back warp should be lowered, and when the pick is inserted into the back fabric all the face warp threads should be raised.

While producing seamless bags, the shuttle inserts two face picks passing from left to right and from right to left. Then two back picks are inserted. As a result, only the left selvedges of the face and back fabrics are joined, forming the bottom of the bag. The sides of the bag are formed by making a short length of the double fabric and then again a whole width of the bag.

**Uses of Tubular fabrics:**

Tubular fabrics are used for making fire hoses, seamless bags and sacks, technical drying cloths, decorative and other cloths.

**Typical weaves:**

For constructing the tubular fabrics, the following weaves can be used as the bases:

Plain weave, hopsack $\frac{2}{2}$, weft rib $\frac{2}{2}$, twill $\frac{2}{1}$ and twill $\frac{2}{2}$. The plain weave is most widely used.

**Construction:**

To construct this weave, two systems of warps, face and back ones, and two systems of wefts are necessary. Both warps are often wound on the same weaver's beam and the face and back picks are inserted by the same shuttle.
Double width cloth:

If a tubular fabric is woven with a sequence 2 top picks – 2 bottom picks, a folded or double width fabric is produced where the two fabric layers are only joined together by the weft on one side. The other side remains open. Which is the open side depends on the pick sequence. Therefore, the point paper presentation of all folded fabrics must specify the sequence of weft insertion. At the edge where the weft passes from one fabric layer to the other, the continuity of the weave must be preserved.

Multi-Ply Fabrics

Basic principle:

The multi-ply fabric consists of three or more fabrics woven one above the other and stitched together. From three to eight layers are used. A narrow eight-ply fabric is applied for making the Industrial belts.

Construction principle:

The multi-ply weave can be constructed, if either longitudinal section or cross section is given. The longitudinal section of a three ply weave is shown in the following figure. The warp repeat of this weave is 6 and the weft repeat, 12.

The sequence of warp threads at the diagram corresponds to that in the reed. The numbers of the picks correspond to the sequence of their insertion in the fabric. Thus there are three systems of warps, i.e. the face, the centre and the back, and the same number of the weft systems. The multi-ply fabric consists of three fabrics, the weave of which is plain.

Stitching system:

The stitching without using extra systems can be effected by the following five methods:
- From face to centre and from centre to back.
- From back to centre and from centre to face.
- From back to centre and from face to centre.
- From centre to face and from centre to back,
- Combination stitching.

In the example of figure A the stitching is effected from back to centre and from centre to face. The stitching of the face and centre fabrics is done by interlacing the centre warp thread 3 with the face weft thread 4, and the stitching of the centre fabric and the back one, by interlacing the back warp thread 6 with the centre weft thread 8.

![Figure A](image)

The diagram of weave at B is constructed by studying the position of each weft thread relatively to the warp threads. For example, the warp threads 1,2,3,4 are placed above the weft thread 1 and the warp thread 5 is placed below this weft thread at A. That is why, 5 warp overlaps are marked at B by painted squares, they are 1,2,3,4,6 and one weft overlap, by a blank square. In such a manner the diagram of weave at B has been constructed.

For producing this fabric six heald shafts are necessary with straight draft of warp threads. More often 6 threads are drawn in one dent of the reed.
STITCHED DOUBLE CLOTHS

Introduction:

Double cloths are fabrics in which there are at least two series of warp and weft threads each of which is engaged primarily in producing its own layer of cloth, thus forming a separate face cloth and a separate back cloth. The two layers may be only loosely connected together in which case each may be readily identified as a different entity or they may be so intricately stitched or tied together that they appear to form a complex single structure.

The purpose of the construction may be entirely utilitarian, such as the improvement of the thermal insulation value of a fabric in which a fine, smart face appearance is necessary; or it may be aesthetic in intention for which purpose the existence of two series of threads in each direction improves the capacity for producing intricate effects dependent upon either colour, or structural changes.

Classification of Double cloths:

Most of the double cloths can be classified under well defined headings and the following list gives the principal structural types with the simple schematic diagrams in the figure illustrating the basic principle of each construction.

1. Self-stitched double cloths:

These fabrics contain only the two series of threads in both directions and the stitching of the face cloth layer to the back layer is accomplished by occasionally dropping a face end under a back pick, or, by lifting a back end over a face pick, or, by utilizing both of the above systems in different portions of the cloth. This type of structure and the three different methods of stitching are illustrated at the following figures.

2. Centre-stitched double cloths:

In these fabrics a third series of threads is introduced either in the warp or in the weft direction whose entire function is to stitch the two otherwise separate layers of cloth together. The centre threads lie between the face and the back cloth and for the purpose of stitching oscillate at regular intervals between the face and the back thus achieving the required interlayer cohesion as shown at the following figure.
3. **Double cloths stitched by thread interchange:**

These structures are similar to the first category in as much as they do not contain an additional series of stitching threads. However, they are distinguished from the self-stitched fabrics by the fact that the stitching of the face and the back cloth is achieved by frequent and continuous interchange of some thread elements between the two cloth layers. Thus, in some portions of the cloth the face ends may be made to interweave with the back picks and the back ends with the face picks as illustrated schematically at the following figure. The point at which the threads interchange represents the stitch point.

![Diagram of thread interchange](image)

4. **Double cloths stitched by cloth interchange:**

In this class of constructions the principle of the interchange is taken one stage further than in the third category and complete cloth layers are made to change places as shown at the following figure. As stitching between the two fabrics occurs only at the point of cloth interchange the degree of cohesion in this type of cloth depends on the frequency of the interchange.

![Diagram of cloth interchange](image)

5. **Alternate single-ply and double-ply construction:**

In some fabrics the constituent thread components are occasionally merged together into a heavily set single cloth and occasionally are separated into distinct layers to form figure areas of open double cloth on the firm single cloth ground. Usually, the effect depends upon a degree of distortion as the cramped single cloth areas tend to spread out, thus affecting the appearance of the double cloth 'pockets'. A cloth of this type is shown at the following figure.

![Diagram of alternate construction](image)

**Points to be considered before going to construction a double cloth as follows:**

1. **Relative proportions and thicknesses of the face and back threads:**

These are decided mainly by the weight to be added to the face texture, but the order of arrangement of the weft threads is determined partly by the weft insertion of the loom. The most common varieties of double cloths are arranged in warp and weft
face, 1 back and 2 face, 1 back. For looms with boxes at one side only, and when the back weft is different from the face weft, similar effects may be obtained in many weaves by changing the wefting to 2 face, 2 back and 4 face, 2 back, respectively. Cloths which require a very fine face are sometimes arranged 3 face, 1 back in warp and weft. The threads may also be arranged in a mixed order, i.e. 1 face, 1 back in warp and 2 face, 1 back in weft and vice versa. Or 2 face, 1 back in warp and 2 face, 2 back in weft. Irregular arrangements such as 5 face to 4 back (FBFBBFFBFB) and 7 face to 5 back (FBFFBFBBFBB) are also employed, and these are occasionally useful as they admit of relative proportions of face backing threads being used which cannot be obtained in any of the regular bases.

In deciding on the relative thicknesses of the face and back yarns, a good rule to follow is to have the relative counts about proportionate to the relative numbers of the threads per unit space. In a 1 face, 1 back double cloth the back yarn should be similar to, or not much thicker than the face yarn. In 2 face to 1 back, the back yarn may be proportionately thicker, or say, from 2/3 to ½ thicker than the face yarn. If the same weave is used on both sides of the cloth the back threads may be 3 or 4 times as heavy as the face threads in the 2-and-1 arrangement, especially when centre threads are employed for stitching.

2. Selection of the face and back weaves:

When the threads are arranged in equal proportions the back weave is usually the same as the face weave, or contains about the same relative number of intersections, as, for instance, the 2-and-2 twill is suitable for backing the 3 up, 2 down, 1 up, 2 down twill. In other arrangements the backing weave is, as a rule, made with a relatively greater number of intersections than the face weave in order to compensate for the reduced number of threads. In the 2 face, 1 back arrangement, the plain weave is suitable for backing the 2-and-2 twill and the 2-and-2 hopsack; the 2-and-1 twill for backing the 3-and-3 twill; and the 2-and-2 twill for backing the 4-and-4 twill. In the making of cloths with a fine, smart face and soft back, the same weave may be used, in the 2-and-1 arrangement, for both the face and back textures. For a similar type of cloth in a 1-and-1 arrangement of the threads, a looser back than face weave may be employed. The most regular effect is obtained by having the repeats of the face and back weaves equal, or one a multiple of the other. For example, the 1-and-3 twill is unsuitable for backing the 2-and-3 twill unless the threads are arranged irregularly in the proportion of 5 face to 4 back threads.

3. Tying or stitching:

The stitching of the back and face fabrics of the double cloth can be effected in five ways. In the first three methods the threads of layers are used for stitching. In two other
methods the extra system either of warp or weft is introduced, which lies between the face and the back fabric, stitching them.

a. The first method which is called the stitching from face to back is carried out by lowering the face warp below the back weft. If the stitching is achieved by dropping a face end under a back pick both these elements must be away from their respective surfaces.

b. The second method is called the stitching from back to face and is carried out by raising the back warp above the face weft. When the method of stitching involves raising the back warp over the face picks then the back end can be used for tying only when it is away from the underside of the back cloth and the pick over which the tie is made must be away from the face of the top cloth. A stitch made in conformity with the above two conditions is invisible on either side of the double cloth.

c. The third method, i.e. the combination stitching, is that when the stitching from back to face and from face to back are applied simultaneously. The warp of each fabric is included in the shed of the other fabric.

d. The fourth method is called the stitching with an extra warp. It occurs when the face and back fabrics are stitched together by extra warp and there is no interlacing of the threads of the face fabric with those of the back fabric. Three systems of warp and two systems of weft are used in this case. It is necessary to distinguish the extra stitching warp from the extra stuffer warp, the threads of which can also lie between the face and back fabrics without interlacing with the weft threads.

e. The fifth method is called the stitching with an extra weft. In this case, the face and back fabrics are stitched together by extra weft which binds the face and back warps. The fabrics are held together only by extra weft threads. For increasing the mass of the fabrics, stuffing weft threads can be introduced between the fabrics. When the extra weft threads differ in count or type of fabrics, the loom should be equipped with a multi-shuttle mechanism.

4. The construction of the point paper design:

5. The beaming, drafting, the construction of the pegging or lifting plans, cross-section and longitudinal section.

Selection of suitable stitching positions:

In double cloths the stitches joining the two fabrics together, if correctly placed, have no effect on the appearance of either the face or the underside of the cloth. The method of tying which is the more suitable is, in some cases, determined by the character of the face weave. If a warp satin, or a warp-faced twill weave is employed for the face fabric, tying by lifting the back warp only is suitable; while in the case of a weft sateen or a weft-faced twill weave, it is only advantageous to tie by dropping the face ends. When there is a choice of the two methods,
other things being equal, the former method is usually preferable, as the back warp is less liable
to show on the face than the back weft, which in the latter system is pulled upwards.

Using the system of tying in which the back ends are raised for stitching over the face picks it
may not be possible to realize the above assumption with some weave combinations and some
face to back thread ratios because for perfect placement of the tie the following four conditions
must coincide:

1. The back end must be at that point away from the underside of the back cloth.
2. It must ‘surface’ between two long warp floats of the face weave.
3. The face pick over which the back end is raised must be absent from the surface of the
   face cloth.
4. It must be only pulled down at a point at which its penetration into the back cloth level
   is covered by two adjacent weft floats on the underside of the back fabric.

Clearly, in some circumstances it will not be possible to achieve the simultaneous coincidence
of all the four conditions.

Similarly, when the face ends are lowered for stitching under the back picks:

1. The face end at that point must be absent from the surface of the face cloth.
2. It must be lowered at a point at which two long back warp floats cover it on the
   underside of the back cloth.
3. The back pick at the tie point must be away from the underside of the back cloth.
4. It must penetrate towards the surface at a point at which it will be covered by two
   adjacent face weft floats on the surface of the face cloth.

Again, the simultaneous coincidence of the conditions may not, in some cases, be possible.

If it is conceded that the conditions (1) and (3) in each system of tying are absolutely
compulsory then a certain degree of freedom must be accepted with regard to the conditions
(2) and (4).

Construction Principle:

**Self stitch double cloth:**

There is no need to separate stitching thread. The threads of the face and back cloth are used
for stitching. There are three types of self stitch double cloth, such as -

**Double cloth produced by back to face stitching system:**

In order to prevent confusion the different stages in working out a double cloth design
should be represented by different kinds of marks, as shown in the following figures,
which illustrates, step by step, the construction of a $\frac{5}{3}$ twill and $\frac{4}{4}$ twill structure in
which the ends and picks are arranged 1 face, 1 back. A and B represent the face and
the back weave respectively. At C an area equal to one repeat of the double weave is marked out with the order of arrangement of the face ends and picks and the back ends and picks indicated clearly at the margins. C shows the first stage of actual double cloth construction which may be defined as: Insert the face weave on the face ends and face picks only, according to the original design. The second stage is similar except that it refers to the back weave: Insert the back weave on the back ends and picks only, according to the original design.

D shows the marks for the separating lifts which ensure that each series of yarns weaves only with its own kind and this may be stated as: Lift all face ends on back picks. Similarly, to complete the sequence, all back ends must be left down on all face picks which means an absence of marks, i.e. all back ends down on face picks. These are called mutual points.

D also represents a stage in which two separate fabrics are produced one above the other. As there is no particular reason for producing two disconnected cloths in this manner, it will be realized that this stage is the intermediate point in the construction reached prior to the insertion of stitches or ties to bind the two cloths together. Before the stitch marks are inserted it must be decided which method of stitching is to be used and how frequently the cloths are to be stitched.

Assuming that it is required to stitch by lifting the back ends on the face picks and that each back end is to stitch once in the repeat, the correct positions of the ties are shown
by the crosses at figure D. The following figure D represent the final weave plan and figure E represent the drafting plan and figure F represent the lifting plan.

**Double cloth produced by face to back stitching system:**

The construction principle is same like as previous one. In this case face and back weaves both are same $\frac{4}{4}$ twill weave. The second stitching method is used here, i.e. stitching by dropping the face ends on back picks. As in the previous system, one stitch per repeat is made, only in this case the face ends and not the back ends are used for the purpose. The following figure shows the weave plan (D) of a double cloth based on same two $\frac{4}{4}$ twill weaves with face to back stitching method. The figure E and F represents drafting and lifting plan of this weave respectively.

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**Double cloth produced by combined stitching system:**

The construction principle is same like as previous one. In this case face and back weaves both are also same $\frac{4}{4}$ twill weave. The third stitching method i.e. the combined stitching system is used here. Back to face and face to back both stitching systems are used. The following figure shows the weave plan (D) of a double cloth based on same two $\frac{4}{4}$ twill weaves with combined stitching method. The figure E and F represents drafting and lifting plan of this weave respectively.
Self stitching system is used to produce the above three structures of double cloth. Only 1:1 thread arrangement is used for both face and back weave described above. It is noted that the different arrangement of threads are also used such as – face warp : back warp = 2:1, face warp : back warp = 2:2, face warp : back warp = 1:2 etc. Similarly the weft yarns are also arranged in different order. The thread arrangement may be same or different for warp and weft yarn. The repeat size of the final design is depends on this thread arrangement.

Wadded double cloth:

A wadded double cloth consists of a face and a back fabric, tied together by floating back ends on face picks, or face ends under back picks as in ordinary self-stitched double cloths, with the addition of a special series of weft or warp threads introduced independently of the face and back yarns. The warp-wadded cloths thus consist of three series of warp and two series of weft threads, while in the weft-wadded cloths there are three series of weft and two series of weft threads. The wadding threads lie between the two fabrics, and are visible neither on the face nor back; hence a thicker and cheaper yarn than that used for the face and back may be employed for wadding without the appearance of the cloth being affected.

The type of construction is therefore useful in cases where increased weight and substance are required to be economically obtained in conjunction with a fine face texture. The wadding threads may be introduced into any arrangement of the face and back threads, but the
common proportions are 1 wadding to 1 face and 1 back, 2 face and 2 back, or 2 face and 1 back. The first arrangement is suitable when the wadding yarn is not so much thicker than the face yarn, and the second and third when very thick wadding is used.

**Warp wadded double cloth:**

The wadding yarn is more economically and conveniently introduced in the warp than in the weft but the greater strain put on the warp threads in weaving necessitates the use of a better quality of wadding material. The construction of the designs is illustrated in the following figure in which the face and back weaves are given at A and B respectively, while the complete design is given at D and the draft at E. The ends are arranged in the order of 1 face, 1 back, 1 wadding, and the picks 1 face, 1 back. The face weave is \( \frac{5}{3} \) twill, the back weave is \( \frac{2}{2} \) twill and a twill order for back warp tying lifts is used. In the warp wadded structures the wadding ends must be raised on all back picks and left down on all face picks.

Draft for the design D in the following figure is given at E. The wadding ends require only one heald, but in fine sets, to avoid crowding, they may be drawn on two or more healds which are then operated as one. The following figure F is the lifting plan of this weave.

**Weft wadded double cloth:**

The construction of designs for these cloths is illustrated by the examples given in the following figure in which A is the plan of the face weave, and B of the back weave. Since the wadding yarn simply lies between the two fabrics without interweaving with either, the same conditions are necessary, so far as regards the face weave, the ties and the back weave, as in the construction of ordinary double cloths.
The wadded design is therefore exactly the same as the ordinary double design except for the inclusion of the wadding threads; and in order that comparisons may be made, the double weave with the wadding is given at C. In the complete design, given at D the crosses indicate the ties (back warp up on the face picks). It will be noted that in weft wadded structures all face ends are up. And all back ends are down, on wadding picks.

In the following example the picks are arranged in the order of 1 face, 1 back, 1 wadding; and the ends 1 face, 1 back. The 7-end satineté weave, warp surface on both sides of the cloth, is employed, the tying being effected by raising the backing ends in a sateen (3-move) order over the face picks. The following figure E and F represents the drafting and lifting plan respectively.

**Centre stitch double cloth:**

In wadding a double cloth the chief object is to get a heavy structure by introducing a yarn which is usually thicker and cheaper than the face and back yarns. In centre stitching, however, although the threads may be introduced in the same order as in wadding, and additional weight thereby be obtained, the specific purpose is to bind the two fabrics together with the centre threads, which as a rule are finer than either the face or backing threads. In this system the threads of one fabric do not interweave with those of the other fabric; the centre threads oscillate between one and the other, and lie between them when not employed for tying. The
two fabrics are less firmly united than with the self-stitching, and the cloth has a softer and fuller handle. The stitching threads may be used as warp yarn or weft yarn.

**Centre warp stitch double cloth:**

The plans in the following figure are illustrative of the construction of double cloths arranged 1 face, 1 back, in which the two fabrics are stitched together by means of centre warp. The design C (left side) is a double 5 × 5 twill, the face weave \( \frac{3}{2} \) twill being as at A, and the back weave \( \frac{2}{3} \) twill as at B, while the ends are arranged in the proportion of 5 face and 5 back to 1 stitching, as indicated at C (left side).

![Centre warp stitch double cloth](image)

As each repeat of the double weave given at C (left side) contains only one stitching end, the ties always occur in the same line, both on the face and back of the cloth. A better arrangement is given in the design C (right side), in the above figure, in which the ends are in the proportion of 3 face and 3 back to 1 stitching; 2 face and 2 back to 1 stitching. The face weave and the back weave are the same as in the design C (left side). In this case there are two stitching ends in one repeat of the double weave, which not only causes the fabrics to be more firmly united, but enables an alternate distribution of the ties to be made. The figure D and E represents the drafting plan and lifting plan respectively of this weave plan.

**Centre weft stitch double cloth:**

This type of stitching is not very often used as it reduces the rate of cloth production. This is due to the fact that when the centre weft picks are introduced the take-up must be rendered inoperative and thus the picks do not contribute to the length of cloth being produced. In constructions in which the use of centre stitching threads is essential it is, therefore preferable to use the centre warp stitches. However, there are some situations which make it necessary
to use the centre weft and one reason for the use of this method occurs when all the existing jacks in a dobby are required to operate the face and the back heads and none are left to control the centre warp ends. Occasionally the centre weft is also used if the mounting of an extra beam required by the centre warp threads presents a particular difficulty in respect of the control or access to the warp yarns.

The plans A to D in the following figure illustrate the principle of stitching by means of centre weft. The double $6 \times 6$ matt weave is employed, the face weave $\frac{3}{3}$ being given at A, and the back weave $\frac{4}{2} (4+2)$ at B. The picks are in the proportion of 3 face and 3 back to 1 stitching as indicated at D, one repeat of the double weave thus containing two centre picks. The complete design is given at D. The following figure E and F represents the drafting plan and lifting plan respectively of this weave plan.

**End uses:**

Double cloths are used as different types of decorative cloth such as – sofa cover, furnishing cloth, curtain fabric, bed cover, pillow cover, and other home textile, etc. It is also used for the production of winter garments, quilts, belts, different types of industrial fabrics etc.
Fabric based on Plain weave:

1. **Georgette**: It is made with filament yarns. In georgette, the direction of the crepe twist (S or Z) for warp and weft yarns alternates. For example, even-numbered warp and weft yarns may be S-twist and odd-numbered yarns may be Z-twist. It can be a solid colour or printed. It is very light weight, drape well, and is used in apparel. It was originally made of silk but now often is made from manufactured filament yarns.

2. **Chiffon**: It is made from fine, highly twisted filament yarns. Because of the tightly twisted crepe yarns, chiffon has excellent drape, very light weight, and although it is delicate in appearance, it is relatively durable. It can be a solid colour or printed. It was originally made of silk but now often is made from manufactured filament yarns. Sheer evening dresses, blouses, lingerie, and other dressy apparel are constructed from the fabric.

3. **Voile**: Voile is a sheer fabric made with high twist or voile twist spun yarns that are combed or worsted. It is a soft fabric with some what lower fabric count and has a distinctive two ply warp and good drapability. It can be solid colour or printed. Voile was originally a cotton or wool fabric, but it is now available with many fibre contents.

4. **Organdy**: It is the sheerest cotton fabric that is given a temporarily or permanently stiffened finish. Combed yarns contribute to its sheer appearance. Its sheerness and crispness are the result of an acid finish on lawn gray goods. Because of its stiffness and fibre content, it is very prone to wrinkling. It is used for curtains and for summer weight apparel. It is available in solid colours or prints. Fabric construction: similar to lawn fabric.
5. **Organza**: It is the filament yarn counterpart to organdy, i.e. it is also a stiff sheer fabric made of filament yarns. It has a lot of body and a crisp hand. It is also used for curtains and for summer weight apparel. It is available in solid colours or prints.

6. **Lawn**: It is a fine, opaque, light weight, plain weave fabric usually made of combed cotton or cotton-blend (cotton/polyester). The fabric may be bleached, dyed or printed. Lawn is similar to organdy fabric, but it does not receive the acid finish like as organdy and, thus, remain opaque. Fabric construction:

\[
\begin{array}{c}
70' s \times 100' s \\
80 \times 80
\end{array}
\]

7. **Batiste**: It is an opaque, light weight, spun yarn, plain weave fabric with a smooth surface. It is the softest of the light weight opaque fabrics. When made of cotton or cotton/polyester, the yarns are usually combed. It can be made of all wool, silk or rayon. Batiste also is similar to organdy fabric, but it does not receive the acid finish like as organdy and, thus, remain opaque. Fabric construction: similar to lawn.

8. **Gingham**: It is a yarn dyed, plain weave fabric that is available in a variety of weights and qualities. It may be balanced or unbalanced and of combed or carded yarns. If two colours of yarns are used, the fabric is called a check or a checked gingham. If three or more colours are used, the fabric is referred to as a plaid gingham. It is usually made of cotton or cotton blends. Better quality fabrics are made with combed yarns. When they are made of another fibre, the fibre content is included in the name; for example, silk gingham. Fabric construction:

\[
\begin{array}{c}
\text{Carded}: \quad \frac{28' s \times 42' s}{64 \times 60 \text{ TO } 64 \times 76} \\
\text{Combed}: \quad \frac{28' s \times 42' s}{84 \times 76 \text{ TO } 88 \times 84}
\end{array}
\]

9. **Chambray**: It is a plain weave fabric, usually of cotton, rayon, or blended with polyester. Usually chambray has white yarns in the weft direction and coloured yarns in the warp direction. Iridescent chambray is made with one colour in the warp and a second colour in the weft. It can also be made with stripes.
10. **Taffeta**: It is a general term that refers to any plain weave filament yarn fabric with a fine, smooth, crisp hand. Unbalanced taffeta has a fine rib made by heavier filling yarns and more warp yarns. Faille taffeta has a crosswise rib made by using many more warp yarns than weft yarns. Moiré taffetas have an embossed water mark design. Balanced taffetas have warp and weft yarns of the same size. Iridescent taffeta has warp and weft yarns of different colours.

11. **Madras**: It is usually all cotton, and has a lower count than gingham. Madras gingham or madras shirting is a light to medium-weight, dobby weave fabric in which the pattern is usually confined to vertical stripes.

12. **Cheese cloth**: It is a light, sheer, plain woven fabric with a very soft texture and a very low count. It may be natural coloured, bleached, or dyed. If dyed, it may be called bunting and could be used for flags or banners.

13. **Crinoline**: It is a stiff, spun yarn, plain weave fabric similar to cheese cloth, used in book bindings, hats and stiffening for apparel. It is heavily sized to serve as stiffening fabrics.

14. **Buckram**: It is heavily sized to serve as stiffening fabrics. Buckram is a heavy, very stiff, spun yarn fabric converted from cheese cloth gray goods with adhesives and fillers. It is used as an interlining to stiffen pinch pleated window treatment fabrics.

15. **Gauge**: It is a sheer, light weight, low count, plain or leno weave balanced fabric made of spun yarns. It is often cotton, rayon, or a blend of these fibres. Gauge, with a higher count than cheese cloth, is used in theatrical costumes and medical dressings, as well as for blouses and dresses. Indian gauge has a crinkled look and is available in a variety of fabric weights.

16. **Ninon**: It is a sheer, slightly crisp, light weight, plain weave fabric made of filament yarns. The warp yarns are grouped in pairs, but it is not a basket weave fabric. It is widely used in sheer curtains and draperies. It is usually 100 percent polyester because of that fibre’s resistance to sunlight, excellent resiliency, and easy washability. Although ninon is a plain weave, warp yarn spacing is not uniform across the fabric. Pairs of warp yarns are spaced close to each other. The space between adjacent warp yarn pairs is...
greater than the space between the two yarns in the pair. Ninon has medium body and hangs well.

17 **Calico:** It is a closely woven and print cloth of cotton or cotton blend with a small busy pattern.

18 **Cambric:** It is a fine, firm, starched plain weave balanced fabric with a slight luster on one side. It is difficult to distinguish from percale.

19 **Percale:** Percale is a smooth, slightly crisp, printed or plain coloured fabric. It is a closely woven, plain weave of cotton or blended fibres, is made from yarns of moderate twist. Percale yard goods are generally carded, but percale sheets are finer and more luxurious in feel and are made of combed yarns. In percale bedsheets, counts of 160, 180, 200, and 250 yarns (warp plus weft) per inch are available. Percale is called calico if it has a small, quaint, printed design; chintz if it has a printed design; and cretonne if it has a large scale floral design. When a fabric is given a highly glazed calendar finish, it is called polished cotton. When chintz is glazed, it is called glazed chintz. Glazed chintz is made in solid colours as well as prints. These fabrics are often made with blends of cotton and polyester or rayon. They are used for shirts, dresses, blouses, pajamas, matching curtains and bedspreads, upholstery, slipcovers, draperies, and wall coverings.

20 **Muslin:** It is a firm, medium to heavy weight, plain weave cotton fabric made in a variety of qualities. It generally woven from cotton or cotton blends, is made in both heavily sized, bleached qualities and in better grades for sheets and pillow cases. Any plain woven, balanced fabric of carded yarns ranging in weight from lawn to heavy bedsheeting may be called muslin. It is usually available in counts of 112, 128 or 140. Muslin is also a name for a medium weight fabric that is unbleached or white.

21 **Flannel:** It is a light to heavy weight, plain or twill weave fabric. Flannel is a suiting fabric of woollen yarns that is napped. It is used for women’s suits, slacks, skirts, and jackets. Flannelette is a light to medium weight, plain weave cotton or cotton blend fabric lightly napped on one side. It can be found as both balanced and unbalanced fabrics. It is available in several weights ranging from 4.0 to 5.7 oz/yd². It is described as flannel and is used for sheets, blankets, and sleepwear. Outing flannel is heavier and stiffer than flannelette, it may be napped on one or both sides. It is used for shirts, dresses, lightweight jackets, and jacket linings. Some outing flannels are made with a twill weave. Both fabrics may be solid colour, yarn dyed or printed.

22 **Poplin:** Poplin is a bottom-weight rib weave (heavy weight ribbed fabrics) is usually made from cotton or cotton blends, polyester/cotton blends are widely used. It is a medium to heavy weight, unbalanced, plain weave, spun yarn fabric that is usually piece dyed. The weft yarns are coarser than the warp yarns. Poplin is similar to broad cloth, but the ribs are heavier and more pronounced because of larger weft yarns.
23. **Broad cloth**: It is a medium weight unbalanced plain weave with fine ribs. The rib weave makes it crisper than medium weight balanced weaves. It is often made from cotton or cotton blends.

24. **Bengaline**: It is a lustrous, durable, warp faced fabric with heavy weft cords completely covered by the warp. It is heavy weight fabrics with large ribs, are used mostly in upholstery and furnishings.

25. **Bedford cord**: It is found most often in furnishing fabrics such as bed spreads. It has spun warp yarns that are larger than the weft yarns. It is a sturdy fabric constructed with a pronounced lengthwise cord. Bedford cord is a heavy, warp faced, unbalanced pique weave fabric with wide warp cords created by extra weft yarns floating across the back to give a raised effect.

26. **Faille**: Faille has a prominent rib and is made with fine filament yarns in the warp and heavy spun yarns in the weft. It is usually heavy weight, although lighter weight tissue failles are also produced.

27. **Dimity**: Dimity is a sheer unbalanced fabric used for apparel and window treatments. It has heavy warp cords at intervals across the fabric. The cords may be formed by yarns larger than those used elsewhere in the fabric or by grouping yarns together in that area. Either technique produces the unique narrow band or stripe indicative of dimity. Dimity is white or printed.

28. **Oxford**: It is usually a 2×1 or 3×2 basket weave. It is most common as a 2×1 half basket weave. It may have a yarn dyed warp and white weft and be called oxford chambray. Oxford looks like a balanced fabric because the warp yarns are finer and have higher twist than the weft. Because of soft yarns and loose weave, yarn slippage may occur. Oxford fabrics are medium weight, soft, porous, and lustrous. It is often made of cotton or cotton blends, that is used for shirts. Frequently, it is made with narrow coloured stripes in the warp, or a coloured warp.

29. **Duck**: It is a strong, coarser, heavy, plain or basket weave fabric available in a variety of weights and qualities. It is similar to canvas. Duck is made with single or ply yarns. Different types of duck relate to which yarns (warp or weft) are plied and how many
plies are used in the ply yarn. Duck is used for slipcovers, boat covers, shoe fabrics, house and store awnings, tarpaulins and covers for military and industrial uses.

30. Canvas: It is a heavy, firm, strong fabric made of cotton or acrylic and used for awnings, slip covers, shoe fabrics, tarpaulins, and boat covers. It is produced in many grades and qualities. It may have a soft or firm hand. It is made in plain or basket weave. Canvas is smoother, more compact, and the heaviest of the three (Duck, canvas and sail cloth). It is tightly woven and very stiff plain weave fabrics made of even yarn for industrial use. They usually have an uneven weave pattern. Because of the tight weave, these fabrics are often used for outdoor purposes. It is made with single or ply yarns. Different types of canvas relate to which yarns (warp and weft) are plied and how many plies are used in the ply yarn.

31. Sail cloth: It is a bottom weight half basket weave (2x1), unbalanced fabric of spun or textured filament yarns that can be piece dyed or printed. Sail cloth is the lightest (among the sail cloth, duck and canvas) in weight and made of single yarns. It is used in slacks, skirts, summer weight suits, and furnishings.

Fabric based on Twill weave:

1. Serge: It is a popular basic twill fabric made from any number of different fibres. When serge is made from wool, it is often woven from worsted yarns. Serge will take a crease well, but wool serge tends to become shiny with wear. It tailors well. Serge is a 2/2 twill with a subdued wale with combed or worsted yarns and a clear or hard finish (not napped or brushed). Serge with fine yarns, a high count, and a water-repellent finish is used for jackets, snowsuits, and raincoats. Heavier serge, with coarse yarns, is used for work pants. Serge often weighs 339.1 (10 oz/yd²) gm/m² or more.

   Fabric construction: Yarn size varies with fibre content
   48X34 To 62 X58

2. Twill Flannel: It is a 2/2 twill. The weft yarns are larger low-twist woolen or worsted yarns, made especially for napping. Worsted flannels have less nap, take and hold a sharp crease better, show less wear, and sag less than woolen flannels. Even-sided flannel is used in apparel and upholstery.

   Fabric construction: Yarn size varies with fibre content
   56X30 To 86 X52

3. Shark skin: It is a 2/2 twill with a sleek appearance. It has a small-step pattern because both warp and weft yarns alternate one white yarn with one coloured yarns. Shark skin is used primarily for slacks and suits.
4. **Herring bone**: This fabric has the twill line reversed at regular intervals across the warp to produce a design that resembles the backbone of a fish, hence the name herring bone. Two different colour yarns may be used to accentuate the pattern. Herring bone patterns can be very subtle or very pronounced. Herring bone is used in both apparel and furnishings. These are common in suiting fabrics.

5. **Hound’s tooth**: It is a \( \frac{3}{2} \) twill fabric with a unique small eight-point pattern. Two yarns in contrasting colours in the warp and weft are used in groups of four to create the distinctive pattern. Hound’s tooth fabrics also are used in apparel and furnishings.

6. **Denim**: It is a cotton or cotton/polyester blend, durable heavy weight twill-weave, yarn-dyed fabric. Usually the warp is coloured and the weft is white. It is often a left-hand twill with a blue (indigo) warp and white weft for use in apparel in a variety of weights. Since it is a warp-faced twill, the coloured warp yarns predominate on the face and the white weft yarns on the back. It is available in several weights, ranging from 203.46 gm/m\(^2\) (6 oz/yd\(^2\)) to 474.74 gm/m\(^2\) (14 oz/yd\(^2\)) or more in a \( \frac{2}{7} \) or \( \frac{3}{7} \) interlacing pattern. Its long term popularity has made it a fashion fabric in casual wear. It may be napped, printed, made with spandex or other stretch yarns, or otherwise modified for fashion.

Fabric construction: 7's to 16's X 8's to 23's
\( \frac{60X36}{72X44} \)

7. **Drill**: It is a strong, medium-to-heavy weight, warp-faced, twill weave fabric. It is usually a \( \frac{2}{2} \) or \( \frac{3}{1} \) left handed twill and piece dyed (solid colour). It is usually seen in work clothing and industrial fabrics.
8. **Jean**: It is a warp faced twill of carded yarns. It is lighter weight than drill, and it has finer yarns but a higher warp-yarn count. It is usually with coloured warp yarns and white weft yarns. Jean is a piece-dyed also or printed medium-weight twill used for sportswear, draperies, slipcovers, and work shirts. Jean is not heavy enough for work pants.

Fabric construction: $21'\text{ s} \times 24'\text{ s} \times 24'\text{ s} \times 30'\text{ s}$

$84\times 56 \text{ to } 100\times 64$

9. **Gabardine**: It is a tightly woven, medium to heavy-weight, warp-faced steep or regular-angle, twill weave fabric with a very prominent, distinct wale that is closely set together and raised. It always has many more warp than weft yarns. It can be made of carded or combed single or ply yarns. The long-wearing fabric may be heather, striped, plaid, or solid colour. The fabric can be wool, a wool blend, or synthetic fabrics that resemble wool. Gabardine can also be 100% texturized polyester or a cotton/polyester blend.

Fabric construction: $15'\text{ s} \times 39/2' \times 15'\text{ s} \times 26'\text{ s}$

10. **Damask**: Woven fabrics made from expensive mercerized cotton for bed clothing and table cloths. The figured design often is made by interchanging satin and sateen weaves.

11. **Fil-à-fil**: $\frac{3}{2}$ twill weave fabrics in which light and dark colours alternate in both warp and weft, making a miniature staircase pattern. Used for suits and costumes.

**Brocade**: Heavily figured jacquard fabric, often with lusture yarn effects. Used in formal wear and furnishings.

**Corduroy**: A cut pile cord, usually in cotton. The cords may be of various widths. Used mainly in leisure and business wear.

**Mull**: Soft, fine, open, plain weave cotton fabric with a very low thread density in both warp and weft. Used for blouses and squares.
**Pin stripe:** Worsted woven fabric with fine light-coloured lines in the warp direction. Used for suits and costumes.

**Ottoman:** Warp-faced rib fabric with 3 to 10 ribs per cm for coats, jackets, and furnishings.

**Panama:** General term for a plain-based weave where two or more warp and weft yarns interlace as one, giving a chequered appearance. Made from cotton for shirts, tropical suits and leisure wear, or wool for suits and costumes.

**Pocketing:** Cotton plain woven fabric made smooth and dense by calendaring, for pocket linings.

**Seersucker fabric:** Cotton fabric with crinkled length-way stripes caused by differential shrinkage. True seersucker is generated by differential warp tensions but finishing treatments can produce a similar effect. Used for blouses, shirts, dresses.

**Amazon:** Very fine, satin weave for business suitings with fine worsted warp yarns and woolen weft. A light milling or raising finish may be given.

**Terry:** A soft, voluminous, loop pile fabric. The loops are formed in a second warp sheet by a special weaving technique. Used for bath robes, towels, sports and leisure wear.
**Whipcord:** General term for densely woven warp-faced fabrics with a steep twill line. In worsted yarns with a clean finish for trousers, suits and coats.

**Blazer cloth:**
Traditionally an all-wool woven fabric for apparel, in either solid colours or stripes, that may be milled and/or raised. Imitation blazer cloths introduce cotton in the weft. The term may be used loosely for other fabrics for blazers.

**Trouser:**
Trouser is a long pant or full pant.

**Fabric Construction or Specification:**

The specification of some export oriented commercial fabrics those are produced in Bangladesh as follows:

<table>
<thead>
<tr>
<th>Name of the fabric</th>
<th>Construction or Specification</th>
<th>Weight</th>
<th>Name of the fabric</th>
<th>Construction or Specification</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gabardine</td>
<td>$110 \times 51 \times 56''$</td>
<td>210 GSM</td>
<td>Gabardine</td>
<td>$20 \times 7 \times 57-58''$</td>
<td>298 GSM</td>
</tr>
<tr>
<td>Gabardine</td>
<td>$72 \times 40 \times 56''$</td>
<td>270 GSM</td>
<td>Gabardine</td>
<td>$7 \times 7 \times 57-58''$</td>
<td>380 GSM</td>
</tr>
<tr>
<td>Gabardine</td>
<td>$124 \times 70 \times 56''$</td>
<td>245 GSM</td>
<td>Gabardine</td>
<td>$30 \times 30 \times 57-58''$</td>
<td>160 GSM</td>
</tr>
<tr>
<td>Gabardine</td>
<td>$108 \times 58 \times 56''$</td>
<td>200 GSM</td>
<td>Gabardine</td>
<td>$16 (slub) \times 9 \times 57-58''$</td>
<td>265 GSM</td>
</tr>
<tr>
<td>Gabardine</td>
<td>$80 \times 48 \times 56''$</td>
<td>300 GSM</td>
<td>Gabardine</td>
<td>$20 \times 20 \times 57-58''$</td>
<td>195 GSM</td>
</tr>
<tr>
<td>Gabardine</td>
<td>$116 \times 40 \times 56''$</td>
<td>285 GSM</td>
<td>Gabardine</td>
<td>$150D \times 150D \times 57-58''$</td>
<td>225 GSM</td>
</tr>
<tr>
<td>Gabardine</td>
<td>$112 \times 54 \times 56''$</td>
<td>270 GSM</td>
<td>Gabardine</td>
<td>$45/2 \times 45/2 \times 57-58''$</td>
<td>200 GSM</td>
</tr>
<tr>
<td></td>
<td>$16 + 16 \times 12 + 12 \times 56''$</td>
<td>80/2 $\times 100/2 \times 58''/59''$</td>
<td>Gabardine</td>
<td>$45/2 \times 45/2 \times 57-58''$</td>
<td>142 $\times 84\times 58''/59''$</td>
</tr>
<tr>
<td>Name of fabric</td>
<td>Construction or Specification</td>
<td>Weight</td>
<td>Name of fabric</td>
<td>Construction or Specification</td>
<td>Weight</td>
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</tr>
<tr>
<td>Canvas</td>
<td>10 x 10 72 x 42 x 57-58&quot;</td>
<td>260 GSM</td>
<td>Sheeting</td>
<td>30 x 30 68 x 68 x 57-58&quot;</td>
<td>105 GSM</td>
</tr>
<tr>
<td>Canvas</td>
<td>20 x 16 100 x 50 x 57-58&quot;</td>
<td>190 GSM</td>
<td>Calico</td>
<td>16 x 16 60 x 60 x 57-58&quot;</td>
<td>180 GSM or 6.15 OZ</td>
</tr>
<tr>
<td>Canvas Panama</td>
<td>16 + 16 x 12 + 12 108 x 60 x 57/58&quot;</td>
<td></td>
<td>Calico</td>
<td>14 x 14 64 x 58 x 57-58&quot;</td>
<td>6.80 OZ</td>
</tr>
<tr>
<td>Slub canvas</td>
<td>16 x 9 80 x 48 x 57-58&quot;</td>
<td>260 GSM</td>
<td>Poplin</td>
<td>30 x 30 104 x 81 x 57-58&quot;</td>
<td></td>
</tr>
<tr>
<td>Light canvas</td>
<td>30 x 30 108 x 80 x 58/59&quot;</td>
<td></td>
<td>Poplin</td>
<td>40 x 40 133 x 72 x 57-58&quot;</td>
<td></td>
</tr>
<tr>
<td>Ribstop hado</td>
<td>20 x 20 108 x 58 x 57-58&quot;</td>
<td>195 GSM</td>
<td>Poplin</td>
<td>40/2 x 30 74 x 72 x 58/59&quot;</td>
<td></td>
</tr>
<tr>
<td>Ribstop hado</td>
<td>20 x 16 96 x 50 x 57-58&quot;</td>
<td>193 GSM</td>
<td>Heavy poplin</td>
<td>40/2 x 40/2 112 x 50 x 58/59&quot;</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>T/C(65/35) blended</td>
<td>45 x 45 133 x 72 x 58/59&quot;</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>poplin</td>
<td>45 x 45 136 x 76 x 58/59&quot;</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Premium poplin</td>
<td>60 x 50 110 x 76 x 58/59&quot;</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Premium poplin</td>
<td>80/2 x 80 128 x 98 x 58/59&quot;</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Premium poplin</td>
<td>100/2 X100/2 144 x 91 x 58/59&quot;</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Bedford Cord</td>
<td>07 x 07 72 x 42 x 57-58&quot;</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Bedford Cord</td>
<td>128 x 72 40 x 40 x 58/59&quot;</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Flannel (Yarn Dyed)</td>
<td>40 x 40 20 x 10 x 42-43&quot;</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Flannel (Yarn Dyed)</td>
<td>42 x 44 24 x 13 x 42-43&quot;</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Twill</td>
<td>64 x 54 21 x 21 x 44-45&quot;</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Flannel (Printed)</td>
<td>64 x 54 21 x 21 x 44-45&quot;</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Flannel (Printed)</td>
<td>64 x 54 21 x 21 x 44-45&quot;</td>
<td></td>
</tr>
</tbody>
</table>
SPECIAL FABRIC PRODUCTION
BRAID FABRICS

Main features of Braid Fabrics:

Braiding is a simple form of narrow fabric construction. Strands are plaited together by criss-crossing them diagonally and lengthwise. A familiar illustration of the method is that of braiding long hair. Braid for fabric use is formed on a braiding machine by interlacing three or more strands of yarn so that each strand passes over and under one or more of the others. They have good elongation characteristics and are very pliable, curving around edges nicely.

The main characteristics of braid include the followings:

- Yarns are interlaced both diagonally and lengthwise.
- Braid is stretchy and easily shaped.
- Flat or three-dimensional braid is used for trim and industrial products.

Types of Braid:

Braids are divided into two types:

1) Flat braids, in the form of strips or narrow flat tapes; and
2) Round braids, tubular in form, which may be hollow or have a center core of some material.

Both types of braiding are produced from any of the textile fibres, as well as from metal threads, tinsel, straw, wire, or leather.
The following figures show the examples of some fancy braids:

a) Patterned round braid  
b) Patterned soutache braid  
c) Corded edge braid  
d) Patterned flat braid  
e) Patterned flat braid  
f) Ricrac braid  
g) Frill braid

Manufacturing Principle:

The traditional circular braiding machine contains a series of bobbins of yarn mounted on a moving track at the bottom of the machine. The braid is produced as the bobbins move in and out around the base of the machine, much as Maypole dancers do. Interweaving yarns by braiding produces a flexible fabric; the fabric can be stretched in one direction, but it contracts in the other.
Schematic if the basic principle of the maypole (round) braider

**End Uses:**

This principle of fabric construction is used for making shaped articles, such as straw hats and small rugs; narrow fabrics, such as ribbons and braids for millinery and accessory dress materials; cords and tapes, such as fish lines, shoe laces, wicks, parachute and glider cords, and elastic of various types; and cord coverings for tires, tubing, hose, wires, and cables.

Circular braids appear in such everyday items as shoe laces and insulation for electric wires, but braiding techniques are also used to produce rocket nozzles, parachute cords, and structural components for other industrial products.

Flat braids are used for such products as decorative trims and industrial belting, where a high degree of flexibility is required.
MULTI COMPONENT FABRICS

A multi component fabric is one in which at least two layers of material or fabric have been combined to produce a new product with properties significantly different from those of its component parts. The components may be intimately joined to produce a material from which it is difficult to separate them, or it may be a loosely joined material in which the components retain their original forms. The major multi component fabrics are bonded fabrics, laminated fabrics, foam-backed fabrics, and quilted fabrics.

A. Bonded Fabrics

A bonded fabric is a layered structure in which a face, or shell, fabric is joined to a backing fabric with an adhesive that does not significantly add to the thickness of the combined fabrics. Such structures are used for design interest as well as fabric stabilization. Some of the artificial leather products could be classified as bonded fabrics.

The bonding may be done with an aqueous acrylic adhesive, a latex adhesive such as an acrylate, a vinyl chloride or vinyl acetate, or a thermosetting resin. The end use performance of the bonded product depends on the strength of the bond formed between the two fabric layers. A fabric resembling woven double cloth can be produced by joining two face fabrics to provide a reversible fabric. In some instances, a lining fabric is bonded to a face fabric to simplify garment construction. Scrim fabrics such as tricot knits and gauze are also bonded to face fabrics to provide stability to the face fabric. This process has been used on loosely woven mohair fabrics and on fabrics constructed from bulky novelty yarns, to prevent yarn slippage and fabric distortion.

Fabric to fabric bonding:

When two layers of fabric are joined, the purpose is to provide greater stability and body to the face fabric or to create a self-lined fabric. The under layer in bonded fabrics is often knitted tricot or jersey, used because they have good flexibility, are relatively inexpensive, and slide readily, making them easy to don over other garments. For the most part, fabrics used in bonding are less expensive and lower-quality fabrics that can be upgraded by this process.

Two methods can be used for attaching fabric to fabric. The wet-adhesive method places an adhesive material on the back of the face fabric, and together the fabrics are passed between heated rollers that activate and set the adhesive.
The second method is known as the flame-foam method. A thin layer of polyurethane foam is melted slightly by passing it over a flame. The two layers of fabric are sandwiched around the foam, which then dries, forming the bond between the two layers of fabric. Ideally, the layer of foam should be so thin that it virtually disappears. (The foam in the finished fabric is about 0.010 inch thick.) The foam does, however, add body to the fabric and produces a somewhat stiffer fabric than does the wet-adhesive method. It is preferable that the flame-foam method not be used with open-weave fabrics because of the possibility that some of the foam may appear on the surface of the fabric.

B. Laminated Fabrics

Laminated fabrics combine layers of fabric and foam. The product may be a single layer of fabric bonded to a foam layer (a foam-backed fabric), or it may be a sandwich laminate, in which the foam layer is bonded between two fabric layers. The primary purpose of the foam layer is to provide insulation for warmth, and the end uses for such products include cold-weather apparel and insulated window coverings. The completed fabric is often bulky, with poor draping qualities.

The foam may also serve as the adhesive agent. The surface of the foam is heated to provide a tacky surface that will adhere to the face fabric(s), and then the layers are pressed together and allowed to cool and cure. Adhesive similar to those used in fabric-to-fabric bonding are also used. Again the end-use performance of the laminate depends on the strength of the fabric-to-foam bond.

A major consumer complaint about bonded and laminated fabrics has been that they delaminate during washing and dry cleaning. Some of the adhesives used are sensitive to water, and others are affected by dry-cleaning solvents; some thermosetting resins
are affected by high temperatures. Read and follow care label instructions to prevent delamination.

Fabric-to-foam-to-fabric bonding process

C. Quilted Fabrics

Quilted fabrics are layered materials consisting of two cloths that encase a filling and are stitched together to form a puffy unit.

Composition of Quilted Fabrics:

The outer layers of quilted fabrics used for apparel are generally of cotton, polyester, nylon, or blends of such fibres. For insulative purposes and to prevent any filling from working through the outer material, the cloth should be closely woven.
The filling may be goose down; a down and feathers mixture; kapok; polyester staple or continuous filament; resin-bonded polyester; acrylic staple fibre; or polyester or polypropylene microfiber. Quilted fabric should be comprised of about 90 percent air and 10 percent fibre. In terms of weight or mass in relation to warmth, down is more effective than acrylic and polyester fibres. When hollow manmade fibres are used, there is a slightly greater insulation than offered by the solid fibres of the same type. The microfibers, which may be as much as ten times finer than the staple fibres with about twenty times more surface area per unit of weight, have a much greater ability to trap air and have been shown to provide still greater insulation. For example, Thinsulate, a batting of either polyester fibre and polypropylene microfiber or of all polypropylene microfiber, is claimed by its manufacturer, the BM Company, to provide 1.8 times as much insulation as a comparable thickness of down.

**Characteristics of Quilted Fabrics:**

All other factors being equal, a fabric with fewer quilt lines will provide greater insulation because there is little insulation at the lines. Furthermore, the insulation itself tends to move away from the quilt lines thus reducing the areas of insulation.

It is important to note that when a quilted fabric gets wet and moisture penetrates into the filling, its insulative property is markedly reduced – as is true for fabrics generally. However, it has been demonstrated that a filling of polyester and polypropylene fibres, particularly microfibers, recovers more fully from compression when wet than other fillings and therefore provides greater volume faster with the consequent insulation. Water-repellent finishes on the outer cloth does help maintain dryness, but heavy rain or other sources of water saturation will eventually penetrate fabric pores and stitching holes. Water proofing will overcome this problem, but that prevents the natural vapour flow of humidity and body perspiration to escape and will ultimately cause discomfort.

Good quilted fabrics for outdoor use should be wind-resistant for greater protection. Wind resistance is achieved by weaving fine yarns very compactly so as to reduce to a minimum the size of the interstices, or pores, of the fabrics. Such fabrics are very frequently made of polyester / cotton blended yarns, but more effective are those made of all-cotton. When given a water-repellent finish, all-cotton fabric can be even more effective against rain and snow than a polyester / cotton fabric. Also effective is an all-nylon polyester fabric with ciré finish which flattens the yarns and closes up the interstices. Weather conditions and personal considerations should affect the consumer’s choice.

**Different types of Quilted Fabrics:**

**Traditional Quilting:**

Two or more fabric layers may be joined by stitching to produce a quilted fabric. The term stitching should be broadly defined to include the intermittent joining of fabrics by
hand or machine sewing, chemical point bonding, and ultrasonic point bonding. Fabrics quilted with both simple and more complex patterns are available.

Machine-stitched quilting

The traditional quilts stitched by hand had three layers: a face fabric, a fibre batt or feather filling for warmth, and a backing fabric. Hand-sewn quilts are still produced as craft items, and machine-sewn products are also available. Such products are used primarily for bed coverings, but quilted apparel, upholstery fabric, and items such as pot-holders are available as well.

**Trapunto:**

Trapunto is a type of quilting in which a design or pattern is outlined with stitches and then stuffed with fibres (or fiberfill) to form a high relief effect. Such designs are periodically fashionable in apparel and upholstery.

**Outline Quilting:**

Outline quilting is a technique that stitches an outline around a printed design motif to form a quilted fabric. Custom bedspreads and comforters of chintz or other printed fabrics often are made in this manner. Outline quilting is also called custom quilting.

**Chemical Quilting:**

Quilted products can also be produced by joining fabric layers with an adhesive or a thermoplastic bonding agent. This process, called chemical quilting, is more popular for joining two fabrics than for joining three layers. The trade name chemstitch is used for a process that produces a fabric by joining two fabrics with different thermal stabilities.
The two layers are spot welded to produce a design, then subjected to heat, which shrinks one layer more than the other and produces a fabric with a rippled or crinkled surface.

**Ultrasonic Bonded Quilting:**

Ultrasonic energy can be used to join thermoplastic materials and produce a product similar in appearance to machine-stitched quilting. The trade name Pinsonic is used for one such process. Ultrasonic energy is mechanical vibratory energy produced at frequencies beyond the level of audible sound, usually 20 to 40 kHz. The vibration produces enough intermolecular mechanical stress to cause polymer melting and provide a tacky surface that can adhere to another surface. The two layers are pressed together in a pattern that can be made to resemble real stitches. Ultrasonic bonding can be accomplished at high speeds and is less damaging to fibres than thermal bonding.

Mattress pads and bedspreads are frequently produced by ultrasonic quilting. Other applications include upholstery fabrics, quilted apparel fabrics, and nonwoven fabric webs for some industrial markets.
Features of the Leno or Gauze Fabric:

Leno or gauze is a weave in which the warp yarns do not lie parallel to each other. Warp yarns work in groups, usually pairs of two; one yarn of each pair is crossed over the other before the filling yarn is inserted. When looking at a leno fabric, one might think that the yarns were twisted fully around each other, but this is not true. Careful examination shows that they are crossed and that one yarn of the pair is always above the other.

The gauze weave must not be confused with the weave used in manufacturing gauze bandages or cheese cloth; these materials are made with the plain weave. The true gauze weave construction produces a fabric very light in weight and with an open-mesh effect. Curtain materials and some shirt and dress goods are woven with this weave. Such light-weight fabrics have a strength that could not be provided by the plain weave. In the gauze weave, strength is gained by the manner in which the yarns are inter-twisted: each weft yarn is encircled by two warp yarns twisted about each other. The gauze weave is sometimes referred to as the leno weave because it is made on a leno loom, but the true leno weave is a variation of the gauze weave.

On the leno loom, the action of one warp yarn is similar to the action of the warp in the plain weave. The dop attachment, a hairpin-like device at the heddle, alternately pulls the second warp yarn up or down to the right or left with each pick passage. This causes the pair of warps to be twisted, in effect, around each weft yarn.
Gauge weave (left) and Leno weave (right)

The leno is sometimes used in combination with the plain weave to produce a stripe or figure on a plain background. Generally, the term ‘leno’ is used synonymously with ‘gauze’. Fabrics made with the gauze weave are manifestly sheer. Yet, their weights vary depending upon the thickness of the yarns, which could be of spun, filament, or combinations of these yarns.

**Weaving Principle:**

Leno is made with a doup attachment, (It is the device used on looms to create the leno weave, in which warp yarns cross over each other to create an open, stable woven structure.) which may be used with a plain or a dobby loom. The attachment consists of a thin needle supported by two heddles. One yarn of each pair is threaded through an eye at the upper end of the needle, and the other yarn is drawn between the two heddles. Both yarns are threaded through the same dent in the reed. During weaving, when one of the two heddles is raised, the yarn that is threaded through the needle is drawn across to the left. When the other heddle is raised, the same yarn is drawn across to the right.

**End Uses:**

Fabrics made by leno weave include marquisette (It is a sheer, light weight, leno weave fabric, usually made of filament yarns), mosquito netting, agritextiles to shade delicate plants, and some bags for laundry, fruit, and vegetables.

Polyester marquisettes are widely used for sheer curtains. Casement draperies (Casement cloth is a general term for any open-weave fabric used for drapery or curtain fabrics. It is usually sheer.) are frequently made with leno-weave and novelty yarns. Thermal blankets are sometimes made of leno weave. All these fabrics are characterized by sheerness or open spaces between the yarns. The crossed-yarn arrangement gives
greater firmness and strength than plain-weave fabrics for a similar low count and minimizes yarn slippage. Snagging may be a problem in used and care, however.
LAPPET AND SWIVEL FABRICS

Features of Lappet Weave:

Lappet weaving is a kind of embroidery, in which various effects and patterns are produced along with the ground fabric. The figures are produced by giving horizontal motion to a thick end, simultaneously upon a fine muslin or gauze ground. Only small solid loose spot figures can be woven and the floats cannot be bound in the middle. However, extensive figure effects may be produced by skilful designing and by the use of several lappet frames.

The lappet weave is used to super impose a small design on the surface of a fabric while it is being woven. In the lappet weave, the design is stitched into the fabric by needles that operate at right angles to the construction. Thus, the lappet weave is very similar to embroidery. This weave is employed on a variety of fabrics where novelty patterns are desired.

Lappet Weaving Principle:

Lappet patterns contain extra warp yarns woven into a base fabric by means of a frame, or rack, fastened to the loom near the reed (set in front of the reed). Long needles are carried in the frame, and the yarns to be used in making the design are threaded through the needles. When the rack is lowered, the needles are pressed to the bottom of the shed and held in position while a pick is laid. The rack is then raised, and the pick is beaten into the cloth. Next the rack is shifted sideways to a new location, and the same action is repeated.
Each time the frame or rack moves sideways, it carries the yarn in the needle across the surface of the fabric and creates a row of the pattern. If long floats are formed on the back of the fabric, they may be trimmed; if they are short, they are usually left alone. This presents both an advantage and a disadvantage. If the floats remain, the pattern is durable, but the floats can easily be snagged, causing damage to the fabric. If the floats are cut, the design area is weakened and may be gradually removed during use and care. The lappet weave is considered strong and durable, but it is comparatively expensive. Currently, no lappet fabrics are produced in the United States, but some are still produced in Europe.

**Features of Swivel Weave:**

The swivel weave is the method by which decorative effects, such as dots, circles, or other figures, are interwoven on the surface of a fabric while it is being constructed on the loom. The weaving of the design requires an extra filling yarn and additional small shuttles or insertion devices. A separate shed is made for them. While the fabric is being constructed, the row of small shuttles drops across the width of the loom, and each interweaves its separate design with a circular motion on a small area of the warp.

The swivel process permits the weaving of different colours in the same row because each figure has its own shuttle; however, each column consists of repeats of the same colour. In fabrics with small designs, the swivel can produce prominent, raised figures with very little additional yarn. The pattern yarn is fastened securely as each figure is completed, and it cannot pull out without severely damaging the fabric.

Swivel weaves can be distinguished by the appearance of an identical pattern on both the face and the back of the fabric. The decoration produced by the swivel weave is not considered durable, because the swivel yarns are cut when the fabric is completed and cannot be securely fastened. The cut ends roughen the under surface of the fabric and may pull out if it is handled roughly, as may happen in laundering.
The swivel weaves is employed with sheer light-weights, such as dotted swiss (generally a voile or lawn construction woven with either clip spots or swivel dots. The clip spot is the more popular version. The fabric is given a crisp, clear finish, which may be permanent or semi permanent. Often yarn dyed dots are woven on a white ground, or a dark ground has white dots. Many imitations on the market e.g. pigment and flock dots.) and grenadine (Fine, loosely woven leno fabric similar to marquisette. May be made on Jacquard loom. Used for curtains, blouses, dresses.) and medium-weights, such as madras (Cotton fabric of plain weave of coarse yarns. Usually comes in stripes, checks, or plaids. Colours may bleed. Used for shirtings.).

Swivel Weaving Principle:

Swivel designs are produced by winding extra weft yarns on small quills in special shuttles. These shuttles are strategically located at the points where the design is to occur. The pattern mechanism produces a shed, and the shuttle carries the yarn through the shed the distance of the pattern; in some cases, only a few warp yarns are interwoven to form the design. The process is repeated for each row of the design pattern. Between repeats of the pattern, the extra weft yarn floats on the back of the fabric; it is trimmed after weaving is completed.

Differences between Lappet and Swivel Design:

The essential difference between a lappet design and a swivel is that in the swivel the design is done with extra weft yarns, which are cut-off short at the end of each design. The lappet pattern appears only on the right side of the fabric, since the floats forming the pattern are fastened to the ground fabric only at their extremities. Lappet designs are made of one continuous yarn and are not clipped.

Lappet, swivel and clipped spot are all woven fabrics; none is embroidered, although the effect is that of machine embroidery.
DENIM FABRICS

Main Features of Denim Fabrics:

Typical denim fabrics are woven from coarse, indigo-dyed cotton yarn. They are hard-wearing, high density fabrics with a high mass per unit area. Today, more denim is produced in the world than any other type of cloth. Denim fabrics are made for a variety of applications and in a wide range of qualities and shades. Even today, classic denim is still dyed with indigo. It is a special process in which only the surface of the warp yarn is dyed; the core stays white. This is why the garment subsequently develops the typical – and desired – signs of wear.

It is a cotton or cotton / polyester blend, durable heavy weight twill weave, yarn-dyed fabric. Usually the warp is coloured and the weft is white. It is often a left-hand twill with a blue (indigo) warp and white weft for use in apparel in a variety of weights. Since it is a warp-faced twill, the coloured warp yarns predominate on the face and the white weft yarns on the back. It is available in several weights, ranging from 203.46 gm/m² (6 oz/yd²) to 474.74 gm/m² (14 oz/yd²) or more in a $\frac{2}{1}$ or, $\frac{3}{1}$ interlacing pattern. Its long term popularity has made it a fashion fabric in casual wear. It may be napped, printed, made with spandex or other stretch yarns, or otherwise modified for fashion.

Fabric construction: \[
\frac{(7's \times 8's \text{ to } 16's \times 23's)}{(60 \times 36 \text{ to } 72 \times 44)} \times \text{ Fabric width.}
\]

Raw materials of Denim Fabric:

To produce good quality denim, the conditions have to be optimal regarding the quality of all the raw materials and yarn used. For raw cotton and the carded OE (rotor) or ring spun yarns made from it, the quality criteria are as follows:

- Minimum staple length: 2.7 cm
- Proportion of short fibres (less than 12 mm long): under 40%
- Micronaire value: 4.0 to 4.5
- The Uster values for strength and elongation, the evenness CV and imperfections must conform at least to the 25% plot
- The usual count range of denim warp yarns is 50 to 90 tex and of weft yarns is 75 to 120 tex; finer yarns as fine as 25 tex in twill or plain weave are often used in denim shirts
- Twist factor: 4.5 to 5.0 for warp yarns, 4.2 for weft yarns
- Low yarn hairiness
- Yarn strength and uniformity.
In the early 1990s, most of the yarns used in denim production were OE yarns. Recently, there is a strong trend towards using more carded ring spun yarns in both warp and weft. They give the fabric a softer handle, fulfilling the requirements for “soft denims”. The following table shows the acceptable values for ring spun and OE cotton yarns with a fineness of 84 tex (7 Ne) for successful denim production.

<table>
<thead>
<tr>
<th>Properties</th>
<th>Ring-spun yarn</th>
<th>OE Rotor yarn</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strength (cN/tex)</td>
<td>17</td>
<td>13</td>
</tr>
<tr>
<td>Elongation (%)</td>
<td>8.5</td>
<td>8.5</td>
</tr>
<tr>
<td>Uniformity (CV%)</td>
<td>12</td>
<td>12.5</td>
</tr>
<tr>
<td>Thin places (per 1000 m)</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Slubs (per 1000 m)</td>
<td>50</td>
<td>20</td>
</tr>
<tr>
<td>Neps (per 1000 m)</td>
<td>50</td>
<td>3</td>
</tr>
</tbody>
</table>

**Types of Denim:**

Demand for fashion variants of classic denim will continue to grow. The most popular variants are:

- Stone-washed and double stone-washed denims
- Chambrays
- Fancy multicolour denims
- Denim with metal-effect yarns
- Elastic denims
- Printed denims
- Jacquard-patterned denims
- Denims with fancy yarns

Lightweight chambrays are used for shirt and blouses. Heavy, classic denims are made up into trousers or coats. Besides classic indigo blue, the fabric is dyed in other fashion shades and colours, the most popular being black denim. The fabrics are graded in clearly defined classes by weight, e.g. light denim 10 to 12 oz/sq.yd. or below it, heavy denim 14 to 16 oz/sq.yd. At present time, the following denim fabrics with their specific commercial name are widely produced in the denim industry of Bangladesh.

- **a. Basic or regular denim** $\frac{3}{1}$
- **b. Ring denim** $\frac{2}{1}$, there are 7, 9, 12 count of yarn used
- **c. Slub denim** only warp slub (one way slub) and weft slub (cross slub)
- **d. Cross hatch denim**
- **e. Stretch denim** weft yarn (elastomer)
- **f. Poly denim** polyester used in weft.
Warp Preparation:

In denim production, warp preparation, dyeing and sizing are crucially important. Dyeing with indigo requires detailed knowledge of the physical and chemical processes involved. The various dyeing and sizing methods, and the corresponding recipes and concentrations, reaction and oxidation times not only influence the weaving process; they are also largely responsible for the appearance and quality of the denim.

Besides the classic indigo rope dyeing process, indigo sheet dyeing is also used. One variant of sheet dyeing is loop dyeing. Dyeing and sizing are either done separately, as in rope and double sheet dyeing, or the two processes are combined in a single operation, as in sheet dyeing and loop dyeing.

Indigo Rope Dyeing:

In warp preparation for rope dyeing, 350 – 400 warp yarns are assembled on the ball warper to form a rope 10,000 to 15,000 meters long. Between 12 and 36 ropes are drawn through the dyeing range side by side. After dyeing they are dried on a drum drier and deposited in cans. The ends are spread out on a rebeamer or long chain beamer (lcb), and the yarn sheet is wound onto warp beams. These beams then come to the sizing machine, where they are sized, dried and assembled in accordance with the total number of ends required to make up the weaving warp beam. This process ensures optimal dyeing of the indigo, but with the disadvantages that broken ends are more frequent and yarn tensions are not always compensated. Modern indigo dyeing ranges normally operate with six dye vats. Using state-of-the-art methods, the same dyeing quality can be achieved with just three vats, with a substantial reduction in the consumption of chemicals. The production rate of this system is normally 2 to 3 times higher than the sheet dyeing system.

Indigo sheet dyeing and double sheet dyeing:

In indigo sheet dyeing, warp beams are brought to the dyeing and sizing range instead of ropes. Dyeing, drying, sizing and after repeated drying, assembly of the warp is carried out in a single operation. In the case of double sheet dyeing, dyeing and sizing are done in two separate steps. As far as indigo dyeing is concerned neither process is always ideal, but both have the advantage that the number of broken ends is low and yarn tension can be extremely well controlled.

Indigo loop dyeing:

In the loop dyeing process, the yarn is dyed in a single bath instead of several. The desired depth of colour is attained by passing the yarn through the vat several times. Subsequently, as part of the same process, the yarn is sized. The advantages and disadvantages of loop dyeing are the same as with sheet dyeing.
Sizing recipes:

The sizing process plays a key role in further processing of the warps. The choice of sizing agents used to achieve the sizing effect is crucially important here. A relatively soft handle can be achieved using a combination of modified starch with a polyacrylate. Warps sized in this way have good running properties, helping to ensure high efficiency and an excellent final appearance. A practical example is given below:

Style data:
Warp: OE yarn, 84 tex (7 N_e), 24 ends/cm
Weft: OE yarn, 100 tex (6 N_e), 16 picks/cm
Total number of warp ends: 3942

Size recipe for 100 liters of liquor:
- 8.0 kg modified starch
- 4.0 kg acrylate size
- 0.2 kg textile wax
- Size concentration: 8.0 %
- Size temperature: 85°C
- Squeezing pressure: approx. 15 kN
- Size pick up: 9 – 10 %

Advantages of the denim size recipe:

Sizing room:
- Easy separation of ends
- No hard size
- Only slight bleeding
- No colour masking
- Minimal dust and fibre fly.

Weaving room:
- High, constant weaving efficiency
- Easy warp take-up
- Minimal dust and fibre fly.

Weaving:

For finished widths of 150cm to 156cm, reed widths of 160cm to 167cm are required. Denims that are stretchable in the weft do not follow this rule. When weaving with projectile weaving machines, these fabrics are generally woven in two panels with weaving widths of 360 or 390 cm. in this way a high weft insertion rate of 1400 m/min is achieved at a machine speed of approximately 400 picks/min. For the production of heavy denims, leno selvedges are advisable. Lighter denims, weighing less than 13 oz/sq. yd, can be woven with tucked selvedges. The fabrics can be inspected with an electronically controlled cloth inspection machine.
The current demand on soft denims in the United States is to use lyocell yarns (e.g. Tencel) in the weft. For structured denims, structured yarns are used for the weft. Slub and knob effects are especially popular.

**Diversification of Denim:**

This fabric became popular at first among people of western countries and then gradually all over the world. But, consumers’ need for new products is unlimited. So, to meet this essential demand, the fabric designers and manufacturers were obliged to produce different types of denim at present, hundreds of derivatives of denim are available. Also new types of denim products are being developed. The diversification of denim has gone so far that some denims are not even twill based. They are being produced on plain-based weave design.

Denim is comparatively heavy fabric composed of higher linear density yarn both in warp and weft. This fabric is not very soft in handle. Different fancy yarn – slub yarn, thick-thin yarns are used in the diversification of denim. Lycra (elastomeric fibre) yarn is also introduced in the diversified denim. Diversification is also done by the change of EPI, PPI and count. Yarn of different count may be used in consecutive insertion for diversification. For increasing the agreed level of denim throughout the world, diversification is the most important factor. Denim is very popular among the teenagers as well as older people.

Denim’s popularity was also on the rise. It was stronger and more expensive than jean, and though the two fabrics were very similar in some ways, they did have one major differences: denim was made of one coloured thread and one white thread; jean was woven of two threads of the same colour.

Denim is no longer a cotton product. Denims come with either polyamide, lycra, polypropylene or with polyester and especial bonding with a 100% nylon net for a more active look. Two way stretch fabrics and special coatings or rubberized effects continue to be a strong trend.

**End Uses or Prospects:**

In modern world, the apparels made from denim have become very popular among wearing. Now days, baby wear, men’s trouser, shirts, ladies wear are also made from denim fabric, and day by day, its acceptability is increasing among consumers. Denim goods are now being used among almost all type of people. Denim wear crosses the line of fashion boundary. In the past, it was used by workers as a safety wear. Now it is used for making decorative cap and ladies hand bag, school and college bag, and travel bag. So, range of denim apparels are widening day by day. So Denim is used for jacket, pant, shirt, denim wine bags, denim pencil case, denim apron, denim pillows, denim quilt etc.
Pile fabrics have been defined as "fabrics with cut or uncut loops which stand up densely on the surface". Pile fabrics may be created by weaving or through other construction techniques, such as tufting, knitting, or stitch through. To create the loops that appear on the surface of woven pile fabrics, the weaving process incorporates an extra set of yarns that form the pile. Construction of woven pile fabrics, therefore, represents a complex form of weaving in which there are at least three sets of yarns. Example of pile fabrics produced by the pile method include corduroy, fleece, frieze, fake fur, plush, poodle cloth, terry cloth, velvet, velveteen and velour.

Woven pile fabrics have an extra set of warp or weft yarns interlaced with the ground warp and weft in such a manner that loops or cut ends extend from the base fabric. The base fabric may be constructed of either a plain or a twill weave.

The pile weave is a fancy weave that also includes a plain or a twill construction. In contrast to the three basic weaves (plain, twill, satin) that produce a flat surface on a fabric, the pile weave introduces a decorative third dimension, creating an effect of depth. Its construction is especially desirable when softness, warmth, and absorbency are desired. Pile weave fabrics are also durable if the proper yarns and adequate compact construction are used.

Pile fabrics can be divided into fabrics with loop pile and cut pile. Woven carpets, velvet and terry fabrics are the best-known pile fabrics.

**Types of Woven Pile Fabric:**

Woven pile fabrics are divided into two categories depending on whether the extra set of yarns is in the warp direction or the weft direction. Pile fabrics are woven by one of several methods, depending on whether they are warp pile or weft pile fabrics. Warp pile fabrics have two sets of warp yarns and one set of weft yarns. Weft pile fabrics have two sets of weft yarns and one set of warp yarns.

**A. Weft Pile Fabrics:**

Weft pile fabrics are woven by the weft pile method. No special weaving machines are needed to weave weft pile fabrics. In this method there are two sets of weft yarns and one set of warp yarns. Although the ground may be of either twill or plain weave, a twill base is preferred for its durability. The extra set of weft yarns forms floats that are over
three or more-frequently five to seven warp yarns in length. The weave used can be a weft satin or a warp rib weave. After weaving is completed, the floating yarns are cut at the center of the float, and these ends are brushed up on the surface of the fabric to form the pile surface. Weft pile fabrics usually have a short pile; the pile height is determined by the length of the floats of the pile weft yarns.

In some weft pile constructions, the weft yarn that makes the pile is interlaced with the ground one time before it is cut; in others, the filling or weft pile interlaces twice. Those fabrics in which there are two interlacings are more durable than when only one interlacing has taken place. Corduroy, velveteen, and some plushes are manufactured by this method.

Some well-known weft pile fabrics are:

1. Corduroy – Fine rib quality often used for women’s wear.
2. Baby roy – Very fine rib quality, used e.g. for women blouses.
3. Velveteen – (known from the trousers) there is pile here over the entire fabric surface, but the pile not forms ribs on the fabric surface like corduroy.
4. Manchester – This is a weft pile fabric with closely woven weft often used for work trousers.
5. Stretch cord – This is a weft pile fabric with a great number of elastomer yarns in the warp. This makes the fabric elastic in length direction.

**Corduroy Fabrics:**

In corduroy, characterized by a pile stripe or wale alternating with a plain wale (no pile), a separate cutting knife is necessary for cutting the floats of each wale. These fabrics are woven to produce lengthwise columns of floats. The columns are formed with sufficient space between them so that when the floats in the long columns are cut and brushed, the face of the fabric has a ribbed effect. The lengthwise ribs of pile are referred to as wales.
The even spacing of corduroy floats produces a stripe or wale characteristic of this fabric. Corduroys are given names according to the numbers of wales. Feather wale or cord corduroy has about 20 to 25 lengthwise wales per inch and weight 5± ounces per yd²; Fine wale or Pinwale corduroy, about 16 to 23 wales per inch and weight 7± ounces per yd²; Mid, medium, or regular wale corduroy, about 14 wales per inch and weight 10± ounces per yd²; Wide wale corduroy, about 6 to 10 wales per inch and weight 12± ounces per yd²; and Broad wale corduroy, about 3 to 5 ribs per inch.

Novelty wale corduroys are also produced in which thick and thin wales are arranged in varying patterns. Some corduroy fabrics are now made with 100% cotton yarns in the pile filling and polyester and cotton blends in the ground yarns. Other decorative effects can be achieved by cutting floats selectively to vary pattern and texture. Most weft pile fabrics are made from spun yarns.

**Velveteen Fabrics:**

Velveteen and weft plush, however, are produced with floats of such a length and closeness that when cut and brushed they produce an all-over, rather than a ribbed effect. They are characterized by a uniform, overall pile.

A twill-back velveteen or plush is more durable than a plain-back. Another point in durability is the way in which the pile is held to the ground. If a pile loop is pulled from the fabric, its shape will be a ‘V’ or a ‘W’. A ‘V’ reveals that the pile weft has interlaced with only one warp yarn, where as ‘W’ reveals an interlacement with three warps. ‘W’ is more durable because it is held to the ground by three warps instead of one.

Velveteen has more body and less drapeability than velvet. The pile is not higher than \(\frac{1}{8}\). Both corduroy and velveteen are available in solid-colour and printed fabrics.

Structurally, the velveteens may be classified as follows:

1. All-over or plain velveteens – in which the surface is uniformly covered by the pile.
2. Weft plushes – similar to above but arranged to produce much longer tufts and used mainly for upholstery purposes.
3. Corded velveteens – also known as corduroys and fustians in which the pile runs in orderly vertical cords of varying width.
4. Figured velveteens – in which pile figure is produced on bare ground.

All the above groups may be further sub-divided into plain-back or twill-back structures depending on the type of weave in which the ground picks interlace with the warp.
**Float Cutting principle:**
Cutting the pile is precision work to be carried out in a separate operation after weaving. Corduroy and velveteen are prepared for cutting in the same manner. The floats are treated to give them cutting surface, and the fabric is stiffened so that it will remain smooth and firm. At one time pile was cut by hand with a thin steel blade; the practice may continue in countries where labor is cheap, but machine cutting is more prevalent today. In one process, thin, flexible metal bands are inserted between the floats and the base fabric, and then circular metal knives cut down the centers of the floats over the metal band. The blades cut the floats without damage to the base fabric.

The machine used here is equipped with a great number of needles with knives. For every rib to be cut, a separate needle with knife is used. The needles are pushed as it were into the tunnels under the pile weft. The needles are split after the needle point. The circular knife turns in this groove thus cutting the pile weft yarns. After the pile yarns have been cut, the fabric surface is brushed to bring the cut ends of the pile yarns into a position perpendicular to the fabric surface.
Novel surface effects can be achieved by having different length floats or by shearing the floats to different lengths to produce patterns. Cutting some floats and leaving others uncut is another way to create interesting fabric surfaces. When wide-wale corduroy is cut, the guides and knives can be set to cut all the floats in one operation. For narrow corduroy and velveteen, the rows are so close together that alternate rows are cut with each pass and the fabric must be run through the machine twice.

It is very important that good yarn qualities should be used for the pile weft. Indeed knots, bulges etc. can block the needles which can result in long cutting faults. Rotor yarn cannot be used as pile yarn.

B. Warp Pile Fabrics:

Warp pile fabrics such as terry cloth, velvet, velour, rug velvet, and Wilton and Axminster rugs are made using extra warp yarns to form the pile. One set of the warp yarns interlaces with the set of weft yarns to form the base or ground fabric, and the extra set of warp yarns is used to create the pile that can be cut or uncut.

Three general methods are used to make warp pile fabrics:
1. The Wire method,
2. The Double-cloth or Double-weave or Face-to-Face method, and
3. The slack tension pile or Terry weave method.

1. The Wire method:

Wire looms allow weaving of carpets with loop pile, cut pile or a combination of loop and cut pile. Carpets woven on wire looms are mainly heavy carpets for the contract market (e.g. for shops, offices, hotels, etc.), either with an all-over structure or with two or three colours. A two-colour carpet is indicated as a two-frame carpet. One of both pile colours forms the pile; the other pile yarn is the dead pile yarn and is either floating at the back of the carpet or woven in.

A distinction can be made between two- and three-pick wire carpets. The former (two-pick wire carpet) means that a wire is inserted in the loom after every two
picks; for the latter (three-pick wire carpet) this is after every three picks. At the reed beat-up following the wire insertion, a loop is formed over the wire. At the cloth fell, the wires stay in the carpet over some cycles. After insertion of a wire, the wire furthest away from the shafts is withdrawn from the carpet. It is necessary that the wires remain in the carpet during a number of insertions in order to obtain a strong binding of the cut pile in the ground fabric.

A distinction is made between cutting and looping wires:

- **Cutting wires**: These wires have a knife at the top; when the wire is withdrawn, the loop is cut, resulting in a cut-pile.

- **Looping wires**: These have no cutting edge and the loops are not cut when the wires are withdrawn. The carpet then has a loop pile.

A carpet with a cut and loop pile can be obtained by combining both wire types during weaving.

The ground warp yarns are unwound from one or more warp beams. Several beams are necessary if the crimp of various warp sets in the fabric is greatly different. The ground weave can be a plain weave either with equal or unequal tensions, or a combination of a $\frac{2}{3}$ weave with a $\frac{1}{3}$ weave; this combination is also referred to as English weave. Other ground weaves can be used. The ground warp yarns are threaded in the back shafts. Shedding of the ground warp yarns is done by means of cams. Shedding of the pile warp yarns can be done by means of cams, dobbies or
Jacquard mechanisms. The pile warp yarns are unwound from one or more pile warp beams or from bobbins in a bobbin frame (creel). The way the pile yarn is set up on the loom depends on the difference in consumption of the various pile warp threads.

In the wire method, one set of warps interlaces with the weft to form the plain or twill-weave ground of the fabric; the other set of warps forms the pile. When a row of pile is made, the warp yarns to form the pile are first raised by the harness to form the shed. Then a wire is inserted through the shed, much as weft yarn is shot through. The size of the wire is determined by the size of the pile to be made. When the set of warps to form the pile is lowered, it loops over the wire and is held in place by the next weft. The wire is then withdrawn. As this is done, a small, sharp knife attached to the end of the wire cuts the pile warp loops. The ground is then woven for a certain number of picks; then the wire is again inserted to form the pile. If the pile has not been cut evenly by the wires, the fabric is sheared again with a device like a lawn mower.

Sometimes the pile is left uncut: a wire with no knife is used, or a number of weft threads are substituted for the wire and are then withdrawn. Friezé, a fabric often used for upholstery is an example of an uncut looped pile fabric or combination of cut and uncut looped pile fabric that can be made by the wire method. Friezé has fewer tufts per square inch than most other pile fabrics. The durability of Friezé
depends on the closeness of the weave. If the fabric is to have a cut pile, the wire has a knife blade at the end that cuts the yarns as the wire is withdrawn. Velvets may be made in this way. If the fabric is to have an uncut pile, the wire has no cutting edge. Velvet can also be made by the over-wire method. Complex patterns using different coloured yarns and loops combined with cut pile result in a wide variety of fabrics.

**Advantages of the wire weaving technique are that:**

- Both cut and loop pile weaving is possible,
- There are no problems to weave logos; there is no mirror image effect as on face-to-face weaving machines,
- The pile height is easily adjustable by changing the wire dimensions.

**Disadvantages however are:**

- The low production speed,
- Over-heating of the wires when they are withdrawn. This may cause problems when weaving synthetic yarns.

On traditional wire looms, the weft is inserted by means of a shuttle. On modern wire looms, rapiers are used with transfer in the middle according to the Dewas-principle. The wires are inserted in and withdrawn from the fabric by means of a special mechanism. The working of the mechanism for wire insertion considerably limits the weaving speed to 50 to 60 insertions per minute. In ITMA’ 1995 it was 145 insertions per minute.

2. **The Double-cloth or Face-to-Face method:**

A carpet or velvet fabric produced on the face-to-face principle is formed by cutting through a double cloth or fabric. The pile yarns are perpendicular between two ground fabrics. Many average-grade millenary and transparent velvets are woven double; that is, two cloths are woven at the same time, face to face. Two fabrics are woven, one above the other, with the extra set of warp yarns interlacing with both fabrics. There are two sheds, one above the other, and one weft yarn is inserted into each shed. The fabrics are cut apart while still on the loom by a traveling knife that passes back and forth across the loom thus forming two fabrics with facing piles. With the double-cloth method of weaving, the depth of the pile i.e. the pile height is determined by the space between the two fabrics. The pile height is changed by adjusting this distance. The interlacing pattern of the pile yarns determines their
denser, and is less durable. The plain, rib, twill, or satin weave may be used as the ground. Velvet, velour, plush and fake fur may be woven and cut apart.

![Weave Diagrams]

The patterns on both fabrics are each other’s mirror image. Once cut through, the carpets do not greatly differ from carpets produced with the aid of wires from a weave-technical point of view. The looms are less wide than wire looms, since there is no system for wire insertion. The dead pile yarns can be woven evenly in both fabrics. The cutting mechanism must cut at high speed while the knife movement at both extremities over the grindstones must be slower. It is very important not to cut during the reed beat-up because the fabric is not under sufficient tension to be cut. Cutting would then not necessarily be done in the middle.

Face-to-face weaving is the weaving technique with the highest productivity for carpet and warp velvet weaving. There are two techniques of face-to-face weaving:

- **Single-shuttle principle**: single shed and only one mechanism for the weft insertion on the loom,
- **Double-shuttle principle**: two sheds are formed and there are two mechanisms for the weft insertion so that two wefts are inserted simultaneously: one for the top and one for the bottom fabric.

**The weaves used here include:**

- Plain weave with equal or unequal tension,
- $\frac{2}{2}$ 2 (hopsack weave),
- $\frac{3}{2}$ combined with $\frac{1}{1}$, with the warp yarns of the latter weave highly tensioned,
- $\frac{3}{3}$ combined with $\frac{2}{1}$, with the warp yarns of the latter weave highly tensioned.

With the single-shuttle weaving technique, a loop is formed on every pick. With the double shuttle technique, a loop is formed for every two or three picks. It is also possible to work with exclusion of weft on the double-shuttle technique: a weft yarn
is inserted alternately in the top and bottom fabrics while the other insertion mechanism inserts no weft yarn. In this way, the double-shuttle technique too can provide a loop for every weft yarn.

![Single shuttle principle](image1.png)

Traditionally, the weft was inserted by means of shuttles. Modern machines are equipped with rapiers for the weft insertion. The weave of the ground warp yarns is mostly formed with a cam mechanism. The shedding of the pile yarns can be done by means of cams, dobbies or a Jacquard mechanism. For carpet looms, mainly jacquards are used.

![Double shuttle principle](image2.png)

On single-shuttle face-to-face looms, a Jacquard mechanism with two positions is enough. On double-shuttle face-to-face looms, a Jacquard mechanism must be used.
that allows three positions of the pile yarns if the dead pile yarns are to be woven in the ground fabrics. There are two techniques for this:

- **Two hooks per harness cord**: if both hooks are up, the yarn is in top position. If only one hook is up, the pile yarn will be in middle position. The pile yarn is of course in the bottom position if no hook is lifted. This system is applied on face-to-face weaving machines by Van De Wiele.

- **One hook per harness cord**, but the grid to which the pulley yarns are attached can take two positions. Combining the hook movement and the grid can give three possible positions for the pile warp yarns. These systems can be applied on face-to-face carpet looms by Van De Wiele.

Face-to-face velvet can be woven with a mirror warp which results in a plain-coloured fabric backside. The mirror warp can be obtained with a jacquard with two positions. For weaving velvet, ‘U’ and ‘W’ bindings can be used besides the ‘V’ bindings.

Velvet is made of filament yarns with a pile height of \( \frac{1}{16} \) " or less. Velvet must be handled carefully so that no folds or creases flatten the pile.

![Double woven velvet before splitting](image)

Velvet fabrics are used in a variety of applications such as jewelry boxes, film sealing, bathroom carpets, curtains, upholstery, automotive interiors, prayer mats and wall rugs. Long pile velvet is used to imitate fur and technical fabrics.

Velvet fabrics have a fluffy surface due to cut loops. Two layers of fabrics are woven together with a yarn binding them. When the binder yarn is cut, the layers are separated resulting in a fluffy surface on one side of each fabric. The following figure shows the schematic of velvet fabric weaving and formation. A bent reed and lancets are used to allow weaving with minimal shed dimensions to reduce the tension peaks on the pile warp ends. Velvet fabrics are produced by plain, dobby, or jacquard design velvet machine.
Schematic of velvet weaving

One method to form loop pile is to use lancets. False picks are inserted above the lancets to form the pile; then, the false picks are automatically removed during weaving.

By controlling the pile and base warp yarns, various weave structures can be obtained. For example, sculptured loop pile velvet can be produced with flat woven weft and warp effects as shown in the following figure.

Shadow loop pile velvet is obtained by giving a direction to the loop pile. Colour effects can be achieved using a weft selector. Any type of natural and manmade yarns are used including cotton, polypropylene, acrylic, polyamide, etc.
Velvet and velveteen can be distinguished by fibre length: velvet is usually made with filaments and velveteen with staple. To identify warp directions in these fabrics, ravel adjacent sides. In weft-pile fabrics, the pile is pushed out as individual tufts when a weft yarn is removed. But when a warp yarn is removed, the pile tufts cling to it and it looks a little like a woolly caterpillar. In warp-pile fabrics, the opposite occurs. Pile tufts cling to weft yarns.

Another way to tell warp direction is to bend the fabric. In velveteen, the pile ‘breaks’ into lengthwise rows because the weft tufts are interlaced with the warp yarns. In velvet, the pile breaks in crosswise rows because the warp tufts are interlaced with the ground-weft yarns. This technique works best with medium-to poor-quality fabrics. Finishing is used to create other looks for velvet.

Crushed velvet is made by mechanically twisting the wet cloth. The surface yarns are randomly flattened in different directions. Panné velvet is an elegant fabric with the pile pressed flat by heavy pressure in one direction to give it high luster. If the pile is disturbed or brushed in the other direction, the smooth, lustrous look is destroyed.

Velour is a warp-pile cotton fabric used primarily for upholstery and draperies. It has a deeper pile than velveteen and is heavier. Plush has a deeper pile than velour or velvet and is usually longer than \( \frac{1}{4} \) ".

Fur like fabrics may be finished by curling, shearing, sculpturing, or printing to resemble different kinds of real fur. Most fur like fabrics are made by other processes.

Face-to-face velvet looms usually have lancets in order to obtain a correct pile height between top and bottom fabrics. This reduces the tension of the ground warp yarns which decreases the number of ground warp end breakages. The tension of the pile yarns is higher which reduces the risk of joining or clinging pile yarns.

As on the wire looms, the concept of ‘number of frames’ of the carpet or velvet is defined. The dead pile yarns can be woven in (partly in the top cloth and partly in the bottom cloth), float between both fabrics, or float at the backside of one of both fabrics. In the second and third cases, the floating yarns must be removed on appropriate machines. The technique with bound in pile yarns has the following advantages:

- No supplementary treatment is needed to remove the floating pile,
- Top and bottom carpets are equal in weight,
- The carpet is thicker (more comfort),
- Greater dimensional stability.
Disadvantages however are that:

- More complex and hence more expensive jacquard machines are needed,
- The jacquard machines are under heavier stress,
- The backing aspect is less nice than with floaters.

Face-to-face fabrics have technical applications. The face-to-face fabrics are not cut through then and are referred to as distance fabrics. The space between the two fabric layers can be filled with foam, sand, cement, etc. Application of such products include: acoustic or thermal insulation, pipes for warm and cold air, pipes in heat exchangers, ground or river bank fortification, sandwich boards, etc.

A recent application consists in the use of face-to-face fabrics of glass for the production of sandwich boards of composite materials. The double-cloth fabric is impregnated with resin which is then cured. The space between both fabrics can be filled for example with a foam layer. Sandwich boards made of face-to-face fabrics have a higher peel and shear strength than boards made according to other techniques.

The following figures represent the examples of carpet weave structures:

![Diagram of carpet weave structures](image)

Ground weave: $\frac{2}{2} + \frac{1}{1}$ and floating dead pile

Ground weave: $\frac{1}{1}$ and dead pile woven in the fabric
Ground weave: $\frac{2}{2} + \frac{1}{1}$ and dead pile woven in the fabric

Ground weave: $\frac{2}{2}$ and floating dead pile

Ground weave: $\frac{1}{1}$ and floating dead pile

Ground weave: $\frac{2}{2} + \frac{1}{1}$, dead pile woven in the fabric and pile over every two picks.
Ground weave: $\frac{2}{2} + \frac{1}{1}$, dead pile floating between both fabrics and pile over every two picks.

Ground weave: $\frac{3}{3} + \frac{2}{1}$, dead pile woven in the fabrics and pile over every three picks.

Exclusion of weft on a double shuttle loom, dead pile woven in the fabric

1/2 V weave structure without mixed colours

1/2 V weave structure, not woven through to the back
Aftertreatment of Woven Carpets and Velvet:

Finishing of velvet depends on the yarn type, the weave structure and the application area of the fabric. In Europe, a back coating of the velvet fabric is avoided as much as possible, except for applications where the velvet has to meet heavy requirements. In the United States, it is common practice to apply a back coating. Further treatment of velvet consists of brushing, tip-shearing and opening the pile.
Finishing of woven carpets implies the following steps:

- Scraper to scrape off the floating dead pile where needed,
- Inspection tables for the detection of weave faults and possible repairing of faults,
- Tip-shearing and brushing the pile,
- Coating line to open the pile by means of steam and to coat the carpet back with an adhesive.

The back coating of the carpet provides better binding of the pile and a better hand as well as offering higher resistance to raveling.

3. The Slack tension Pile or Terry Weave method:

Articles made of terry fabrics are used daily in many areas. They have loops at least on one side and usually on both sides. Most terry fabrics are produced with loops
- Low spare parts consumption
- Easy operation, with few mechanical settings needed
- Short style changing times

**Types of Terry Fabric:**

There are basically two qualities of terry, according to the loop structure:

a) Classic terry, with upright loops (made of twisted yarns). These terries are usually patterned with dyed yarns.

b) Fashion terry, also known as milled or fulled goods, with spiral loops (of single yarns). These are mainly piece dyed or printed fabrics.

A blend of single and twisted yarns produces additional pattern effects.

According to the terry aspect, three types can be distinguished:

a) Terry with ordered standing loop piles: this is the type of pile fabrics which is most produced. Most of the time, unsized, bleached or dyed pile warp yarns are used in weaving which require no further aftertreatment. The first wash after **purchasing the product** may cause a considerable change of the aspect.
reed pushes the pick group, on the tightly tensioned ground warps, towards the fell and the loose pile warp ends woven into the pick group are uprighted and form loops. Depending on the weave, loops are thus formed on one or both sides of the fabric. With the basic method, known as three-pick terry, three picks form a pick group. It is possible to have pile heights up to 10 mm. Base weaves are usually \frac{1}{1}, \frac{2}{2}, \frac{3}{2}.

The loom for terry cloth requires two warp beams. One is at the rear of the weaving machine in a plane with the weaving surface, and the second beam is placed at the back but above the weaving surface. Both shuttle looms and shuttleless weaving machines are used in making pile fabrics just as they are used for all types of woven fabric. For complex patterns the weaving machine has to be equipped with a jacquard machine. For less demanding patterns a dobby is sufficient, and very simple, non-patterned fabrics can be woven with a cam motion. The following figure shows a rapier terry weaving machine with two warp beams.

![Rapier terry weaving machine with two warp beams](image)

Quality is determined by the yarn type (carded or combed), fibre (pima, Egyptian, or regular cotton), and the number of weft yarns or picks used to create the weave. Warp yarns used for the pile in terry cloth have low twist to produce a soft, fluffy, highly absorbent surface. Common varieties include two- and three-pick terries. For example, a three-pick terry cloth, the highest quality, has two picks under the pile loop and one pick between loops. The following figure shows a three-pick terry cloth with closed loops on both sides of the fabric.
In general, the reed has two beat-up positions which do not impose alternative movements to the warp, fabric and various components of the weaving machine. The sley has a special mechanism built in which allows different beat-up positions for pile formation. Tucked in selvedge or leno selvedge are commonly used. The warp is evenly let-off by a system of constant tension control from full to empty beam, this is controlled by a highly sensitive electronic device. Air-jet machines are also successfully used in terry manufacturing. The individual components of an air-jet terry weaving machine are shown in the following figure.
As far as weaves are concerned, two types of terry are distinguished: four-pick and three-pick terry. Three-pick terry is produced most. Four-pick terry is more cost-intensive and is only applied for high-quality products. For three-pick terry, the weave of the ground warp yarns is a $\frac{1}{2}$ rib weave whereas the weave of the loop warp is a $\frac{1}{2}$ or $\frac{2}{1}$ twill weave, depending on the side where the loop is to be formed. For four-pick terry, the basket weave (or hopsack weave) is used for the ground warp. The weave used for the loop warp is a $\frac{1}{3}$ or $\frac{3}{1}$ twill weave depending on the side where the loop pile is to be formed.

For both types of terry weave (three- and four-pick) the following rules apply:

- The loop warp yarns always bind around the second weft after the full reed beat-up,
- There must be a shed crossing of the ground warp yarns after the full reed beat-up in order to avoid slipping back of the weft yarns after the reed beat-up. This rule is sometimes, albeit very exceptionally, deviated from for four-pick terry.
If the loops must be formed alternately above and under the fabric according to a certain directive, a special weave interchange is necessary. Two types of weave interchanges are used:

- South-German pile interchange: a disadvantage here is that the pile loops do not have the same height at the interchange. However, these loops are well bound in.

- Burghard-Vossen pile interchange: this pile crossing can be used if the pattern in the fabric requires sharp outlines. A drawback is the weak binding in of the loops at the interchange, which makes these loops easily removable.

Terry fabrics are often very complex, with different coloured warp ends in combination with loop patterns. They are subject to changing fashions, the market is constantly demanding new qualities and designs. The rapid development of electronics, with microprocessor controls and highly dynamic stepping motors in combination with modern mechanisms, has enabled fabric designers to produce completely new patterns. Three- and four-pick terry, and even fancy types of terry can be combined in the same length of fabric. The following figure shows a special seven pick weave combined with full beat up at the sixth and seventh pick. A second pile height is also formed in weft direction, making sculptured patterning possible by the difference in pile height in warp and weft direction.
End Uses and Related Properties:

Terry cloth is used for bath towel, bath mats, bathrobes, beach robes, and sportswear. Each loop acts as a tiny sponge. Moreover, bathrobes are warm cloths since terry fabrics contain a lot of air. Terry fabrics are easy in maintenance; they need no ironing. Sheared loops are brushed to loosen and intermesh the fibres of adjacent yarns. The surface becomes more compact, less porous, and absorbs more slowly as compared with loop-pile terry.

Since terry fabrics are used for applications where great water absorbency is required, only fibres from natural polymers can be used. Cotton is by far most often used. Viscose presents the drawback of swelling more in wet condition, which makes viscose fabrics shrink more. Besides, viscose presents a considerable loss of strength in wet condition and viscose terry fabrics has a less soft hand than cotton terry. Institutional cotton / polyester terry towels have blended ground yarns and cotton pile; the cotton pile yarns are for absorbency and the polyester ground yarns are for strength and durability, especially in selvedges. There is no up and down in terry cloth unless it is printed. Some friezés are made by this method. Another slack-tension fabric, shagbark, has widely spaced rows of occasional loops.

Guides to the Buyer of Pile Fabrics:

If pile construction is used for silk, man-made fibres, or fur, these textiles are presented to the consumer in their richest, most luxurious textures. Pile fabrics feel soft and downy. Silk pile takes a rich, deep colour, especially when one looks directly into the pile. If the pile is pressed down, the fabric takes on a silvery, satin cast.

Pile fabrics are warm and hence are best used for fall and winter wear. Transparent velvet with a long pile and loosely woven back is not so warm as a fabric with a short pile and a tightly woven back. An all-silk velvet is warmer than a silk with a cotton back or rayon pile. Nylon pile is very resilient, resists waterborne stains, and is easily maintained.
For velvet dresses, dressmakers usually cut the fabric so that the pile runs up. The wearer then can appreciate the richness of the fabric by looking into the pile. Another reason for having the pile run up is that the pile is less likely to mat from friction. Velvet drapes well, especially when it is all silk, and looks effective in both tailored and feminine lines. Cotton velvet is stiffer and because of its bulkiness is generally more appropriate for sportswear than for lightweight dresses. Velvets and corduroys can be made spot-resistant and of durable press. Corduroys are frequently made water-repellent for raincoats. And there are some washable velvets.

In upholstery, pile fabrics look soft, cushiony, and inviting. Pile upholstery is warm-looking in summer and so may be covered with lighter fabric covers.

**The Care of Pile Fabrics:**

Upholstery pile fabrics should be brushed frequently with a soft brush. Brushing first against the pile and then with the pile will usually remove matted spots.

It is best to steam velvets and velveteens to remove creases and matted spots. A good way is to hang the fabric near the shower bath. Very hot water, hot enough to make steam, should be run from the shower for about ten minutes, but at no time should the fabric get soaking wet. When it is removed from the steam, it should be shaken gently and hung over a line (with the pile out) or on a hanger to dry. A garment should not be worn until the pile is thoroughly dry. Water spots can usually be removed by steaming, but other stains can best be removed by a reliable dry cleaner. Velvet that has rayon pile can be steamed the same way as silk velvet, but care should be taken not to shake it while it is wet. Two kinds of finishes are used on velvets: spot- and stain-resistant and crush-resistant. No problems are evidenced on the former type of finish; the latter may reflect light differently when pile is distorted. A steam brushing may cause the pile to resume its original erect position.

Velvets and velveteens may be steamed by still another method. Stand a hot iron upright on the ironing stand; place a damp cotton cloth over the iron to generate steam; pass the velvet slowly over the damp cloth, with the pile away from the cloth. Velvets should never be ironed flat.

The terry weave generally appears in towels, bath mats, and bathrobes. The fibres are usually cotton. Since the pile is uncut cotton yarn, the fabric washes well and should be fluffed, not ironed. The more loops on the surface of the fabric, the more absorbent the cloth. Bathmats may have rayon pile and cotton groundwork. While these fabrics are most attractive, their laundering quality and durability are questionable.

Frieze, an upholstery and drapery fabric, may be made in wool, nylon, mohair, and cotton. It is a very durable, uncut-pile fabric that dry-cleans satisfactorily, but since the dirt settles between rows of pile, frequent brushings are essential.
Main features of Flocked Fabric:

A surface effect that is similar to a nap or a pile may be created by flocking, a process in which short fibres are “glued” onto the surface of fabrics by an adhesive material. If the adhesive coats the entire surface of the fabric, the flocking will cover the entire surface of the fabric, but if the adhesive is printed onto the fabric in a pattern of some sort, the flock will adhere only in the printed areas. All-over flocked fabrics may have a suedelike appearance.

Short lengths of fibre flocking can be made from any generic fibre type. Rayon is often used for flocking. Nylon may be selected for situations that require good abrasion resistance.

Fibres for flocking are made from bundles of tow fibre (continuous filament fibres without twist). The tow is fed through a finish removal bath and then into a bank of cutters that cut flock of the desired length. The fibres may be dyed before they are attached to the fabric, or the completed fabric may be dyed.

Application of Flock to Fabrics:

The flock is applied to the fabric in one of two methods. The mechanical flocking process sifts loose flock onto the surface of the fabric to be coated. A series of beaters agitate the fabric, causing most of the fibres to be set in an upright position, with one end of each fibre “locked” into the adhesive.
The second method causes the fibres to be attached in an upright position by passing them through an electrostatic field. The fibres pick up the electric charge and align themselves vertically. One end penetrates into the adhesive, and the flock is formed. Electrostatic flocking ensures more complete vertical positioning, and the resultant fabrics are of better quality. It is a more costly process. When buying fabrics, a consumer cannot tell which process was used.

**Durability of Flocked Fabrics:**

The durability of flocked fabrics depends largely on the adhesives that hold the flock firmly during either laundering or dry cleaning. In some cases, flock may be removed by dry-cleaning solvents. Permanent care labels should tell the consumer how to handle flocked fabrics. A second factor in the durability of flocked fabrics has to do with the fibre from which the flock has been made.
Introduction:

The tufting technique is a very important technique for the production of floor covering material such as pile carpets. However, it is also applied for the production of e.g. blankets, toweling, coats and fur imitations.

Tufting consists in piercing yarns through a primary support fabric by means of needles in such a way that piles (cut or loop piles) are formed on the support fabric. After further treatment e.g. anchoring the pile by means of a precoat and applying a secondary backing a completely finished tufted carpet is obtained.

So, various elements can be distinguished in a tufted carpet:

1. The pile (either cut or loop),
2. The primary support fabric or primary backing,
3. The precoat (adhesive),
4. The secondary backing.

All these elements are represented in the following figure.

Basic elements in a Tufted Carpet:

1. Pile yarn:

Pile yarns for tufted carpets are usually made of man-made fibres. However, wool also takes a fairly important share. The man-made fibres are mostly the so-called Bulked Continuous Filament Yarns or BCF yarns. These bulked filament yarns are usually made
of polyamide, or sometimes polypropene or other man-made fibres. The pile yarn can contain metal or carbon fibres if antistatic properties are required.

A pile yarn should present the following properties:

- Be well wear resistant,
- Have good dyeing properties,
- Present good resilience,
- Difficult soilability,
- Easy cleanability (release of dirt particles).

Naturally, other important aspects which determine the choice of a pile yarn include resistance to micro-organisms and insects, moisture absorption capacity, hiding of dirt particles, soil resistance, electrostatic properties, flame resistance etc.

It goes without saying that the yarn should have sufficient and uniform strength so as to avoid as many breakages, and hence machine stops, as possible. Moreover, threading of the yarn through the needle eyes requires a uniform cross-section and therefore regular thickness. Knots in the yarn must be avoided. Hence, yarns must preferably be joined with latex or by air (splicers).

2. Support fabric (primary backing):

During tufting, pile yarn is stitched through a support fabric (or primary backing). It can either be a woven fabric or a non-woven (actually, a spinning fleece). Fabrics include jute, polyester filament yarn or staple fibre, polypropene tapes, glass fibres etc. Non-wovens are mainly based on polyester and polypropene (sometimes blended with polyethylene).

Whilst before the fabric was almost always based on jute, nowadays this has almost completely disappeared. Indeed, jute contains oils which can penetrate the pile and thus cause soiling and problems when dyeing. Also, jute is less rot resistant and therefore subject to micro-organisms.

Polypropene is an important substitution product for jute. Fabrics made of polypropene tapes, usually in plain weave, have a mass of 80 to 150 g/m². These are thin fabrics, which can easily be pierced and are suited for all needle gauges. Such material is dimensionally stable, but is sensitive to high temperatures (> 170°C). Fraying at the border can be avoided by applying a butyl coating on the warp and weft threads. Examples of such fabrics of polypropene tapes are polybac, polital etc. Polybac FLW is also a fabric made of polypropene tapes but with a nylon cap needled on it. When dyed, the colour difference between the polypropene and the pile yarns will be masked by the application of this nylon fleece since nylon takes up dyestuff more readily than polypropene. Fuzzback is another example of such a construction.

Fabrics made of polyester filament yarn consist of highly shrinkable yarns of 1,100 dtex and with a weight up to approx. 120 g/m². Such fabrics are strong, not sensitive to
temperature differences, can be stretched well, are not thick and can easily be pierced. An example is the TTT-fabric by Hoechst (Trevira-Tufting Träger). Some disadvantages include less favourable pile anchoring, a tendency towards bowing (also in case of polypropene fabrics) and the fact of not being suited for all stitch gauges.

Apart from woven fabrics, there are the non-woven such as spun-bonded fabrics made of polypropene. An example is Typar (Du Pont) which is suited for all gauges and has no tendency towards bowing. As mentioned above, this material is sensitive to high temperatures and cannot be stretched well. Further, there are the non-wovens made of staple fibres, e.g. Loktuft. It can be strengthened with polyamide yarns. The fibre fleece weight ranges between 90 to 190 g/m². Non-wovens present little or no resistance to the needle when piercing. This furthers uniform pile height and placing of the loops (tufts).

A non-woven used for the primary backing can also be based on polyester filaments. For example, Reemay and Tyvek by Du Pont with a mass up to 120 g/m². Such non-wovens are suited for all stitch gauges, give good pile anchoring and present no tendency towards bowing. These non-wovens are fairly sensitive to temperature changes, are difficult to stretch and are not cheap.

3. Precoat:

The pile which is applied on the primary backing, must be anchored during a following operation. Such anchoring improves the dimensional stability, gives better sound and heat insulation, good shear resistance, etc. Anchoring is done by applying a precoat. This is either a latex (natural or synthetic rubber) or a dispersion on the basis of polyvinylacetate, polyvinylchloride, polyurethane or polyacrylate. In many cases, a rubber is used as precoat. After applying the dispersion, the latex must be polymerized at the appropriate temperature and with the appropriate means (initiators, catalysts, etc.).

When applying the precoat, a conductive material (carbon) can be added to it, even if measures had already been taken to make the pile layer conductive. Sometimes, even a flame resistant product is added.

4. Secondary backing:

After this (first) precoat, a second layer or foam coating can be applied, i.e. the secondary backing, which enhances comfort, strength and dimensional stability of the whole. Applying this layer is done in a continuous process after applying and polymerizing the first layer. Mostly, this is a latex of synthetic rubber to which a large amount of fillers (e.g. chalk = CaCO₃) is added. The material to be applied forms a 'foam'. Applying the right temperature in an oven causes polymerization and hence formation of the secondary backing.
Before the secondary backing is fully cured, it can be treated with an engraved calendar roller which gives an embossed pattern. So, the plastic condition of the material at that moment is used here. An embossing gives extra resilience and anti-slip capacity. Subsequently, definitive curing is carried out: approx. $140^\circ C$ for a rubber latex and approx. $180^\circ C$ for a polyvinylchloride foam backing.

A jute fabric can also be applied (glued) as secondary backing, possibly a spun-bonded based on polyolefin filaments. An example is Action Bac (Amoco Fabrics and Fibre Company). Further, there is also Millibac (Milliken): the basis is a glass fibre to strengthen a vinyl-based precoat. Another possibility is TTC (Thiocol Ten Cate).

**Tufting process:**

Tufting consists in piercing a yarn through a primary backing by means of needles (on a needle bar). A loop is formed at the bottom side of the support fabric when the looper comes into operation with the yarn when the needle returns. Eventually, the loop may be cut which gives a cut pile tufted carpet in contrast to a loop pile tufted carpet (not cut).

The working of a simple tufting machine is described as follows. The movement of the needles, which must pierce the pile yarn through the primary backing, is controlled by the head shaft with eccentric discs, via crank shafts and pressure shafts. The fine needles, which are mounted on the needle bar, are given an up and downward movement. The pile yarn is supplied constantly and regularly via the feed rollers. The primary backing (substrate) is fed by spiked roller.

![Tufting process diagram](image)

Making a tufted carpet with closed (short-loop) pile

If the needles pierce through the primary backing, the resulting loops must be held under the support fabric by the loopers fixed on a shaft. The distance between the loopers and the support fabric determines the desired pile height. The tension device of the pile yarn keeps the pile backs close to the bottom side of the primary backing.

If the support fabric or non-woven passes over the reed plate (or support table), the loopers withdraw and the loops come free. The needles with the pile yarn which pierce through the backing, move up again and the loopers return in the pile loops formed: this gives a loop or closed pile carpet.
Making a tufted carpet with open or cut pile

When making a carpet with cut pile, the loopers are in a direction opposite to the one above (loop pile). Here too, a support fabric passes over the reed plate while the needles with the pile yarn pierce through the substrate. The loops formed lie over the looper and must be cut by means of inclined knives moving up and down.

The following figure gives a schematic representation of the formation of a tufted carpet with cut pile.

The pile height of a tufted carpet depends on the delivery of the pile yarn, the length of the needles and the distance between the primary backing and the loopers. The pile height ranges from 3mm to over 40mm. A high cut pile is applied for so-called shag carpets. In case of a non-cut pile, pile height reaches approx. half the height of that of a shag carpet.

An important concept on a tufting machine is the gauge: i.e. the distance between two successive needle points expressed in inches. The gauge determines, for example, the pile
density. The gauge most often used is $\frac{5}{32}$ inch; $\frac{1}{8}$ inch is also a frequently used gauge. Machines with a fine gauge often have a gauge of $\frac{1}{10}$ inch, $\frac{1}{12}$ inch or even $\frac{1}{20}$ inch. These machines are used, for example, for fine carpets with loop pile for the 'object market' as in nursing homes, hospitals, hotels, schools, supermarkets, etc. Sometimes they are also used for blankets, fur imitation, toweling, etc.

**Major Tufted Carpet Construction:**

Tufted carpet with loop pile  
Tufted carpet with cut pile  
Tufted carpet with high-low structure  
Tufted carpet with low loop pile and high cut pile  
Tufted carpet with high loop pile and low cut pile  
Tufted carpet with level-sheared pile  
Level loop  
Velvet plush  
saxony  
Cut and loop

**Other End Uses for Tufted Fabrics:**

Some tufted fabric is made in light weights for use as apparel fabric and home furnishings such as bedspreads and upholstery. The tufted bedspreads often resemble traditional chenille bedspreads; the upholstery fabrics have the appearance of woven velvet. Tufted fabrics can also be used for automobile interiors. Blanket fabric can be constructed by forming loops on both sides of a base fabric and then cutting and often napping the loops to create the blanket's surface texture. Tufted blankets have been more popular in Europe than in the United States.

**Care of Tufted Fabrics:**

Care of tufted fabrics that can be safely and conveniently cleaned at home depends on the fibre type used, the closeness or looseness of the pile or tufts, the type of yarn structure (simple or complex), the presence or absence of an adhesive binder on the back of the fabric, and the size of the article. Most tufted fabrics found in household articles or apparel that are small enough to fit into home laundry equipment are washable. However, where care labels are provided, it is essential to follow all directions carefully.
KNITTED FABRIC AND KNITTING TECHNOLOGY
INTRODUCTION

AND

HISTORICAL BACKGROUND OF KNITTING TECHNOLOGY

Knitted fabric differs vastly from woven fabrics. Woven fabric is formed substantially by interlacing of a series of lengthwise and crosswise threads. Knitting, in its simplest form, consists in forming loops through those previously formed. This interloping and the continuous formation of more loops into each other produce the knitted fabric structure. In machine knitting, a multiplicity of needles, needle holders and yarn feeders replace the pins, hand and fingers used in hand knitting.

Knitting is the method of creating fabric by transforming continuous strands of yarn into a series of interlocking loops, each row of such loops hanging from the one immediately preceding it. The basic element of a knit fabric structure is the loop intermeshed with the loops adjacent to it on both sides and above and below it.

Knitted fabrics are divided into two main groups, weft and warp knitted fabrics.

The weft knitted structure is very different from the warp knitted one. The difference is apparent from both warp and weft knitted structures are shown in simplest forms in below. It is seen from this figure that in a weft knitted structure a horizontal row of loops can be made using one thread and the thread runs in horizontal direction.
In a warp knitted structure, each loop in the horizontal direction is made from a different thread and the number of threads used to produce such a fabric is at least equal to the number of loops in a horizontal row. One can say that in a warp knitted fabric the threads run roughly in a vertical direction.

The knitting industry belongs to the branches of the textile industry with long tradition and the knitted goods have been known for centuries. In the early days they were made by hand and the first hand operated knitting machine was not invented until the sixteenth century. This invention is usually attributed to a certain English clergyman (1589) William Lee. Since that time knitting machines have been developed and redesigned so that nowadays they present the most complicated and most automated machinery in the textile industry.

A skilled hand knitter produced 120 to 150 stitches per minute. In comparison, a modern high speed circular knitting machine makes about 20 million stitches per minute.

1589: William Lee, the inventor of the mechanical stitch formation technique.

1758: Jedediah Strutt, the inventor of the double knit (rechts – rechts) technique. This invention refers to an attachment for the hand knitting frame, which became world famous under the name “Derby rib machine”.

1798: Monsieur Decroix arranges the needles radially into a corona, which rotates and thus moves the needles one after the other through the knitting stages. The circular knitting frame is born.

1805: Joseph Marie Jacquard presented his control apparatus for shed building on weaving looms in Lyon. It is not clear as to when Jacquard started getting interested in the problems of the knitting industry after his success in the weaving field. But today we do encounter the jacquard device in different variations on knitting machines for the same purposes: individual movement of knitting and transfer needles, sinkers or guide needles for patterning.
1847: Matthew Townsend obtains a patent for his invention of the latch needle. A new epoch in the knitting technique begins. With the help of these needles stitch formation became easier, because the press was no longer necessary. The result was: simplification of the mechanism, increase in production speeds, and reduction of costs.

1850: The circular knitting machine has been developed from the English circular knitting frame. It was initially equipped with stationary bearded needles in vertical position. Later on, it was built with latched needles, which can be individually moved; this is characteristic for a circular knitting machine.

1852: Theodor Groz. Opened his workshop in Ebingen in the Swabian Alb and Ernst Beckert started making needles in Chemnitz. Both of them wanted to assist the manufacturers of knitted stockings by presenting them with needles, which would not get bent or broken. This meant that the needles were no longer made from iron but from steel. Today the concern Groz – Beckert delivers exactly adapted needles for every kind of knitting machine.

1878: D. Griswold gets a patent for a circular knitting machine, which can produce plain or ribbed fabric tubes in any desired distribution. The vertical cylinder needles are enhanced by horizontal dial needles, also individually moveable in radial slots. This leads for the first time to two new denotations: small rib machine and large rib machine.

1910: The firm Robert Walter Scott in Philadelphia was granted a patent for “interlock fabrics”. The interlock fabric is a double faced fabric composed of two crossed double knit fabrics.

1918: The first double cylinder, small circular knitting machine with a double hook needle and sliders (needle pushers) was built in England by the firm Wildt.

1920: Besides flat knitting machines, increasing use is made of circular knitting machines for the fabrication of colour patterned fabrics. This is done with the help of yarn changer devices and needle selection via pattern wheels and punched tapes made from steel or paper.

1935: After the production of circular sinker wheel machines was started in 1906, the firm Mayer & Cie. began producing circular knitting machines. Mayer & Cie. introduced mass-line production of these machines in 1939.

1946: After this period notable further developments were made in circular knitting with regard to higher performance and new products as a result of an increase in feeder numbers, a raise in the production speeds and the use of new needle technologies. The old pinion feed wheel units were replaced by new yarn delivery devices like tape feeders and measuring meters with yarn reserve for smooth fabrics and knit patterns as well as storage feeders for jacquards. These new devices have increasingly taken over the control and monitoring of yarn delivery. Such peripheral equipment is continually gaining significance in order to cope up with the demands placed on high speed circular knitting machines and fabric quality.

1963: The era the electronics begins at the International Textile Machinery Exhibition ITMA 1963 in Hanover. The first electronic needle selection is demonstrated by the firm Morat on its
film-taper-controlled "Moratronik", which later on gets into serial production. Today a computer is used for data storage and a diskette is the data carrier.

1967: The legendary OVJA 36, which is probably world-wide the most successful circular knitting machine so far, is exhibited at the ITMA in Basle. More than 7000 machines of this type were built in the following years.

1987: The firm Mayer & Cie begins with the serial production of the RELANIT, a plain (rechts-links) circular knitting machine having a relative movement between needles and sinkers. It will be producing more than 1000 machines till the ITMA 1991.

Modern circular knitting technology will be determined by increases in performance, reductions in setting-up times and flexible utilization. The technical designer will have to deal with this challenge now and in the future.

Knitting is the most common method of interloping and is second only to weaving as a method of manufacturing textile structures. It is estimated that over seven million tons of knitted goods are produced annually throughout the world. Although the unique capability of knitting to manufacture shaped and form-fitting articles has been utilized for centuries, modern technology has enabled knitted constructions in shaped and unshaped fabric form to expand into a wide range of apparel, domestic and industrial end-uses.

Knitted fabrics of a wide variety of types are presently enjoying unprecedented consumer demand. In many end-uses, where formerly woven fabrics held undisputed away, knitted cloth has taken a commanding lead, while in those end-uses where the knitted fabric traditionally has been supreme, production advanced by leaps and bounds.

To most people, knitted fabric is somewhat of an unknown quantity. Few people can distinguish it readily from woven fabrics; fewer still have any conception how it is produced.
GENERAL TERMS RELATED TO KNITTING TECHNOLOGY

Kink of yarn:
A length of yarn that has been bent into a shape appropriate for its transformation into a weft knitted loop.

Knitted loop:
A kink of yarn that is intermeshed at its base i.e. when intermeshed two kink of yarn is called loop.

Knitted stitch:
Stitch is a kink of yarn that is intermeshed at its base and at its top. The knitted stitch is the basic unit of intermeshing and usually consists of three or more intermeshed loops, the centre loop having been drawn through the head of the lower loop which had in turn been intermeshed through its head by the loop which appears above it.

Top arc:
The upper curved portion of the knitted loop is called top arc.

Bottom half-arc:
The lower curved portion that constitutes in a weft knitted loop, half of the connection to the adjacent loop in the same course.

Legs or side limbs:
The lateral parts of the knitted loop that connect the top arc to the bottom half-arcs.
**Needle loop:**
The needle loop is the simplest unit of knitted structure. Needle loop formed by the top arc and the two legs of the weft knitted loop

\[ \text{Needle loop} = \text{Top arc} + \text{Two legs} \]

**Sinker loop:**
The yarn portion that connects two adjacent needle loops belonging in the same knitted course. Bottom arc also called sinker loop.

**Open loop:**
A knitted loop of which a thread enters and leaves at the opposite sides without crossing over itself.

**Closed loop:**
A knitted loop of which a thread enters and leaves at the opposite sides with crossing over itself. It is made by special needle.

**Knitted loop structure:**
The properties of a knitted structure are largely determined by the interdependence of each stitch with its neighbours on either side and above and below it. Knitted loops are arranged in rows and columns roughly equivalent to the weft and warp of woven structures termed “courses” and “wales” respectively.
Course:

A course is a predominantly horizontal row of loops (in an upright fabric) produced by adjacent needles during the same knitting cycle.

In weft knitted fabrics a course is composed of yarn from a single supply termed a course length. A pattern row is a horizontal row of cleared loops produced by one bed of adjacent needles. In a plain weft knitted fabric this is identical to a course but in more complex fabrics a pattern row may be composed of two or more course lengths.

In warp knitting each loop in a course is normally composed of a separate yarn.

Wale:

A wale is a predominantly vertical column of needle loops produced by the same needle knitting at successive knitting cycles and thus intermeshing each new loop through the previous loop. In warp knitting a wale can be produced from the same yarn if a warp guide laps around the same needle at successive knitting cycles thus are making a pillar or chain stitch lapping movement. Wales are joined to each other by the sinker loops or underlaps.

Stitch density:

The term stitch density is frequently used in knitting instead of a linear measurement of courses or wales, it is the total number of needle loops in a square area measurement such as a square inch or square centimeter. It is obtained by multiplying, for example, the number of courses and wales, per inch together. Stitch density tends to be a more accurate measurement because tension acting in one direction in the fabric may, for example, produce a low reading for the courses and a high reading for the wales, which when multiplied together cancels the effect out. Usually pattern rows and courses are, for convenience, considered to be synonymous when counting courses per unit of linear measurement.

\[
\text{Stitch density} = \text{Wales per inch (wpi)} \times \text{Courses per inch (cpi)}. \]

Intermeshing points or cross over point of a needle loop:

All needle loops or overlaps have four possible intermeshing or cross-over points, two at the head, where the next new loop will be drawn through by that needle and another two at the base where the loop has intermeshed with the head of the previously formed loop. Any one of the four points at which stitches are intermeshed. The intermeshings at the head are always identical with each other as are intermeshings at the base with each other.
It is impossible to draw a new loop through the old loop so that its two feet are alternately intermeshed. A new loop can thus only be intermeshed through the head of the old loop in a manner which will show a face loop stitch on one side and a reverse loop stitch on the other side, because the needle hook is unidirectional and can only draw a new loop down through an old loop. Bottom cross-over point is situated at the base and top cross-over point is situated at the head.

**Loop or Stitch length:**

The length of yarn knitted into one stitch in a weft knitted fabric. Stitch length is theoretically a single length of yarn which includes one needle loop and half the length of yarn (half a sinker loop) between that needle loop and the adjacent needle loops on either side of it. Generally, the larger the stitch length the more elastic and lighter the fabric, and the poorer its cover opacity and bursting strength.

\[
\text{Stitch Length, } l = \text{one needle loop} + \text{two half a sinker loop.}
\]

**Extended sinker loop:**

A sinker loop that is wider than the other sinker loops in the fabric and that is produced when a needle is inactive or has been removed from the needle bed or needle bar.

**Face loop or stitch:**

Also called plain stitch or jersey stitch or flat stitch. A stitch that is so intermeshed in the fabric that its legs are situated above the top arc of the stitch formed in the same wale in the previous course. This side of the stitch shows the new loop coming through towards the viewer as it passes over and covers the head of the old loop. Face loop stitches tend to show the side limbs
or legs of the needle loops or over laps as a series of interfitting “V’s”. The notation of the face loop is ⬜ and by graph paper is ⨯.

**Technical face or right side:**

The under surface of the fabric on the needles will thus only show the face stitches in the form of the side limbs or legs of the loops or over laps as a series of interfitting “V’s”.

![Technical face and Technical back](image)

**(a) Technical face**

**(b) Technical back**

**Reverse or back loop or stitch:**

Also called purl stitch. A stitch that is so intermeshed in the fabric that the top arc and the bottom arcs are situated above the legs of the stitch formed in the same wale in the previous and in the following course. This is the opposite side of the stitch to the face loop side and shows the new loop meshing away from the viewer as it passes under the head of the old loop. Reverse stitches show the sinker loops in weft knitting and the under laps in warp knitting most prominently on the surface. The reverse loop side is the nearest to the head of the needle because the needle draws the new loops downwards through the old loops. The notation of back loop is ⬜ and by graph paper is O.

**Technical back or left side:**

The upper surface of the fabric on the needles will only show reverse stitches in the form of sinker loops or under laps and the heads of the loops.

**Double thread stitch:**

Also called double loop stitch or spliced stitch. A stitch formed from two ends of yarn.
Single faced structures:
Single faced structures are produced in warp and weft knitting by the needles (arranged either in a straight line or in a circle) operating as a single set. Adjacent needles will thus have their hooks facing towards the same direction and the heads of the needles will always draw the new loops downwards through the old loops in the same direction so that intermeshing points 3 and 4 will be identical with intermeshing points 1 and 2.

![Technical face side](image1)
![Technical back side](image2)

Double faced structures:
Double faced structures are produced in weft and warp knitting when two sets of independently controlled needles are employed with the hooks of one set knitting or facing in the opposite direction to the other set. The two sets of needles thus draw their loops from the same yarn in opposite directions, so that the fabric, formed in the gap between the two sets, shows the face loops of one set on one side and the face loops of the other set on the opposite side. The two faces of the fabric are held together by the sinker loops or under laps which are inside the fabric so that the reverse stitches tend to be hidden.

Balanced structure:
This is a double faced structure which has an identical number of each type of stitch produced on each needle bed and therefore showing on each fabric surface usually in the same sequence. These structures do not normally show curling at their edges.

Face and reverse stitches on the same surface:
These are normally produced on purl weft knitting machines which have double headed needles capable of drawing a face stitch with one hook and a reverse stitch on the other, so that intermeshing points 3 and 4 will not always be identical with intermeshing points 1 and 2.
Fabric draw-off:

Fabric is always drawn from the needles on the side remote from their hooks. When two sets of needles are employed, either arranged vertically or at some other angle to each other, each set of hooks will face away from the other set and the fabric will be produced and drawn away in the gap between the two sets.

Knitting machines:

The machines those produced fabrics by intermeshing or interloping of one or one set of yarn. Knitting machines are divided as follows:

- **Weft knitting machine:**
  A machine producing a knitted fabric by intermeshing loops formed successively across the width of the fabric from a yarn fed substantially crosswise to the length of fabric.

- **Warp knitting machine:**
  A machine in which the fabric formation occurs by interlacement of loops formed simultaneously across the full width of the fabric from a system of yarns which are fed to the needles substantially in the direction of the length of fabric.

- **Other loop forming and combined technique machines:**
  Machines that form the fabric by the technique of intermeshing of yarn loops but which cannot be defined either as weft or as warp knitting machines.

Needles:

Needle is the principal knitting element. Needles are divided into two categories according to their functions as follows:

- **Independent needles:**
  Needles which can slide in the needle bed and be moved individually during the stitch or loop forming process.

- **United needles:**
  Needles which are fixed in the needle bar and which can only be moved in unison during the stitch or loop forming process.
Needle carrier:

A part of the knitting machine containing independently moved needles in a needle bed or united needles in a needle bar. The needle carrier may be flat or circular, cylindrical or dial type.

Fabric face type:

The basic type of construction of fabrics produced on the respective knitting machines:

- **RL:** Single face fabric, also called right – left fabric; knitted on one row of needles.
- **RR:** Double face fabric, also called right – right or double right fabric; knitted on two rows of needles.
- **LL:** Links – links fabric, also called left – left or double left fabric; knitted on one or two rows of needles.

Number of feed system:

On the circumference of a circular knitting machine up to 120 knitting cam sets can be mounted, each cam set fed with a separate yarn. This results in obtaining 120 knitted loop courses in one machine revolution.

\[
\text{Number of feeders} = \text{Number of courses}
\]

Specification of knitting machine:

The needle beds and needle bars, and thus the knitting machines, are specified with three features, namely:

- The working diameter (Circular needle beds and needle bars)
  
  Or The working width (Flat needle beds and needle bars)

- The needle gauge or needle pitch.
• The working diameter:
The diameter of a knitting machine is measured at the bottoms of two opposite needle grooves in a cylinder or at the tops of two opposite needles in a circular bar, and is usually expressed in inches.

• The working width:
The working width of the machine should not be miss used with the "actual working width". The working width of a knitting machine is a measure (in cm or inches) describing the distance between the first and last needle in a flat needle bed, whilst the "actual working width" is the distance between the first and last needle actually used in the needle bed during knitting.

• Machine or needle gauge:
The needle gauge of a knitting machine (also called cut or gage) is a measure expressing the number of needles per a unit of the needle bed (bar) width.

\[
\text{Gauge, } N = \frac{\text{Number of needles}}{\text{One English inch}}.
\]

Highest needle gauge is about 60 and lowest needle gauge is about 2 to 2.5.

The needle pitch is the distance between two neighbouring needles in the same needle bed (bar), from the centre of a needle to the centre of the neighbouring needle.

Relationship between the needle gauge and the needle pitch is as follows:

\[
\text{Needle pitch (Length units / needle)} = \frac{1}{\text{Needle gauge (length unit)}}
\]

The pitch or distance between one needle and another is proportional to the needle gauge or
around a given machine diameter (for example 30") so therefore coarser gauge machines often have fewer feeders.

**Selvedged fabric:**

A selvedged fabric is one having a “self – edge” to it and can only be produced on machines whose yarn reciprocates backwards and forwards across the needle bed so that a selvedge is formed as the yarn rises up to the next course at the edge of the fabric.

**Cut edge fabric:**

Cut edge fabric is usually produced by slitting open a tube of fabric produced on a circular machine. A slit tube of fabric from a 30” diameter machine will have an open width of 94” (πd) at knitting and before relaxation.

**Tubular fabric:**

This may be produced in double faced or single faced structures on circular machines, or in a single faced form on straight machines with two sets of needles provided each needle set only knits at alternate cycles and that the yarn only passes across from one needle bed to the other at the two selvedge needles at each end, thus closing the edges of the tube by joining the two single faced fabrics produced on each needle set together.

**Warp knitted laps:**

Loops are termed laps in warp knitting because the guides lap the warp yarn around the needles in order to form the loops, the laps may be either open or closed. So, lap is a length of yarn in a warp knitted fabric that consists of an overlap and of an underlap.

**Open lap:**

An open lap is produced either when the underlap is in the same direction as the overlap, or it is omitted so that the next overlap commences from the space where the previous overlap finished. Closed laps are heavier, more compact, opaque and less extensible than open laps produced from the same yarn and at a comparable knitting quality.

![Open lap](image)

![Closed lap](image)

![Overlap, Underlap](image)
Closed lap:
A closed lap is produced when an underlap follows in the opposite direction to the overlap and thus laps the thread around both sides of the needles.

The overlap:
The overlap is a shog usually across one needle hook by a warp guide which forms the warp yarn into the head of the loop. The swinging movement of the guide to the hook side and the return swing after the overlap produce the two side limbs or legs of the loop which has a very similar appearance on the face side of the fabric to a needle loop produced by weft knitting. So, overlap is a length of yarn in a warp knitted fabric that has been placed over the needle during loop formation.

The underlap:
The underlap shog occurs across the side of the needles remote from the hooks, on the front of single bar and in the centre of double bar needle machines, it supplies the yarn between one overlap and the next. So, underlap is a length of yarn in a warp knitted fabric that connects two overlaps in consecutive courses.

Underlaps as well as overlaps are essential in all warp knitted structures in order to join the wales of loops together, but they may be contributed by a different guide bar to those for the overlaps.
Basic elements of knitting:

There are three basic elements of knitting, such as needle, cam and sinker. This chapter deals with the features, functions, uses etc. of these knitting elements and also focus the principles of knitting based on these elements as follows.

The Needles:

The fundamental element in construction of knitted fabrics is the knitting needle. Needle is the main knitting tools and also the principal element of machine knitting. During yarn feeding the hook is opened to release the retained old loop and to receive the new loop which is then enclosed in the hook. The new loop is then drawn by the hook through the old loop which slides on the outside of the bridge of the closed hook. All needles must therefore have some method of closing the needle hook to retain the new loop and exclude the old loop.

There are hundreds and hundreds of different shapes of knitting needles used for production of knitted loops but all of them can be grouped in three main needle types:

- The spring-bearded needles
- The latch needles and
- The compound needles.

- The Spring-Bearded Needles:

  The spring-bearded needles made of steel wire consist of the following parts:
  a. The Stem: The stem around which the needle loop is formed.
  b. The Head: Where the stem is turned into a hook to draw the newloop through the old loop.
  c. The Beard: Which is the curved downwards continuation of the hook that is used to separate the trapped new loop inside from the old loop as it slides off the needle beard.
  d. The Eye or groove: Cut in the stem to receive the pointed tip of the beard when it is pressed, thus enclosing the new loop.
The latch needle is the most widely used needle in weft knitting, because it is self – acting or loop controlled. It is also regarded as more versatile in terms of the range of materials that can be processed on latch needle machines. Bearded needles are less expensive to manufacture, can be produced in finer gauges and supposedly knit tighter and more uniform stitches compared with latch needles, but have limitations with regard to the types of material that can be processed as well as the range of structures that can be knitted on them. Bearded needle machines are faster than the equivalent latch needle machines. The compound needle has a short, smooth and simple action, and because it requires a very small displacement to form a stitch in both warp and weft knitting, its production rate is the highest of the three main types of needle. Compound needles are now the most widely used needles in warp knitting and a number of manufacturers also offer circular machines equipped with compound needles. The operation speeds of these machines are up to twice those of the equivalent latch needle machines.

The main parts of the bearded, latch and compound needle are describe and shown in the above figures respectively. Variations of latch needles include rib loop transfer needles and double – ended purl needles, which can slide through the old loop in order to knit from an opposing bed thus draw a loop from the opposite direction.

**Friction and Frictionless Needles:**

There are two types of latch needle, friction and frictionless. Friction needles have a slight flex, cramp or bend in the tails so that they contact the side – walls of the tricks in which they are housed. They are used in open cam systems where cams may be introduced or taken out of action to divert the needle path.

Frictionless needles are employed in closed cam – tracks which have guard or safety cams on the opposite side to the knitting cams, to produce a completely enclosed track through which the needles run, otherwise the freely moving needles would be thrown out of their tricks at high speed.

**The Needle Bed:**

The needles are disposed in the slots of needle beds which can be flat or circular (dial and cylinder), or mounted on the needle bars. A flat needle bed consists of a steel plate with grooves. In the grooves the latch needles are inserted in such a way that their butts protrude above the plane of the steel plate. From below in the grooves, the needles are supported with special springs. Upper part of the flat needle bed is shaped in milled – off teeth helping in the process of stitch formation.

In a cylindrical needle bed the knitting needles are placed between the tricks inserted in cuts along the cylinder surface generator. The dial needle beds have the needle grooves cut radially i.e. horizontally. The butts of the needles in circular needle beds, both cylinder and dial, protrude from their surfaces. Thanks to the needle butts the needles can be driven along their grooves by cams located in cam boxes.
d. The Rivet: Which may be plain or threaded. This has been dispensed with on most plate metal needles by pinching in the slot walls to retain the latch blade.
e. The Slot or Saw cut: Which receives the latch blade.
f. The Cheeks or Slot walls: Which are either punched or riveted to fulcrum the latch blade.
g. The Butt: Which serving to displace the needle along the needle bed slot. The butt which enables the needle to be reciprocated when contacted by cam profiles on either side of it forming a track. Double-ended purl type needles have a hook at each end, whilst one hook knits, the inactive hook is controlled as a butt by a cam reciprocated element called a slider.
h. The Tail: Which is an extension below the butt giving additional support to the needle and keeping the needle in its trick. Sometimes used for the same purpose as the butt.

• The Compound Needles:

The compound needles are used in weft and warp knitting machines. In contrast to standard spring-bearded needles and latch needles the compound needle consists of two separate parts—the stem and the sliding latch. At the top of the compound needle stem there is a hook. The two parts rise and fall as a single unit but at the top of the rise the hook moves faster to open and at the start of the fall the hook descends faster to close the hook.

The compound needle stem can be made of a U-shaped steel wire or of a steel tube. The sliding latch (closing element) is made of a steel wire. During the cycle of loop or stitch formation the sliding latch slides along the groove of the U-shaped stem or in the tube-shaped stem. Prior to mounting onto a warp knitting machine the stems and latches of the compound needles are cast in leads (separately, in stem leads and latch leads).
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The Cams:

Cam is the second primary knitting element. The cams are the mechanical devices which convert the rotary machine drive into a suitable reciprocating action for the needles or other elements. Because all needles have a reciprocating action either serially or seriatim, except on the bearded needle sinker wheel and loop wheel frames where the fixed needle circle merely revolves. The cams are carefully profiled to produce precisely-timed movement and dwell periods.

The cams are of two types, Engineering cams and Knitting cams.

- **Engineering Cam:**
  
  It is circular cam. This circular engineering cams or high speed eccentrics indirectly control the motion of bars of elements which move en masse as single units in cottons Patent and warp knitting machines. They are attached to a rotary drive shaft situated parallel to and below the needle bar. A number of identical cams are positioned along the shaft to ensure correctly aligned movement. The drive is transmitted and adapted via cam – followers, levers, pivots and rocker shafts. One complete 360 – degree revolution of the drive shaft is equivalent to one knitting cycle and it produces all the required movements of the elements once only in their correct timing relationship.

  In warp knitting machines, four types of cam drive have been employed:

  a. Single acting cams
  b. Cam and counter cams
  c. Box cams, and
  d. Contour cams.

  a. Single acting cams: This type requires a powerful spring to negatively retain the cam truck or follower in contact with the cam surface, bounce and excessive wear occurs at speed.

  b. Cam and counter cams: This arrangement provides a cam and its follower in each direction of movement but is obviously more expensive to manufacture.

  c. The box or enclosed cams: This employs a single cam follower which is guided by the two cam races of a groove on the face of the cam. However, change of contact from one face to the other causes the follower to turn in the opposite direction producing wear which cannot be compensated.

  d. The contour, ring or pot cams: It is the reverse of the box cam as the cam profile projects out from one face of the cam in the form of lip with a cam – follower placed on either side of it. This is a popular and easily adaptable arrangement.

Although cams are comparatively cheap, simple and accurate, at speeds above 800 courses per minute they are subject to excessive vibration. For this reason, at speeds in excess of that Eccentric drive is now employed.
Eccentric:

The eccentric is a form of crank which provides a simple harmonic movement with smooth acceleration and deceleration. Its wide spread use is the result of adapting this simple motion and modifying it to the requirements of the warp knitting machine so that even dwell (stationary periods) in the element cycle can be achieved. Now, however, the simpler single eccentric drive is successfully driving element bars at speeds of 2000 courses per minute or more.

• Knitting Cam:

The angular knitting cam acts directly on to the butts of needles or other elements to produce individual or seriatim movement in the tricks of latch needle weft knitting machines as the butts pass through the stationary cam system (revolving cylinder machines) or the cams pass across the stationary tricks (reciprocating cam box flat machines or rotating cam – box circular machines).

On weft knitting machines, yarn feeds must move if the cams move, in order to supply yarn at the knitting point, and if the cam - boxes rotate the yarn packages and tackle must rotate with them. If, however, the yarn carriers reciprocate as on flat machines their yarn supply packages may be situated in a suitable stationary position.

Knitting cams are attached either individually or in unit form to a cam - plate and, depending upon machine design, are fixed, exchangeable or adjustable.

The knitting cams are divided in to three groups, such as knit cam, tuck cam and miss cam. At each yarn feed position there is a set of cams (mainly knit cam) consisting of at least a raising or clearing cam, a stitch or lowering cam, guard cam and an up throw cam whose combined effect is to cause a needle to carry out a knitting cycle if required. On circular machines there is a removable cam section or door so that knitting elements can be replaced.
a. The Raising Cam: This causes the needles to be lifted to either tuck, clearing loop transfer or needle transfer height depending upon machine design. A swing cam is fulcrummed so that the butts will be unaffected when it is out of the track and may also be swing into the track to raise the butts. A bolt cam can be caused to descend into the cam track and towards the element tricks to control the butts or be withdrawn out of action so that the butts pass undisturbed across its face, it is mostly used on garment – length machines to produce changes of rib.

b. The Stitch Cam: It controls the depth to which the needle descends thus controlling the amount of yarn drawn into the needle loop, it also functions simultaneously as a knock – over cam.

c. The Up throw Cam: It takes the needles back to the rest position and allows the newly – formed loops to relax. The stitch cam is normally adjustable for different loop lengths and it may be attached to a slide together with the upthrow cam so that the two are adjusted in unison. In the above figure there is no separate upthrow cam, section X – of the raising cam is acting as an upthrow cam.

d. The Guard Cam: These are often placed on the opposite side of the cam – race to limit the movement of the butts and to prevent needles from falling out of track.
The Sinkers:

The sinker is the third primary knitting element. It is a thin metal plate with an individual or collective action approximately at right angles from the hook side between adjoining needles.

Functions of Sinkers:

It may perform one or more of the following functions dependent upon the machines knitting action and consequent sinker shape and movement:

- Loop formation
- Holding – down and
- Knocking – over.

According to these functions the sinkers are also divided into three groups, such as loop forming sinker, holding-down sinker and knocking-over sinker.

- The first function of the sinker is loop formation. On bearded needle weft knitting machines of the straight bar frame and sinker wheel type the main purpose of a sinker is to sink or kink the newly laid yarn into a loop as its forward edge or catch advances between the two adjoining needles. On the bearded needle loop wheel frame, the blades of burr wheels perform this function whereas on latch needle weft knitting machines and warp knitting machines, loop formation is not a function of the sinkers.
- A second and more common function of sinkers on modern machines is to hold down the old loops at a lower level on the needle stems than the new loops which are being formed and prevent the old loops from being lifted as the needles rise to clear them from their hooks. The protruding nib or nose of the sinker is positioned over the sinker loops of the old loops preventing them from rising with the needles.
On tricot warp knitting machines and single bed weft knitting machines, a slot or throat is cut to hold and control the old loop. The sole function of the sinker may be as a web holder or stitch comb as on the Raschel warp knitting machine in which case only the underside of the nose performs the function.

On latch needle weft knitting machines the holding-down sinkers have a rectangular gap cut on their upper surface remote from the nose into which the sinker cam race fits to positively control the sinker’s movement.

Holding-down sinkers enable tighter structures with improved appearance to be obtained, the minimum draw-off tension is reduced, higher knitting speeds are possible and knitting can be commenced on empty needles.

Holding-down sinkers may be unnecessary when knitting with two needle beds as the second bed restrains the fabric loops whilst the other set of needles move.

- The third function of the sinker – as a knock-over surface – where its upper surface or belly supports the old loop as the new loop is drawn through it.

On tricot warp knitting machines the sinker belly is specially shaped to assist with landing as well as knock-over.

On latch needle machines the verge or upper surface of the trick – plate serves as the knock – over surface.

**The Jack:**

The jack is a secondary weft knitting element which may be used to provide flexibility of latch needle selection and movement. It is placed below and in the same trick as the needle and has its own operating butt and cam system. The needle may thus be controlled directly by its butt and cam system or indirectly by the movement of the jack.

**Methods of Yarn Feeding:**

There are two methods of yarn feeding. Yarn feeding involves either moving the yarn past the needles or moving the needles past a stationary yarn feed position.

When the yarn moves past the needles, the fabric will be stationary because the loops hang from the needles. This arrangement exists on all warp knitting machines and on weft knitting machines with straight beds or circular machines with stationary cylinder and dials. On straight machines of both weft and warp type the yarn carrier or guide has a reciprocating traversing movement which takes it towards and away from a suitably – placed yarn supply. On stationary cylinder and dial machines, however, the yarn supply packages must rotate in order to keep with the continuously revolving yarn feeds. Because the latch needle beds of these flat and circular weft knitting machines are stationary, it is necessary to reciprocate the cam – carriages
and revolve the cam - boxes so that the needle butts of the stationary tricks pass through and the needles are thus reciprocated into a knitting action at the exact moment when the traversing feed supplies a new yarn.

Most circular weft knitting machines have revolving needle cylinders and stationary cams, feeders and yarn packages. In this case, the fabric tube must revolve with the needles as must the fabric rollers and take-up mechanism.

**Methods of Forming Yarn into Needle Loops:**

There are three methods of forming the newly - fed yarn into the shape of a needle loop:

- **Method – a:**
  
  By sinking the yarn into the space between adjacent needles using loop forming sinkers or other elements which approach from the beard side. The action of a straight bar frame is illustrated but a similar action occurs on other bearded needle weft knitting machines. The distance SL of the following figure which the catch of the sinker moves past the hook side of the needle is approximately half the stitch length.

- **Method – b:**
  
  By causing latch needles to draw their own needle loops down through the old loops as they descend one at a time down the stitch cam. This method is employed on all latch needle weft knitting machines. The distance SL of the above figure which the head of the latch needle descends below the knock - over surface, is approximately half the stitch length.

- **Method – c:**
  
  By causing a warp yarn guide to warp the yarn loop around the needle. The lapping movement of the guide is produced from the combination of two separate motions, a swinging motion which occurs between the needles from the front of the machine to the hook side and return and a lateral shogging of the guide parallel with the needle bar on the hook side and also the front of the machine. The swinging motion is fixed but the direction and extent of the shogging motion may or may not be
varied from a pattern mechanism. This method is employed on all warp knitting machines and for wrap patterning on weft knitting machines. The length of yarn per stitch unit is generally determined by the rate of warp yarn feed.

**Knitting Action or Loop or Stitch Formation on Spring-Bearded Needles:**

Loop or stitch formation on a single-needle bed weft knitting machine with spring-bearded needles consists of the following stages:

1. Yarn feeding
2. Yarn sinking or kinking
3. Under lapping
4. Pressing
5. Landing
6. Joining and casting-off
7. Clearing

The essence of these stages consists in the following operations:
1. Yarn feeding (a): The newly fed yarn is laid under the throats of kinking sinkers.

2. Yarn sinking (b): The sinkers fall down between the needles, with the yarn held in the sinker throats. Depth of sinking determines the loop length, i.e. the yarn length used to form a knitted loop.

3. Under lapping (c): The yarn laid on the needle stems is withdrawn by the sinkers in direction of needle hooks and under the needle beards.

4. Pressing (d): Now, the needle beard is immersed in the needle groove by a presser disc. In this way the fed yarn is closed in the needle hook.

5. Landing (e): The knitted fabric resting on the needle stems at the needle bed is now pushed by cast-off sinkers towards the pressed needle beards, and the fabric loops (called old loops) land on the beards.

6. Joining and Casting-off (f): After passing the presser disc, the cast-off sinkers push further the knitted fabric towards the tips of the needles. At the same time the kinking sinkers leave the kinked yarn and the cast-off sinkers push the old loops off the needles on to the kinked lengths of yarn.

7. Clearing (a): At this stage the newly formed loops are pushed back along the needle stems, towards the needle bed; the knitted fabric enlarged by a new course of knitted loops, is drawn down by means of a take-down mechanism, and the process of loop formation may be started again.

Consecutive stages of loop formation on spring-bearded needles
Knitting Action or Loop or Stitch Formation on Latch Needles:

The loop or stitch forming process in a single needle bed machine is illustrated in the following figure. The loop forming process is divided into nine operations:

1. Clearing
2. Yarn laying or feeding
3. Under lapping or yarn drawing
4. Pressing
5. Landing
6. Joining
7. Casting-off or knocking-over
8. Loop forming and sinking, and
9. Loop draw – off

Knitting Action or knitting cycle on latch needles

1. Clearing (a): The process of stitch formation is started by the clearing operation. Its aim is to draw the old loops behind the needle latch. Clearing is effected during needle lift. The old loop is retained by the beak of the sinker shifted to the cylinder centre so as to avoid its displacement together with the needle. At the time of clearing, the sinker remains immobile. Clearing is completed when the needle reaches its upper position.
2. Yarn laying or feeding (b): In the course of needle downward motion, the hook takes hold of yarn coming from the yarn guide and effects it's laying. At the moment when laying is started, the sinker beak must retreat a little from the cylinder centre so as not to further impede the loop forming process.

3. Under lapping or yarn drawing (c): Further movement of yarn just laid and its forwarding under the needle hook is called under lapping or drawing. Actually, drawing is performed simultaneously with the yarn laying when the needle starts to move down.

4. Pressing (c): The aim of pressing is to close the needle hook with the yarn laid in it. When the needle lowers, its latch contacts the old loop lying near the knock – off plane and retained from lowering by the sinker chin. The old loop interacts with the latch and closes it.

5. Landing (d): The essence of this operation consists in shifting the old loop on the closed latch. The landing operation in latch needle machine begins simultaneously with pressing.

6. Joining (d): At joining, the new yarn comes in contact with the old loop. Joining is accomplished simultaneously with the beginning of casting – off.

7. Casting-off or knocking-over (e): The casting-off operation consists in the retreat of the old loop from the needle hook.

8. Loop forming and sinking (e & g): Loop forming consists in drawing the yarn grasped by the needle through the old loop retained by the sinker chin. The lower the needle moves in respect to the knock – off plane at kinking, the longer is the formed loop and the less the stitch density.
9. Loop draw-off (f): The aim of this operation is to draw the old loop behind the needle back. Draw-off of new loops is effected by sinker throats. At the same time, exercising their action on the knitted fabric, the chins of sinkers withdraw the old loops from the knitting zone. The machine take-down mechanism promotes this operation.

Loop draw-off is completed when the apex on the interior side of the hook head reaches the knock-off plane level, which corresponds to the initial position for the described loop forming process.

**Knitting Action or Loop or Stitch Formation on a Warp Knitting machine equipped with Compound Needles:**

The loop forming process on single – bar warp knitting machines with compound needles may be divided into ten operations:

1. Clearing
2. Overlapping or yarn laying
3. Underlapping
4. Pressing
5. Landing – over
6. Joining or meshing
7. Sinking
8. Casting – off
9. Loop – forming and
10. Draw – off

The operations are described as follows:

1. Clearing (b): The stem of the compound needle lifts from the bottom position. The newly formed loop is under the needle hook. The guide bar is racking over one or several needle spacings (depending on the kind of interlacing) behind the needles, and occupies the initial position to form the next loop course. The sinkers retain with their nibs, the knitted fabric from lifting together with the needles. On further rotation of the machine the needles come to occupy the initial position for warp yarn laying.

2. Overlapping or yarn laying (c – g): The needle stem rises and the guide bar starts its motion, intersecting the line of needles. At the moment when the guide bar passes between the needles the hooks must reach the bottom half of the guide needle hole (d). In the farthest position from the needles, the guide bar makes a rack for yarn overlapping, usually for one needle spacing. Figure f illustrates the position of the guide needle in relation to the needles in the return swinging of the guide bars. On further rotation of the main shaft, the needle stem starts moving downward and yarn overlapping is terminated. The direction of sinker and sliding latch motion in overlapping is shown by arrows in figure c to g.
Knitting Action or knitting cycle on compound needles

3. Underlapping (g): The needles stem continues its descent. The guide needle has already intersected the line of needles and pursues its motion. The newly overlapped yarn does not move together with the needle stem being retained by the upper edge of the sinker nib. The combined motions of the guide needles and needle stems bring the new yarns under the hooks. In underlapping, the sinker starts moving backward to the machine centre.
4. Pressing (h): The needle continues its downward motion having risen to its highest position, the sliding latch overlaps the needle hook so that the hook tip engages into the groove in the upper part of the latch. The sinker continues its motion and, with its belly, brings the old loop along the sliding latch to the closed hook of the needle.

5. Landing – over (h): The sinker continues its travel and, with its belly, brings the old loop on the sliding latch. The guide needle continues to retreat. The sliding latch together with the stem moves downwards.

6. Joining or meshing (i): The needle stem with the sliding latch continues the downward motion. On the descent of the needle head to the level of the upper edge of the sinker belly, the old loop joins the new warp yarn which is under the needle hook. The guide needle continues to move away from the machine centre.

7. Sinking (l,j): This operation (i.e. bending the new warp yarn which is under the needle hook) is effected by further needle lowering.

8. Casting-off (i): The needle stem with the sliding latch lowers below the upper edge of the sinker belly. The old loop with the sliding latch is cast on to the newly formed loop which is under the needle hook.

9. Loop forming (i): The needle continues to move downward.

10. Draw – off (j): Draw – off is carried out on further rotation of the machine’s main shaft and needle lift. As the needle lifts, the yarn may be drawn from the newly formed loop to the guide.
Main features of a knitting machine:

A knitting machine is thus an apparatus for applying mechanical movement, either hand or power derived, to primary knitting elements, in order to convert yarn into knitted loop structures. The machine incorporates and co-ordinates the action of a number of mechanisms and devices, each performing specific functions that contribute towards the efficiency of the knitting action.

The main features of a knitting machine are listed below:

- **Frame**: The frame, normally free-standing and either circular or rectilinear according to needle bed shape, provides the support for the majority of the machines mechanisms.
- **Power supply**: The machine control and drive system co-ordinates the power for the drive of the devices and mechanisms.
- **Yarn supply or feeding**: The yarn supply consists of the yarn package or beam accommodation, tensioning devices, yarn feed control and yarn feed carriers or guides.
- **Knitting action**: The knitting system includes the knitting elements, their housing, drive and control, as well as associated pattern selection and garment-length control devices (if equipped).
- **Fabric Take-away**: The fabric take-away mechanism includes fabric tensioning, wind-up and accommodation devices.
- **Quality control**: The quality control system includes stop motions, fault detectors, automatic oilers and lint removal systems.

Machines may range from high-production, limited-capability models to versatile, multi-purpose models having extensive patterning capabilities. The more complex the structure being knitted, the lower the knitting speed and efficiency. The simplest of the knitting machines would be hand-powered and manipulated whereas power-driven machines may be fully automatically-programmed and controlled from a computer system.

**Classification of weft knitting machines:**

Weft knitting machines are divided into the several ways as follows:

A. According to the frame design and needle bed arrangement or construction
   
   I. Circular knitting machine
   
   II. Flat knitting machine
B. According to the number of needle bed or number of needle set used
   i. Single Jersey knitting machine
   ii. Double Jersey knitting machine

C. According to the end product of the weft knitting machine
   i. Fabric machine
   ii. Garment length machine

D. According to the basic structure of the weft knitting
   i. Plain or Single jersey circular knitting machine
   ii. Rib Circular or Flat knitting machine
   iii. Interlock circular knitting machine
   iv. Links-links or Purl flat or circular knitting machine

E. According to the types of needle used
   i. Knitting machine equipped with Latch needle
      a. Circular knitting machine
         One needle bed
         Plain, Single-jersey jacquard, Pile and Sliver knit machine
         Two needle beds (Dial-cylinder machine)
         Rib, Interlock, Double-jersey jacquard machine
         Double cylinder
         Purl knitting machine
      b. Flat-bed knitting machine
         One needle bed
         Domestic type
         Two needle beds
         Vee-bed, Flat purl knitting machine
   ii. Knitting machine equipped with Spring Bearded needle
      a. Circular knitting machine
         One needle bed
         Sinker wheel, Loop wheel frame
      b. Straight bar frame
         One needle bed and Two needle beds
         Cotton’s Patent or Fully-fashioned machine
Flat Knitting Machine:

General structure of a Flat knitting machine:

- **The Frame:**
  - The needle beds
  - Concept of machine gauge
  - The carriage and yarn guides
  - Feeding the yarn
  - The take-down device
  - Selecting the needles
  - Selection of high and low butts

- **Main Features:**
  - Flat knitting machine has two stationary needle beds
  - Latch needles are used
  - Angular cams of a bi-directional cam system is used
  - The cam system is attached to the underside of a carriage, which with its selected yarn carriers.
  - The carriage traverses in a reciprocating manner across the machine width
  - There is a separate cam system for each needle bed
  - The two cam systems are linked together by a bridge, which passes across from one needle bed to the other.
  - Normally machine gauge is 3 to 18 needles per inch and machine width up to 79 inches.

\[\text{Diagram of a V bed, and b Diagram showing relative positions of needles from front and back beds}\]
Advantages of Flat knitting machine:

- The flat machine is the most versatile of weft knitting machines, its stitch potential includes needle selection on one or both beds, racked stitches, needle-out designs, striping, tubular knitting, changes of knitting width and loop transfer.
- A wide range of yarn counts may be knitted per machine gauge including a number of ends of yarn in one knitting system, the stitch length range is wide and there is the possibility of changing the machine gauge.
- The operation and supervision of the machines of the simpler type is relatively less arduous than for other weft knitting machines.
- The number of garments or panels simultaneously knitted across the machine is dependent upon its knitting width, yarn carrier arrangement, yarn path and package accommodation.

Uses of Flat knitting machines:

Articles knitted on flat machines range from trimmings, edgings and collars to garment panels and integrally knitted garments. The common products: jumpers, pullovers, cardigans, dresses, suits, trouser suits, hats, scarves, accessories, ribs for straight-bar machines (fully fashioned machines). Cleaning clothes, three-dimensional and fashioned products for technical applications, multiaxial machines are under development.

Classifications of Flat machines:

Machines range from hand propelled and manipulated models to fully-automated electronically controlled power driven machines. The four classes of flat knitting machines are:

a) The Vee-bed flat which is by far the largest class;

b) Flat bed purl machines which employ double ended or double headed latch needles

c) Machines having a single bed of needles which include most domestic models and the few hand manipulated intarsia machines

d) The uni-directional multi-carriage machines made by one manufacturer.

a) Vee-bed Flat knitting machine:

Vee-bed flat knitting machines are widely used for the production of sweater, collar-cuff, etc. This machine describe in details in the following chapter of sweater knitting.

b) Flat Purl knitting machine:

- Flat purl or links-links machine with double-headed latch needles are less common than Vee-bed types to which they are similar in method of operation.
They share with Vee-bed type very good patterning scope, increasing shaping potential and relatively low productivity.

End-uses and machine types show slightly less diversity than Vee-bed equipment but hand operated types and circular-flat purl machines exist.

c) Domestic Single bed Flat machine:
- These machines are no longer produced for industrial use.
- The needles are actuated by cams mounted in a carriage traversed by hand. Patterning and ability to shape the fabric depend upon manual operations.
- A typical machine has a 36 inch working width with 5 to 6 needles per inch.

Circular knitting machine:

The term circular covers all those weft knitting machines whose needle beds are arranged in circular cylinders and / or dials, including latch, spring bearded and very occasionally compound needle machinery, producing a wide range of fabric structures, garments, hosiery and other articles in a variety of diameters and machine gauges.

Features of a Circular knitting machine:

The common features of a circular knitting machine as follows:

- Circular knitting machine normally has rotating (clockwise) cylindrical needle bed(s).
- On circular knitting machines latch and compound needles are used. One seldom finds bearded needles or other needle types. Normally one or two sets of Latch needles are used.
- For single-jersey machine holding down sinkers are used, one between every needle space.
- Normally stationary angular cam systems are used for needle and sinker.
- Latch needle cylinder and sinker ring (for single-jersey machine) / dial (for double-jersey rib and interlock machine) revolve through the stationary knitting cam system.
- For single-jersey machine, sinker trick ring which is simply and directly attached to the outside top of the needle cylinder thus causing the sinkers to revolve in unison with the needles.
- Needle retaining spring is also used
- Stationary yarn feeders are situated at regular intervals around the circumference of the rotating cylinder.
- Yarn is supplied from cones, placed either on an integral overhead bobbin stand or on a freestanding creel through tensioners, stop motions and yarn guide eyes down to the yarn feeder guides.
The following features of a modern circular fabric producing machine that ensure the high quality fabric is knitted at speed with the minimum of supervision:

- The top and bottom stop motions are spring-loaded yarn supports that pivot downwards when the yarn end breaks or its tension is increased. This action releases the surplus yarn to the feeder, thus preventing a press-off, and simultaneously completes a circuit which stops the machine and illuminates an indicator warning light.
- Various spring-loaded detector points are carefully positioned around the cylinder according to their particular function. A pointer is tripped to stop the machine by a fault or malfunctioning element such as a yarn slub, fabric lump, needle head, latch spoon, etc.
- The tape positive feed provides three different speeds (course lengths) and is driven and can be adjusted from the drive arrangement.
- The cylinder needle cam system for each feed is contained in a single replaceable section and having an exterior adjustment for the stitch cam slide.
- The automatic lubrication system.
- Start, stop and inching buttons.
- The cam-driven fabric winding down mechanism, which revolves with the fabric tube.
The revolution counters for each of the three shifts and a pre-set counter for stopping the machine on completion of a specific fabric length (in courses).

- Normally side creel is used.
- Lint blower is used. This reduces the incidence of knitted-in lint slubs, to improve quality when using open-end spun yarns. It also reduces cross-contamination by fibres from other machines.

Products of Circular knitting machine:

Fabric machines: rolls of fabric with the following end-uses: jackets, ladies’ tops, sports and T-shirts, casual wear, suits, dresses, swimwear, bath robes, dressing gowns, track suits, jogging suits, furnishing, upholstery, automotive and technical fabrics, household fabrics.

Garment blank machines: Underwear, T-shirts, jumpers, pullovers, cardigans, dresses, suits, trouser suits, vests, briefs, thermal wear, cleaning cloths, technical fabrics.

Hose machines: seamfree hose, tights, industrial use dye bags, knit-de-knit yarns, industrial fabrics.

Half-hose machines: men’s and boy’s half-hose, ladies’ stockings, children’s tights sports socks.
Classification of circular knitting machines:
There are three types of circular knitting machines

a) Revolving cylinder latch needle machines:
They produce most weft knitted fabrics. They are of two main types –

1. Open top or Sinker top or Single jersey machines
2. Dial and cylinder machine

- Open top machines have one set of needles usually arranged in the cylinder.
- Except in the case of certain effect fabric machines such as pelerine, cylinder and
dial machines are of either the rib or interlock type.
- Machines of both types may or may not have patterning capabilities.

b) Revolving cylinder bearded needle single-jersey fabric machine:
There are two types of circular bearded needle single-jersey fabric machines still
manufactured,

1. The Sinker Wheel machine or French or Terrot type machine.
2. The Loop wheel frame or English type machine.

Both have the following features in common:
- Needles are fixed in needle bed.
- Revolving needle bed
- Ancillary elements moving yarn and loops along the needle stems.
- Fabric tube knitted with its technical back facing outwards.
- Less number of feeders accommodates.
- Comparatively low productivity compensated by an ability to produce unusual
and superior quality knitted structures.

c) Circular garment length machines:
- They are generally of body-width size or larger having a cylinder and dial
arrangement or a double cylinder.
- They are of the small-diameter hosiery type with either a single cylinder, a
cylinder and dial or double cylinders.

Fabric Machine:

The fabric machine has the following main features:

- Circular machines, knitting tubular fabric in a continuous uninterrupted length of
constant width.
Large diameter, latch needle machines, knit fabric at high speed (also known as yard goods or piece goods machines).

The fabric is manually cut away from the machine; usually in roll form, after a convenient length has been knitted.

Most fabric is knitted on circular machines, either single-cylinder (single-jersey) or cylinder and dial (double-jersey), of the revolving needle cylinder type, because of their high speed and productive efficiency.

Sinker wheel and loop wheel frames could knit high quality specialty fabrics, with bearded needles, although circular machines employing bearded needles are now obsolete. The production rates of these machines were uncompetitive.

Unless used in tubular body-width, the fabric tube requires splitting into open width.

The fabric is finished on continuous finishing equipment and is cut-and-sewn into garments, or it is used for household and technical fabrics.

The productivity, versatility and patterning facilities of fabric machines vary considerably.

Generally cam settings and needle set-outs are not altered during the knitting of the fabric.

**Garment-length machines:**

The garment-length machine has the following main features:

- They include straight bar frames, most flats, hosiery, leg wears and glove machines, and circular garment machines including sweater strip machines.

- They knitting garment-length sequences, which have a timing or counting device to initiate an additional garment-length programming (collectively termed "the machine control") mechanism. This co-ordinates the knitting action to produce a garment-length structural repeat sequence in a wale-wise direction. The garment width may or may not vary with in the garment length.

- They are coarser gauge machine than fabric machines.

- It automatically initiates any alteration to the other facilities on the machine needed to knit a garment-length construction sequence instead of a continuous fabric.

- The machine control may have to initiate correctly-timed changes in some or all of the following:
  
  Cam-settings, needle set-outs, feeders and machine speeds.

- It must be able to override and cancel the effect of the patterning mechanism in rib borders and be easily adjustable for different garment sizes.

- The fabric take-down mechanism must be more sophisticated than for continuous fabric knitting.

- This take-down mechanism has to adapt to varying rates of production during the knitting of the sequence and, on some machines be able to assist both in the setting
up on empty needles and the take-away of separate garments or pieces on completion of the sequence.

- Garments may be knitted to size either in tubular or open-width; in the latter case more than one garment panel may be knitted simultaneously across the knitting bed.

- Large-diameter circular machines and wide Vee-bed flat machines can knit garment blanks that are latter split into two or more garment widths (blanket-width knitting).

- They produce knitwear, outerwear and underwear. Underwear may be knitted either in garment-length or fabric form, whereas knitwear is normally in garment-length form, which is a generic term applied to most weft knitted outerwear garments such as pullovers, jumpers, cardigans and sweaters, usually knitted in machine gauges coarser than E14. Jersey wear is a generic name applied to weft knitted fabric (single-jersey, double-jersey). It is cut and made-up from fabric usually knitted on large circular machines (26" or 30" diameter), although there are larger and smaller diameter machines used. Generally, gauges are finer than E14.

Plain or Single-Jersey Circular Latch Needle Knitting Machine:

Description of the machine:

Plain fabric is a single jersey fabric and is produced by one set of needle. Most of single – jersey fabric is produced on circular machines whose latch needle cylinder and sinker ring revolve through the stationary knitting cam systems, which together with their yarn feeders are situated at regular intervals around the circumference of the cylinder.

The yarn is supplied from cones, placed either on an integral overhead bobbin stand or on a free – standing creel, through tensioners, stop motions and guide eyes down to the yarn feeder guides. The fabric, in tube form, is drawn downwards from inside the needle cylinder by tension rollers and is wound onto the fabric batching roller of the winding down frame. The winding down mechanism revolves in unison with the cylinder and fabric tube and is rack – lever operated via cam – followers running on the underside of a profiled cam ring.

As the sinker cam – plate is mounted out side on the needle circle, the centre of the cylinder is open and the machine is referred to as an open top or sinker top machine. Compared with a rib machine, a plain machine is simpler and more economical with a potential of more feeders, higher running speeds and the possibility of knitting a wider range of yarn counts. The most popular diameter is 26" giving an approximate finished fabric width of 60" to 70".

An approximately suitable count may be obtained using the formula \( N_e = \frac{G^2}{18} \), where \( N_e \) = cotton count or English system and \( G \) = gauge in npi. For fine gauges a heavier and stronger count may be necessary.

The following figure shows a cross-section of the knitting head all of whose stationary parts are shaded.
1. Yarn feeder guide which is associated with its own set of knitting cams.
2. Latch needle
3. Holding – down sinker, one between every needle space
4. Needle cylinder (in this case, revolving clockwise)
5. Cylinder driving wheel

6. Cylinder driving gear
7. Sinker operating cams which form a raised track operating in the recess of the sinker
8. Sinker cam – cap
9. Sinker trick ring which is simply and directly attached to the outside top of the needle cylinder thus causing the sinkers to revolve in unison with the needles
10. Needle retaining spring
11. Needle – operating cams which, like the sinker cams are stationary
12. Cam – box
13. Cam – plate
14. Head plate
15. Cylinder driving pinion attached to the main driving shaft.

**Cam system:**
The cam system consists of needle cam system and sinker cam system. The following figure shows the arrangement and relationship between the needle cams and sinker cams as the
elements pass through in a left to right direction with the letters indicating the positions of the elements at the various points in the knitting cycle.

The needle cam race consists of the followings,

1. The clearing cam or raising cam
2. Stitch or lowering cam
3. Upthrow cam
4. Guard cam of clearing cam (1)
5. Return cam and
6. Guard cam of return cam (5)

Stitch cam (2) and upthrow cam (3) are vertically adjustable together for alteration of stitch length.

The sinker cam race consists of the followings,

7. The race cam
8. The sinker – withdrawing cam and
9. The sinker – return cam

The sinker – return cam is adjustable in accordance with the stitch length.

The arrangement of the knitting elements:

The following figures show the arrangement of the knitting elements and their combined action during stitch formation on a plain circular knitting machine. The figure (a) shows a perspective of a cylinder cam of a plain circular knitting machine as seen from outside; Figure (b) is a perspective of the related sinker cam as seen from above. In both the figures important needle and sinker (holding-down and knock-over version) positions during stitch formation are marked (position 1 to position 6).
The arrangement of the knitting elements can be seen in the figure (c). The cylinder needle 1 is housed and guided in a vertical groove 2 of a rotating cylinder. Its needle butt 4, extending into a cam track 5, is responsible for its vertical movement needed for stitch formation. The cam segments 6 and 7 are fixed to a stationary cylinder cam covering 8 and form the cam track. During the rotary movement of the cylinder the needle obtains its vertical movement depending on the shape of the cam track in figure (a). A sinker ring 9 is placed on the top part of the needle cylinder 3; it rotates with the cylinder. Holding-down or knocking-over sinkers 11 are housed in radial grooves 10 and they cross with the cylinder needles.

![Figure - a](image)

**Figure - a**


![Figure - b](image)

**Figure - b**

![Figure - c](image)

**Figure - c**

1 = cylinder needle  
2 = cylinder groove  
3 = needle cylinder  
4 = needle butt  
5 = cam track  
6 = cylinder cam segment  
7 = cylinder cam segment  
8 = cylinder cam covering  
9 = sinker ring  
10 = sinker ring groove  
11 = holding-down/knocking-over sinker  
12 = sinker cam segment  
13 = sinker cam ring  
14 = holding fixture  
15 = holding-down throat  
16 = knock-over edge (belay)  
17 = yarn feeder  
18 = take-down cam segment  
19 = take-down cam counter segment
These sinkers obtained their movements for stitch formation by means of the sinker cam segment 12, which is fixed to a stationary sinker cam ring 13. In the construction shown, the sinker cam ring 13 is loosely housed on the sinker ring 9; the holding fixture prevents it from turning round. The sinker throat 15 of the holding-down or knocking-over sinker holds down the fabric when the needle is moved upwards. The stitches are knocked over at the knock-over edge 16. The feeder 17 presents the yarn to the needles.

Position – 1: Rest or ground position, Position – 2: Tucking – in position, Position – 3: Clearing position


- Position – 1: The rest position is shown in the following figure. The top edge of the needle head is on level with the knock – over edge of the holding – down or knocking – over sinker. The latter has been moved towards the cylinder centre to such an extent, that its throat holds down the sinker loop of the kinked yarn loop, present in the needle head.
- Position – 2: This position is shown in the figure below. The needle has been moved upwards from its rest position, whereby the fabric was held down in the sinker throat.
The old loop has opened the needle latch and lies on it. The arrangement of the yarn feeder prevents the closing of the latch when the needle is moved further up. The sinker rests in this position.

- Position – 3: From the tucking-in position the needle has now been moved into its highest position. Since the fabric had been held down by the throat of the sinker, the old loop slides on the needle stem to a position beneath the latch. The yarn feeder prevents a closing of the latch. The sinker remains at rest.

- Position – 4: The needle is moved down from the clearing position. Just before the old loop begins to close the latch the new yarn must be laid into the needle head by the yarn feeder. In order that the latch can be closed by a further downward movement of the needle, yarn feeding must be completed immediately after crossing the yarn presenting position. In the figure, the sinker begins moving towards the right and away from the cylinder centre, since the fabric no longer needs to be held by the sinker throat. The vertical position of the needle is the same in the yarn presenting position and the tucking-in position. The fundamental difference, however, is that in the tucking-in position the old loop from the previous row lies on the needle latch, but is beneath the latch for stitch formation in the yarn presenting position.

- Position – 5: From the yarn presenting position the needle is moved further downwards by means of the take-down segment 18 along with the counter guide segment 19, figure (a). Now the needle latch is closed by the old loop and the new yarn is held in the closed needle head. The sinker has been moved into its extreme right position, so that the old loop lies on the knock-over edge and the new yarn can be pulled through the old loop.

- Position – 6: The needle is moved further downwards by means of the take-down cam segment 18 and the counter guide segment 19, figure (a) and it pulls the new yarn through the old loop. This is now knocked over as a new stitch. At the same time a loop is formed by the new yarn. The take-down segment 18 and the counter guide segment 19 can be shifted diagonally and be exactly set to given values with the help of a scale. Thus it is possible to precisely adjust the length of the newly formed loop.

**Sinker Timing:**

The most forward position of the sinker during the knitting cycle is known as the push point and its relationship to the needles is known as the sinker timing.

If the sinker cam ring is adjusted so that the sinkers are advanced to the point where they rob yarn from the new stitches being formed, a lighter-weight fabric with oversized sinker loops and smaller needle loops is produced.

If the ring is moved in the opposite direction a tighter, heavier fabric is produced having smaller sinker loops and larger needle loops. The timing is normally set between these two extremes.
Rib Circular Knitting Machine:

Description of the machine:

In this machine group there is one set of needles on the circumference of a vertical cylinder and a second set of needles, arranged perpendicular to the first set and mounted on a horizontal dial. On most of the circular knitting machines the cylinder and dial rotate, whereas the cams with yarn feeder guides are stationary.

The following figure shows a cross-sectional view of the region containing the knitting elements of a rib (double knit) circular knitting machine. The set-up of the cylinder 3 with its knitting elements 1 to 9 is the same as with plain circular knitting machines. In a horizontal (rib) dial 10 grooves 11 are milled in. The latch needles 12 are housed and guided in these grooves. The dial needle 12 obtains its motion for stitch formation through its butt 13, which extends into a cam track 14. This cam track 14 is formed by the cam parts 15 and 17, which in turn are fixed to a dial cam plate 18. During the rotation of the cylinder and the dial the cylinder needle 1 is moved vertically and the dial needle 12 is moved horizontally, corresponding to the shape of the cam track in the cylinder and dial cams.

In a gauge range from 5 to 20 needle per inch (npi), an approximately suitable count may be obtained using the formula $N_e = \frac{G^2}{8.4}$, where $N_e =$ cotton count or English system and $G =$ npi.

Needle gating or setting or Coordination between cylinder and dial grooves:

Depending on the coordination between the cylinder groove and the (rib) dial groove one differentiates between the rib setting for the production of double knit fabrics and the interlock setting for the production of double knit locked fabrics (interlock fabrics).
- **Rib gating:** The following figure shows this setting in a front view and in a top view. The grooves 1 to 6 of the dial (Y) and the grooves 1 to 6 of the cylinder (Z) are alternately arranged or gated. With this arrangement the cylinder and dial needles cross one another. In any given working point (feeder) all the cylinder and dial needles can be used. The majority of circular knitting machines work with a rib setting. They are generally called rib machines; those of them in the gauge range E14 to E20 are also called fine rib machines.

- **Interlock gating:** Front and top views of this setting or gating are shown in the figure below, whereas figure (with needles) illustrates it at an angle. In figure the grooves 1 to 6 of the dial (Y) are aligned directly opposite to the grooves 1 to 6 of the cylinder (Z). As such, the cylinder and dial needles are also directly one opposite to the other, figure (with needles). Therefore at any given working point (feeder), cylinder and dial needles opposite to one another can never work at the same time, because they would collide while being cleared, figure (with needles). Related to a working point (feeder), it is thus normal usage in interlock setting to work with
  
  - Dial needles in grooves 1,3,5,
  - Cylinder needles in grooves 2,4,6,
  - Dial needles in grooves 2,4,6,
  - Cylinder needles in grooves 1,3,5,
  - Dial needles only
  - Cylinder needles only.
Working with an interlock setting therefore requires two sorts of needles in the cylinder and in the dial, and these have to be controlled and cleared independently. One sort of needle is normally present in the grooves 1, 3, 5, ... and the other needle sort in the grooves 2, 4, 6, ... However, other needle combinations are also possible.

In figure (with needles) the needle types z1 and zk in the cylinder (Z) and the needle types yk and yl in the dial (Y) have differently arranged needle butts. The distance between needle head and needle butt (working length) is not the same. One also refers to a short dial needle yk and a long dial needle yl or to a short cylinder needle zk and a long cylinder needle zl. The needle arrangement in figure (with needle) is such, that a long cylinder needle zl is directly opposite to a short dial needle yk and a short cylinder needle zk is directly opposite to a long dial needle yl. As a result, the short dial and cylinder needles are gated towards one another, and similarly the long dial and cylinder needles. At any given working point (feeder) one can work either with all the short needles or with all the long needles. Correspondingly, one also refers to a short or to a long feeder. Double knit (rechts – rechts) interlock machines are normally built as rib machines with finer gauges.

Conversion from Rib to Interlock gating:

As a rule rib machines can be converted into interlock machines when they have at least two different needle types both in the cylinder and in the dial, whereby these needles can be independently controlled. A clutch in the drive for the cylinder and the dial is used to turn either the cylinder or the dial over half a needle pitch, so that the cylinder and dial needles are directly opposite to one another. The working procedure at any given feeder is now the same as in the usual interlock setting. Theoretically, interlock machines can also be converted into rib machines in the same manner. Interlock machines are however normally in a finer gauge range. When cylinder and dial needles cross one another in rib setting, there would be very little space in between, and this could lead to strain and damage of yarns. Generally double knit (rechts – rechts) circular knitting machines with an interlock setting have gauges finer than E24.

Needle Timing or Coordination between cylinder and dial cams:

Needle timing is the position of the dial needle knock-over point relative to the cylinder needle knock-over point measured as a distance between the knock-over points of the two lowering cams, i.e. the cylinder and dial stitch cams, in needles. Collective timing adjustment is achieved by moving the dial camplate clockwise or anti-clockwise relative to the cylinder, individual adjustment at particular feeders as required is obtained by moving or exchanging the stitch cam profile. Depending on the coordination between the cylinder and dial cams, one differentiates between synchronized timing (also known as point, jacquard or 2×2 timing) and delayed timing (also referred to as rib or interlock timing).

Needle timing influence the appearance, the quality and properties of the fabric produced on a rib circular knitting machine.
Synchronized timing:

The cylinder and the dial needles knock-over their knitted loops at the same time. It is the term used when the two positions coincide with the yarn being pulled in an alternating manner in two directions by the needles thus creating a high tension during loop formation.

In this case the important things that “the knocking-over depth of the cylinder needles is equal to the knocking-over depth of the dial needles.

When this timing is used the cylinder and dial needles are pulled in the same position. The knocking-over position is attained at the same point by the cylinder and dial needles. Synchronized timing can be used on all machines and for all rib and interlock knitted structures except:

- Those with laid-in yarns
- Simultaneous tucking at cylinder and dial needles
- Rib and interlock based pile fabrics.
Structures knitted using synchronized timing will be loose and consist of uneven stitches. The following figures illustrate the phases of stitch or loop formation on a rib circular knitting machine working with synchronized timing.
Delayed timing:

The dial needles knock-over their knitted loops later than the corresponding cylinder needles. With delayed timing the dial knock-over occurs after about four cylinder needles have drawn loops and are rising slightly to relieve the strain. The dial loops are thus composed of the extended loops drawn over the dial needle stems during cylinder knock-over, plus a little yarn robbed from the cylinder loops. The dial loops are thus larger than the cylinder loops and the fabric is tighter and has better rigidity, it is also heavier and wider and less strain is produced on the yarn. So the advantages of using delayed timing as follows:

- Tight structure
- Evenly formed stitches
- Good rigidity
- Heavier and wider fabric
- Less strain on the yarn during the stitch formation
- Longer dial stitches compared to cylinder stitches.

The knocking-over depth of the cylinder needle must be k times the knocking-over depth of the dial needle, where k = 1.2 .............1.5.

Rib jacquard or broad ribs cannot be produced in delayed timing because there will not always be cylinder needles knitting either side of the dial needles from which to draw yarn. Although the dial knock-over is delayed, it is actually achieved by advancing the timing of the cylinder knock-over.

When this timing is set, the dial needles knock over their loops later than the cylinder needles lying opposite to them. Based on the synchronous timing, the dial camplate is moved in the direction of rotation of the machine over a distance equaling about five to six needle pitches.
The figure shows a cylinder and a dial cam set for delayed timing. The knock-over point of the dial needles, position 8, is shifted in the direction of rotation of the machine over the distance corresponding to the delayed timing, in relation to the knock-over point of the cylinder needles, position 6. On a circular knitting machine set for delayed timing, only such fabric types can be produced, where all the cylinder needles work in each feeder. If fabrics are produced using only every second cylinder needle, knitting can be carried out in an intermediate position. For this purpose the knock-over point of the dial needles is shifted over just two or three needle pitches with regard to the knock-over point of the cylinder needles. As a rule, knitting with delayed timing results in fabrics with a more even loop appearance as compared to synchronous timing.

The following figures show the various stitch formation phases of a rib circular knitting machine with delayed timing. They differ to some extent as compared to synchronous timing.

Stitch or loop formation of Rib circular knitting machine with delayed timing

Position – 1: The rest position for the cylinder and dial needles. The heads of both these needles are in the area of the corresponding knock-over edges of the cylinder and the dial.

Position – 2: The dial and cylinder needles move more or less simultaneously into their tucking positions, as can be seen in the above figure, position 2.

Position – 3: After the latches of the dial and cylinder needles have been opened in the tucking position, the yarn feeder comes into action in circumferential direction; its task here is to
prevent a premature closing of the latches. The cylinder and dial needles attain their clearing positions, above figure, position 3, roughly at the same time.

Position – 4: The cylinder and dial needles are pulled back again and they move into their yarn presenting positions. The newly presented yarn is laid in the open needle hooks of both the needles, above figure, position 4.

Position – 5: Since the dial cams have been shifted in the direction of rotation of the machine the cylinder needles are pulled earlier than the dial needles. The cylinder needle loop closes the latch and lies on the closed head of the cylinder needle. The dial needle is approximately in its yarn presenting position, above figure, position 5. The yarn feeder stops prior to the cast-on position, so that the cylinder needle latch can be closed.

Position – 6: The cylinder needle is pulled further until it reaches its lowest point in the clearing position, as shown in the above figure, position 6. The dial needle is still roughly in its yarn presenting position. The newly presented yarn is pulled through the cylinder needle loop to form a new loop. The old loop is knocked over as a cylinder stitch. The length of this new cylinder loop determines the length of the cylinder and dial stitches to be formed later, since the dial needle can obtain yarn only from the neighbouring cylinder loops during knock-over. Therefore the drawing-in depth of the cylinder needle is set somewhat longer in delayed timing as compared to synchronous timing.

Position – 7: The dial needle is now pulled back and it moves into the cast-on position, above figure position 7; the loop lies on the closed latch of the dial needle. From its knock-over position the cylinder needle now begins to move upwards in the direction of its rest position.

Position – 8: In this position, the dial needle attains its knock-over position, while the cylinder needle is still approaching its rest position. Here the drawing-in depth of the dial needle must be sufficiently measured so that the dial needle can form a loop out of the yarn lengths of the cylinder loops, drawn in earlier by the neighbouring cylinder needles in their knock-over positions, position 6. A closer examination reveals that, while being pulled back, the dial needle draws in more yarn from the cylinder loop placed contrary to the direction of machine rotation, as compared to the other neighbouring cylinder loop, since the latter has already given up a part of its yarn reserve to the previously formed dial loop.

Due to the delayed knock-over of the dial needle one obtains more uniform stitch lengths, since the given yarn length, determined by the drawing-in depth of the cylinder needle, is evenly distributed over several stitches. This results in a more even appearance of the fabric. After the knock-over position the dial needle is guided into its rest position.

**Advanced timing:**
This is reverse of delayed timing in that the cylinder loops rob from the dial producing tighter dial loops, advancement can only be about one needle, this type of timing is sometimes used in the production of figured ripple double jersey fabrics where selected cylinder needles can rob from the all knitting dial needles.
Interlock Circular Knitting Machine:

Main features of Interlock machine:

Interlock is produced mainly on special cylinder and dial circular machines and on some double-system Vee-bed flat machines. An interlock machine must fulfill the following requirements:

- Interlock gating, the needles in two beds must be exactly opposite to each other so only one of the two can knit at any feeder.
- Two separate cam systems in each bed, each controlling half the needles in an alternate sequence, one cam system controls knitting at one feeder and the other at the next feeder.
- The needles are set out alternately, one controlled from one cam system the next from the other, diagonal and not opposite needles in each bed knit together.

The conventional interlock machine has needles of two different lengths, long needles knit in one cam-track and short needles knit in a track nearer to the needle heads. Long needle cams are arranged for knitting at the first feeder and short needle cams at the second feeder. The needles are set-out alternately in each bed with long needles opposite to short needles. At the first feeder long needles in cylinder and dial knit, and at the second feeder short needles knit together, needles not knitting at a feeder follow a run-through track. On modern interlock machines the needles are of the same length.

The knitting action or Stitch formation or Loop formation of Circular Interlock Machine:

A very popular variant of a circular two needle-bed machine is the interlock machine. In the interlock machines, the consecutive loop-forming process is effected with distribution. In this case, the needles of both beds (systems) operate consecutively and then after a certain delay on the passive needle bed (dial). The active needle bed is that which receives the yarn for forming loops from the yarn carrier.

The following figure illustrates the loop forming process in the interlock machine where short cylinder needles are designated with 1,2,3, and so on; the long cylinder needles are designated with 1’,2’,3’ and so on; short dial needles with I,II,III and so on; long dial needles with I’,II’,III’ and so on; old loops with C and the new thread with N.

Upon reaching its extreme top position for clearing, the cylinder needle 7 starts moving down, as it must receive the yarn which is being laid. In the course of this operation, the loops of the cylinder and the dial needles shift from the needle latches onto their stems.

The dial needle VII, which has effected clearing, retreats backwards just enough to bring the old loop which it carries under its hook. The needle 8 receives a new loop, while the needle VII remains at dwell. The needle 9 is shown in the moment when pressing is effected and needle 10 during the operations of joining, casting-off and at the beginning of loop forming. The new loop formed of oncoming yarn lies on the stem of the dial needles X and XI. At the same time of
loop forming on the interlock machines, the sinker loops of new loops are disposed on the needles X and XI, rather than on the knock-over teeth.

The needle XI effects landing over and the needles 12 and 13 lift, and as a result, the loops formed by these needles are released. The needles XII and XIII thus acquire the possibility of forming new loops by robbing the yarn from the released loops. So, for instance, the needle XII starts forming a new loop by reducing the new loop of the needle 12. The needle 13 and 14 continue their upward motion. While the needles XIII, XIV from their loops, the needles 15 and XV have already formed new loops. A full loop course on the interlock machine is formed by two knitting feeders.

**Interlock Cam System:**

The cam system consists of cylinder needle cam system and dial needle cam system. The following figure shows the necessary cylinder and dial needle camming to produce one course of ordinary interlock fabric which is actually the work of two knitting feeders. In this example the dial has a swing tuck cam which will produce tucking if swung out of the cam-track and knitting if in action.
**Cylinder cam system**: The cylinder needle cam system consists of the followings,

- A, is a clearing cam which lifts the needle to clear the old loops.
- B and C, are the stitch and guard cams respectively and are vertically adjustable for varying stitch length.
- D, is a upthrow cam, to raise cylinder needle whilst dial needle knocks over.
- E and F, are the guard cams, to complete the track.
- G and H, provide the track for the idling needles.

**Dial cam system**: The dial needle cam system consists of the followings,

- 1, is a raising cam to the tuck position only.
- 2 and 3, are the adjustable dial knock-over cams.
- 4, is a guard cam to complete the track.
- 5, is an auxiliary knock-over cam to prevent the dial needle re-entering old loop.
- 6 and 7, provide the track for the idling needles.
- 8, is a swing type clearing cam, which may occupy the knitting position as shown at feeder 1 or the tuck position as shown at feeder 2.

Interlock thus requires eight cam systems or locks in order to produce one complete course, two cam systems for each feeder in each needle bed. Basic cylinder and dial machines and flat-machines having this arrangement are often referred to as eight-lock machines.
Links-Links or Purl Knitting Machine

Stitch formation or loop formation on a purl knitting machine:

Links is the German word for left and it indicates that there are left or reverse loops visible on each side of the fabric. In a similar manner, the German term for rib is rechts-rechts (right-right).

The following figures show the main loop-forming elements are two headed latch needles and needle sliders.

![Double headed latch needle and Slider](image)

In flat links-links machines, the double headed latch needles are arranged in slots formed either by grinding or by inserting tricks c and d in the following figure (a) into special slots of the needle beds a and b. The needles may pass from the slot of one needle bed into the slot of the other, as these slots are disposed one opposite the other. The ribs of the partitions c and d have teeth D and J which form a knock-over bar.

Two sliders M and N correspond to each needle. The slider M can engage the needle’s left head, while the slider N can engage the right head of the needle, and displace it in a longitudinal direction. The figure (a) shows that the slider N is engaged with the needle’s right head. On the movement of the needle from right to left, the needle latch opens and the loop is transferred to the middle of the needle, as shown in the figure (b).

On the forward movement of the sliders, their heads raise the bosses L and R and both sliders disengage with the needle. The slider which is first to begin its backward motion lowers and engages the needle head. As shown in the figure (c), the slider M, upon engagement with the needle’s left head, moves the needle in the direction of the arrow e₁, while the slider N remains free.

The yarn Y is laid on the right head of the needle. At the time of yarn laying onto the needle, the same conditions must be satisfied as when knitting in single-bar machines, i.e. the yarn must get under the needle hook at yarn drawing and must not be intersected by the needle latch at the moment of pressing. On the movement of the needle along the arrow e₁ in the figure (d), the old loop O is retained by the knock-over teeth and closes the needle latch. The following figures (c) and (d) illustrate the operations of yarn laying, underlapping, or drawing and pressing on the needle’s right head.
The operations of landing, joining, casting-off and loop formation are carried out by the further motion of the needle along the arrow e₁ in the above figure (e). After a new loop c is formed the slider M starts moving from left to right in the direction of the arrow e₂, displacing the needle in the same direction. The hook of the slider M then disengages from the needle’s left hook in the above figures (f),(g),(h), and simultaneously clearing the loop c in respect to the needle’s right head takes place in figure (h). On further displacement of the slider N in the direction of the arrow e₃, it engages the needles right head in figure (i). In this case, the new loop will be formed by the needle’s left head, and it will cast off its old loop to the left side of its wale.

Thus, when the loop-forming process is effected by the left heads of the needles, the loops are cast off to the left side, while when the loop-forming process is effected by the right heads – the loops are cast off to the right side, owing to which a purl stitch is obtained.

To avoid breakage of needles at their transfer from one needle bed to the other, the machines are provided with latch openers which is not shown in the above figure.

If, after the formation of a course of loops in one needle bed, the following course of loops is formed on the other needle bed, a reverse jersey is obtained with a repeat of \( R_H = 2 \) (\( R_H \) = height of the repeat). If two courses of loops are formed on the same needle bed, and the next
two other courses on the other needle bed, then a reverse stitch is obtained in which two face courses alternate with two reverse courses. The repeat of this knit will be \( R_H = 4 \).

**Links-Links Cam System:**

The cam systems of a flat links-links machine are illustrated in the following figure. They consist of the following cams: the pointers 7 and 7' by means of which the sliders are directed to the big central cams 9 and 9'; the top or clearing movable central cams 13 and 13' serving to effect clearing and needle transfer from one needle bed to the other; the guide cams 6, 6' and 10, 10' bringing the sliders in operation position; the stationary top central cams 15 and 15', limiting the upward movement of the sliders and lowering them after the lift; the switch cams 8, 11 and 8', 11' and the bridges P and P'.

The bridge has the following parts: cams for raising the sliders 2 and 2'; the lowering cams 14 and 14', which press the sliders at the moment of their engagement with the needles; the latch openers 1, 1' and 4, 4'; the big bosses 3 and 3', impeding the needle's independent lifting at the moment of their engagement and disengagement with the sliders; the small bosses 5, 12 and 5', 12', supporting the needles at the moment when the latch openers come in action.

The heads of sliders in both needle beds lift at different moments: the receiving sliders are the first to rise and the first to lower. Correspondingly the sections of the bridge 2, 2' and 14, 14' as well as the clearing cams (central cams) 13, 13' are somewhat displaced in relation to each other.

As the knitting carriage moves from left to right, the back slider rises sooner than the front one to engage the needles. This is the receiving slider and the needles pass from the front needle bed to the back one. The needle transfer from the back needle bed to the front one takes place during the movement of the knitting carriage from right to left.
BASIC WEFT KNITTED STRUCTURES

All weft knitted structures are classified into four basic groups according to the arrangement of loops in their courses and wales. Four primary structures plain, rib, purl and interlock are the base structures from which all weft knitted fabrics are derived. The main properties of these structures are described in this area.

The plain knit structures or plain fabric:

The simplest and most basic structure is the “plain knit” which is also called “single knit”. Plain is a knit structure family, which is produced by the needles of only one set of needle with all the loops intermeshed in the same direction. Although the plain knit family encompasses a great number of structures all produced on a single needle bed, its general characteristics are described as follows:

a. Appearance: The fabric is unbalanced, because each side of the fabric exhibits a different appearance. Within each side, the loops on all courses and wales are identical. Each side of the fabric is made of a single type of loop i.e. either face or back (reverse). The top and bottom of each loop occurs on the fabric back and the centre (legs) of the loop appears on the fabric face. So the face of the fabric is smooth and shows the side limbs of the loops as a series of interlocking “V”s. The reverse is rough and looks like columns of interlacing semicircles.

Plain / Single jersey structure (Face)

Plain / Single jersey structure (Back)

b. Extensibility: The fabric is stretchable although not always elastic. Usually, the fabric can be stretched much more in the width than in the length. The fabric is extensible in a course wise direction and in a wale wise direction. However, the degree of extensibility is different when pulled top to bottom from when pulled
side to side. The course wise extension is approximately twice that of the wale wise extension due to the degree of constraint imposed on each loop by its intermeshing. The loop pulled vertically extends by half its length \( \frac{1}{2} l \), while the loop pulled horizontally extends by its whole length, \( l \). The degree of recovery from stretch is not a property of the construction but depends on the nature of the raw material and yarn construction. It normally has a potential recovery of 40% in width after stretching.

**Plain / Single jersey structure (Face)**  
**Plain / Single jersey structure (Back)**

c. **Edge curling:** This fabric curls at the edge when the fabric after cut in relax state. It has a tendency to curl towards the back at the sides and towards the front at the top and bottom. The difference in construction between the two faces causes stress in the structure so that the fabric tends to curl. The loop arms (face) exert a length wise stress that curls the top and bottom edges of the fabric towards the face. The needle and sinker loops which are on a horizontal plain, pull the sides of the fabric and curl them towards the reverse side of the fabric. Pressing or other heat / water processes are used to minimize or eliminate such curling which is caused by the directionality of the loop formation.

d. **Unroving:** The plain knit structure can be easily unravelled from the edge which was knitted last. This selvedge is the top edge when the fabric is held upright, as produced on the knitting machine. In contrast to other knit families, the plain knit construction is symmetrical and can also be unravelled from the edge knitted first. This edge is at the bottom when the fabric is held upright. So the plain fabric can be unroved (unravelled) from either end. The ability of the structure to unravel from both edges is demonstrated in figure (Raz. 52). Note that this ability is limited to the most basic structures of the plain family when no special loop types are incorporated.

e. **Ladderin:** If a stitch is dropped during the knitting or at a later stage, a chain reaction may occur in which the following loops in the same wale will drop in
succession and a “ladder” will form. It is a fault but we consider it as properties. We mending (repair) it by manually with single needle. Since the fabric is symmetrical it might ladder vertically towards the bottom or the top. It must be appreciated that the tendency of the structure to curl, unravel and ladder is greater if the fabric is slack. The unraveling and laddering tendencies are also more severe when the fabric is made of smooth yarns.

This structure has the maximum covering power. Plain fabric is the commonest weft knitted fabric and is produced by widely different sorts of knitting machinery in all forms from circular fabric piece goods to fully-fashioned panels. It is the base structure of ladies hosiery, fully-fashioned knitwear and single jersey fabric.

End uses of plain knit structures:

Plain knit structures are used for basic T-shirt, under garments, men’s vest, ladies hosiery, fully-fashioned knitwear etc.
End use depends on some factors such as material used; yarn types and yarn count / linear density; machine gauge; fabric thickness and weight; types of finishing etc.

Notation of plain knit structure:

The following figure shows the symbols of one popular method used in many countries around the world. In this system an “x” symbol represents a face loop and an “o” is used to represent a reverse loop.

![Notation of plain knit structure](image)

The Rib Structure or Rib Fabric:

Rib, also called “Double-knit” is the second family of knit structures. Rib requires two sets of needles operating inbetween each other so that wales of face stitches and wales of back stitches are knitted on each side of the fabric. Rib fabrics are knitted on machines with two sets of needles. These needles are arranged in such a way as to allow them to intermesh when raised, and this needle arrangement is called rib gaiting. Flat machines with two sets of needles arranged in this way are usually called “V” beds because from the side they look like an inverted “V”. The needle beds are called the front and the back beds. Circular machines with two sets of needles have a dial and cylinder. The cylinder needles are arranged vertically round the machine and are the equivalent of the flat machine’s front bed. The dial needles are arranged horizontally inside the cylinder and are the equivalent of the flat machine’s back bed.
Many types of rib structures can be produced according to the arrangement of active needles in the front and back needle beds. The simplest rib structure is the 1×1 rib. To knit this structure, all the needles in both needle beds are active. The arrangement of the needles, each positioned in between two from the opposite bed and a sequential movement, ensure that the loops are produced alternately, one towards the front and one towards the back. When every third needle is inactive and is positioned between two active needles on the opposite bed the 2×2 rib fabric is formed.

The general characteristics of the rib structure family are as follows:

a. **Appearance:** Same appearance in both sides of the rib fabric. Both sides of the fabric will show face loops since the fabric is produced on the needles of both needle beds. Taken off the needles, the fabric contracts immediately in a widthwise direction. The rear or back loops which can normally seen between the front wales when the fabric is extended, will be hidden. The fabric looks as if it is made only of face loops on both sides, hence such names as right / right, Double face or Double knit. Each wale in the fabric is uniform i.e. made of a single type of loop, either face or reverse. On each side of the fabric there are face and reverse wales. The arrangement is alternate in 1×1 rib and different in various other rib structures. The fabric usually being symmetrical on both sides, is not subjected to unbalanced stresses.

![1x1 Rib structure (Face side)](image1)

![1x1 Rib structure (Back side)](image2)

b. **Extensibility:** The 1×1 rib is an elastic structure with good widthways recovery after it has been stretched because the face loop wales move over and in front of the reverse loop wales. The rib fabric is very elastic and springy in the width direction due to the tendency of the yarn to straighten and resume its previous shape. This special property of the rib structure in the width direction is frequently used to form the elastic bands in garments. In a similar way to plain knits, rib structures are stretchable rather then elastic in the length direction. The amount of possible stretch, however, is quite limited. Extensions of up to 120% can be obtained along the course, with normal constructions. Along the wale, rib fabric behaves very much like plain fabric, with very limited extensibility.
Other constructions of rib are possible and are widely used, such as two wales of face loops alternating with two wales of back loops to form 2×2 rib. On the same basis there are 3×3, 2×1, 3×2 rib etc. As the number of wales in each rib increases, the elasticity decreases because the number of changeovers from back to front diminishes. Over 3×3 rib the fabric more and more behaves like plain fabric, even curling in favour of the dominant rib. Such structures are known as “broad ribs”.

1×1 Rib structure (Face side)  
1×1 Rib structure (Back side)

Edge curling: The fabric being in many cases symmetrical on both faces is not exposed to unbalanced stress and therefore does not curl, it lies flat, when cut.

Unroving: Rib structures can easily be unravelled from the edge knitted last i.e. the top when the fabric is held upright as produced on the knitting machine. Rib structures however, cannot be unravelled from the edge knitted first i.e. from the bottom. The arms of the connecting loops enter the loops above them from both sides. Any attempt to pull the yarn causes the connecting loops to tighten and blocks unravelling. Because ribs cannot be unroved from the end knitted first and because of their elasticity, they are particularly suited to the edge of garments such as the tops of socks, cuffs and the waist edge of garments.

Inability of 1×1rib to unrove from the lower edge
e. **Ladder**: A dropped stitch can start a chain reaction and produce a "ladder" in the structure. The tendency of drop stitches to run is increased when the fabric is produced of smooth yarns, when the loops are large and when the fabric is stretched. In rib structures, drop stitches can only run towards the edge knitted first i.e. downwards when the fabric is held upright. The stitches cannot run in the other direction since connecting loops in rib are anchored. Such a property reinforces the argument for using ribs on the extremities of garments.

![2x2 Rib structure](image)

f. **Weight and thickness**: Rib structures are bulkier and heavier than plain knit structures made of a similar yarn thickness on machines of a similar gauge. The width of a 1x1 rib fabric is approximately half the width of a plain stitch fabric when knitted with the same length of yarn in the loop and the same number of loops in a course. On the other hand, thickness, weight and extensibility of the rib structure are approximately twice that of the corresponding plain fabric. After removing from the machine a 1x1 rib fabric shrinks in width so that the front loops cover the back ones. This phenomenon is accompanied by a thickness increase to approximately twice that of a plain knit fabric.

**End uses of rib structures:**

Wide range of uses, waist bands, cuffs and collars are typical applications, together with whole garments of a fitting nature. Rib fabrics are used where portions of garments are expected to cling to the shape of the human form and yet be capable of stretching when required. Cotton rib knitted fabric, bottom of the sweater, skirt belt, various types of fancy borders, under wears, sweaters etc.

**Notation of Rib structures:**

![1x1 rib structure](image)

![3x3 rib structure](image)
The Purl Knit Structures or Purl Fabrics:

The third family of knit structures is the purl knit. As with rib structures, it requires the participation of both needle beds for the production of the loops. The German name Links / Links, which can be translated as Left / Left or Reverse / Reverse, is widely used even in English speaking countries.

Purl fabrics are knitted on machines with special equipment (one set of needles), which are double-ended latch needles and special devices of drive them, allowing loops to be intermeshed in two directions. Purl fabrics are characterized by the fact that they have face and reverse loops in the same wale. This type of structure can only be achieved on purl machines or by rib loop transfer. Rib machines will knit purl structures if loop transfer between the beds is possible. Loops on the front bed can be transferred to needles on the back bed and vice versa to produce face and reverse loops in the same wale.

On a purl machine, the tricks (the slots in which the needles are located) of the two needle beds are directly opposite and in the same plane. This allows the double-ended needles to be transferred across from one needle bed to the other, enabling fabrics to be made that have face and reverse loops in the same wale.

There are two types of purl machine – Flat purls, the needle beds of these machines are set on the same plane instead of being in an inverted “V” formation and circular purls, which have two superimposed cylinder one above the other so that the needles move in a vertical direction, both types of machines are capable of producing garment length or other article sequences.

The knitting procedure of the flat purl knitting machine, called a “Links / Links” machine is described below:

As can be observed, there is one set of needles for both needle beds and the procedure is as follows:

I. The needle is positioned in the front needle bed in which it has just formed a face loop.
II. The needle slides through the loop toward the rear needle bed.
III. A reverse loop is produced by the other needle head through the previous face loop within the same wale.
IV. The needle slides through the loop toward the front needle bed.

The popularity of the purl flat knitting machine has been reduced during the last few years, as the sophisticated “V” bed flat knitting machines developed. However, a large number of purl flat knitting machines can still be found on production lines around the world.
To produce a purl knit structure on a “V” bed flat knitting machine, a loop transfer ability is required. The simplest 1x1 purl structure is produced according to the following procedure:

I. A course is knitted on the front needle bed while the rear bed remains idle.
II. All the loops are mechanically taken from the needles of the front needle bed and transferred to the empty needles of the rear bed.
III. A course of reverse loops is now knitted by the needles of the rear bed through the transferred loops.
IV. All the loops are now transferred from the rear needles to the front needles, which in the next cycle knit through them.

Not all loops have to be transferred after the completion of each course. The 2x2 purl structure is produced when two courses are knitted on each needle bed before the transfer operation.

When the knitting machine is sophisticated enough to handle both loop transfer and needle selection, the variety of possible purl structures is unlimited.

Although the purl knit family includes many different structures, the general characteristics can be summarized as follows:

a. Appearance: Each wale can be made up of a combination of face and reverse loops. Each course can be made up of a combination of face and reverse loops. Basic purl knit structures such as 1x1 or 2x1, contract in the length direction. The face loops are covered so the needle and connection arches typical of reverse loops show on both sides. The popular German term “Links / Links”, meaning “Left / Left” or “Reverse / Reverse”, is based on this fabric appearance.

b. Extensibility: Fabric made of the above basic purl structures have, due to contraction, a horizontal rib effect which makes them elastic in the length direction. This is an advantage, especially when compared with the very limited lengthwise extensibility of plain or rib structures. The fabric is stretchable in the
width as with all loop-based structures. Due to the contracting tendency of the structure in length, the fabric is elastic in this direction which is unusual for other knit structure families. This flexibility in length and width makes the purl knit ideal for baby wear where elongation and expansion are required due to the fast growing rate of infants and to simplify the dressing process.

c. **Edge curling:** The fabric is usually balanced and does not tend to curl. This however depends on the arrangement of the loops on the face and reverse side of the fabric. An unbalanced arrangement can result in a certain amount of curling.

d. **Unroving:** Purl knit structures can easily be unraveled from the edge knitted last i.e. the top edge of the fabric when held upright, as produced on the knitting machine. Basic 1×1, 2×1 and other purl structures in which each course is made of only one type of loop, behave like plain knits when unravelling is concerned. They can be unravelled from both ends.

e. **Laddering:** A dropped stitch can easily start a chain reaction and produce a “Ladder” in the fabric. As in all knit structures, the dropped stitch can run downwards when the fabric is held upright. Basic structures like 1×1, 2×2 etc. behave as plain knits where laddering is concerned and stitches can run in them either upwards or downwards.

f. **Weight and thickness:** The fabric is very bulky and soft to the touch. Purl knits are usually bulkier than plain knits produced from the same yarn thickness and on the same machine gauge. It has excellent thermal insulation properties.
As with rib fabrics there are other combinations of simple purls, such as 2×2, 3×3 etc. These are uncommon, however, and not particularly useful. Unlike the rib fabric, however, the classification “purl” covers any fabric with face and back loops in the same wale. This covers a vast range of fabrics with designs in back and face loops, known as “fancy purls”. Another term used, particularly in the USA is “links-links”.

End uses:
Purl fabrics are widely used for baby wear children’s clothing, sweater, knitwear, thick and heavy outerwear, under garments etc.

**Notation of 1×1 purl knit structure:**

```
O O O 3 O O O
X X X 2 O O O
O O O 1 O O O
```

**The Interlock Structures or Interlock Fabrics:**

Interlock is another 1×1 rib variant structure which is produced on specially designed machines. These machines possess two sets of needles (short and long needles) in both cylinder and dial and at least two feeders. For normal interlock, the needles in both cylinder and dial are arranged to be alternately long and short, and at the odd feeders the long needles are selected to knit and at the even feeders, the short needles are selected to knit. At each feeder a 1×1 rib structures knitted at adjacent feeders interlace each other and form a double 1×1 rib fabric. So interlock fabric is produced by two 1×1 rib structure interlace to each other.

Interlock has the technical face of plain fabric on both sides, but its smooth surface cannot be stretched out to reveal the reverse meshed loop wales because the wales on each side are exactly opposite to each other and are locked together.
Basic interlock is a balanced, smooth, stable structure that lies flat without curl. Like 1×1 rib, it will not unrove from the end knitted first, but it is thicker, heavier and narrower than rib of equivalent gauge, and requires a finer, better, more expensive yarn. It also possesses good recovery properties.

When two different-coloured yarns are used, horizontal stripes are produced if the same colour is knitted at two consecutive feeders, and vertical stripes if odd feeders knit one colour and even feeders knit the other colour. The number of interlock pattern rows per inch is often double the machine gauge in needles per inch.

**Notation of Interlock structures:**

Eightlock is a double-faced interlock based fabric that usually repeats over four wales. It is a 2×2 version of interlock that may be produced using an arrangement of two long and two short needles, provided all the tricks are fully cut through to accommodate them and knock-over bits are fitted to the verges to assist with loop formation on adjacent needles in the same bed.
It was first produced on double-system Vee – bed flat machines having needles with butt positions, each having its own cam system. This involved a total of eight locks, four for each needle bed, making one complete row per traverse. Set-outs for 4×4 and 3×3 can also be produced.

It is a well-balanced, uniform structure with a softer, fuller handle, greater widthwise relaxation, and more elasticity than interlock fabric. Simple geometric designs with a four wale wide repeat composed of every two loops of identical colour, can be achieved with careful arrangement of yarns.

Comparison between basic structures of weft knitted fabric:

<table>
<thead>
<tr>
<th>Property</th>
<th>Structure</th>
<th>1x1 Rib</th>
<th>1x1 Purl</th>
<th>1x1 Interlock</th>
</tr>
</thead>
<tbody>
<tr>
<td>Practical view</td>
<td>Plain</td>
<td>1x1 Rib</td>
<td>1x1 Purl</td>
<td>1x1 Interlock</td>
</tr>
<tr>
<td>Appearance</td>
<td>Different on face and back; V-shapes on face, arcs on back</td>
<td>Same on both sides, like face of plain.</td>
<td>Same on both sides, like back of plain.</td>
<td>Same on both sides, like face of plain.</td>
</tr>
<tr>
<td>Extensibility</td>
<td>Moderate (10–20%)</td>
<td>Moderate Very high</td>
<td>Very high</td>
<td>Moderate Moderate Moderate</td>
</tr>
<tr>
<td>Widthwise Extensibility</td>
<td>High (30 – 50%)</td>
<td>Very high (50-100%)</td>
<td>High</td>
<td>Moderate Moderate Moderate</td>
</tr>
<tr>
<td>Widthwise Area</td>
<td>Moderate- high</td>
<td>High</td>
<td>Very high</td>
<td>Moderate Moderate Moderate</td>
</tr>
<tr>
<td>Thickness and Warmth</td>
<td>Thicker and warmer than plain woven made from same yarn</td>
<td>Much thicker and warmer than plain woven</td>
<td>Very much thicker and warmer than plain woven</td>
<td>Very much thicker and warmer than plain woven</td>
</tr>
<tr>
<td>Unroving</td>
<td>Either end</td>
<td>Only from end knitted last</td>
<td>Either end</td>
<td>Only from end knitted last</td>
</tr>
<tr>
<td>Curling</td>
<td>Tendency to curl</td>
<td>No tendency to curl</td>
<td>No tendency to curl</td>
<td>No tendency to curl</td>
</tr>
</tbody>
</table>
Identification of Single jersey and Double jersey fabric:

Weft knitted fabrics may be approximately divided into single or double jersey (double-knit) according to whether they were knitted with one or two sets of needles.

Single jersey fabrics have the following features –

- All face loops are in one side and all back loops are in other side.
- Both sides should be different appearance.

Double jersey fabrics have the following features –

- Both sides of the fabric contain only face loops (basic rib and interlock fabrics) or only back loops (basic purl fabric) or combination of face and back loops.
- Both sides are same appearance for basic and balanced structure, but different on other structures.
As mentioned in the previous chapter, the basic structure families were introduced as being constructed of only one type of knitted loop. In reality however, most knitted structures contain, in addition to the standard knit loops. The standard loop is a flexible formation, can easily change its shape under small loads and is responsible for the stretchable characteristics of the fabric.

A knitted loop stitch is produced when at each yarn feed, a needle receives a new loop and knocks-over the old loop which is held from the previous knitting cycle, so that the old loop now becomes a needle loop of normal configuration.

Other types of stitch may be produced on each of the four needle arrangement base structures by varying the timing of the intermeshing sequence of the old and new loops. These stitches may be deliberately selected as part of the design of the weft and warp knitted structure or they may be produced accidentally by a malfunction of the knitting action so that they occur as fabric faults.

When these stitches are deliberately selected, a preponderance of knitted loop stitches is necessary within the structure in order to maintain its requisite physical properties. Apart from the knitted loop stitch, the two most commonly-produced stitches are the float or miss stitch and the tuck stitch. Each is produced with a ‘held loop’ and shows its own particular loop most clearly on the reverse side of the stitch as the limbs of the held loop cover it from view on the face.

To simplify explanations, all knit structure families were described as being made only of basic loops. In reality however, other loop types exist which, together with the simple one, combine to enhance the patterning potential and the variety of knitted garments.

**The held loop:**

A held loop is an old knit loop which the needle has retained and not released and knocked-over at the next yarn feed. A held loop can only be retained by a needle for a limited number of knitting cycles before it is cast-off and a new loop drawn through, otherwise the tension on the yarn in the loop becomes excessive even though there is a tendency to rob extra yarn from adjacent loops in the same course.
The limbs of the held loop are often elongated as they extend from its base intermeshing in one course to where its head is finally intermeshed a number of courses higher in the structure, alongside it in adjacent wales there may be normally-knitted loops at each course. So the size of the held loop is bigger than the normal knit loop and held loop is produced at the same time when tuck and miss loop will be produced.

Held loops are obtained by changing or obviating some operations from the usual cycle of loop formation.

On knitting machines equipped with latch needles three methods are used in order to obtain the held loops

a. Tucking on the latch – without cast-off operation in loop forming cycle
b. Tucking in the hook – without clearing operation in loop forming cycle.
c. With switching a needle out of action for a loop forming cycle.

a. When tuck or held stitch formation is performed without cast-off (figure – a), joining, casting-off and sinking are excluded from the loop formation cycle. In this case, the needles 4 and 7 knit the loops 3 and 6, while the needle 5 performs all the operations up to joining, and stops. Then a new yarn 2 is fed in its hook and this will be the tuck loop. The old loop 1 remains on the closed latch and this will be the held loop.

b. When tuck stitch formation is performed without clearing operation (figure - b) the selected needle is lifted for incomplete clearing. After clearing on needles 4 and 7 has been performed, these needles are fed with the yarn 3 from which they knit normal loops. At the same time the selected needle is lifted just enough for the old loop1 to open its latch but the loop 1 remains on the opened latch. Having been fed with the yarn 3 the needle 5 does not knit a loop, as there will be no pressing, landing and
further operations; the held loop 1 and the tuck loop from yarn 3 are in the hook of needle 5. In this method control of held loop length is possible, as the operation of sinking is performed by the needle holding the loop 1.

c. Held loop formation by switching a selected needle out of action can be performed by two methods. One of them is based on simple leaving the needle idle in lowest position for one (or two, three) loop formation cycle; The other method consists in leaving the needle in its top most position for the rest of loop formation cycle in question (figure – c). In this cycle, the needles 4 and 7 knit the loops 3 and 6 from the fed yarn, performing all necessary operations. In the next cycle the needle resting in its top most position forms a new loop.

In both cases, the yarn of which loops 3 and 6 are made, remains in form of a long floating link between loops 3 and 6; the long link (a float) is laid on the held loop 1. The process of producing held loops is described with the term "missing".

The Float Stitch or Loop:

The float stitch which is also called a 'miss' or 'welt' stitch is a variation of the basic loop structure. It is created in the fabric when a needle is inactive. The previous loop is held within the hook, the yarn fed from the yarn carrier fails to reach the needle and so skips over it.

A float stitch is composed of a held loop, one or more float loops and knitted loops. It is produced when a needle holding its old loops fails to receive the new yarn which passes as a float loop, to the back of the needle and to the reverse side of the resultant stitch, joining together the two nearest needle loops knitted from it. The float stitch shows the missed yarn floating freely on the reverse side of the held loop which is the technical back of single jersey structures, but is the inside of rib and interlock structures.

The following figure shows the effect created on the face of the fabric by a knitting sequence called “missing”. As the schematic illustration shows, the main effect is created by two elements i.e. an enlarged knitted loop and a straight element of yarn.

![Face side of Single Miss or Float Stitch](image-url)
As suggested by its name, the miss stitch effect is created when one of the knitted loops is missed during the production sequence. The deformed loop is the result of a needle which has not participated in one sequence of loop formation. It has retained its loop longer than the rest of the needles.

A following macro photograph, shows the actual configuration of the miss stitch. The deformed, stretched loop, tends to rob some yarn from its adjacent loops and so reduces them in size.

In some cases, the excessive pull on the yarn in the stretched loop may pull the yarn from loops which are even farther away from the miss stitch.

The effect of the miss stitch looks different from the reverse side of the structure, as illustrated in the following figure. On this side the straight segment of yarn is visible on the surface.

The loop formation of a float stitch:

The following series of diagrams show the forming procedure of a miss or float stitch.

1. Only two of the needles ascend to clearing position and clear the latches. The needle in the centre fails to ascend and remains in the lower position while holding onto its loop.
2. The yarn carrier travels across the machine feeding new yarn into the hooks of the active needles.

3. Active needles descend to knockover and form new loops. The needle in the centre creates the "miss" effect by retaining its loop. The connecting yarn between the newly formed loops simply passes behind it. The elongated loop formation is called a "held" loop.

The notation of the float stitch:

The inactive needle and the unformed loop are shown in notation systems by empty spaces. When the fabric is illustrated in squares, the appropriate square is left blank as illustrated in the following figure. The notation in this figure is of the structure presented in the above figure. These structures are produced on a knitting machine with one needle bed only. The two common notation systems in squares are shown as used in the English speaking countries (a) and in Germany (b).

![Diagram of knitting notation systems](image)

When the needle notation system is used, the yarn is simply drawn as skipping the inactive needles, much the same as in actual practice. The illustration in the above figure (right) is of the same structure as in the previous above figure. It is drawn to demonstrate the miss stitch effect, as produced on a Vee-bed flat knitting machine with two needle beds.

While the notation in squares represents the structure in a pictorial mode, the needle notation system represents the knitting sequence, course by course, as produced by the machine.

The properties and uses of the float or miss stitch:

The practice of missing certain needles during the knitting procedure is widely used in the flat knitting trade. The various uses and the loop properties exploited are:

- Knitting plain knits. When the raising cams of one needle bed are completely withdrawn to miss all the needles, the machine knits with the other needle bed only. It produces a plain knit structure, as illustrated in all notation system in the following figure. The missing procedure can be carried out on the front needle bed so the rear needle bed is active (a) or on the rear needle bed leaving the front active (b). The
blank squares in the English and German systems are the inactive (missing) needles of the inactive needle beds.

- Knitting a variety of rib structures. Besides the 1×1 rib, all other rib structures require some of the needles to miss. The 2×2 (in German 2:1) in the following figure (a) is the most popular rib structure for garments elasticated welts. As can be observed from the illustration, in each needle bed two needles are active and one misses. In another rib structure shown in the figure (b), the combination of active and missing needles is different.

Note that in notation in squares, the 2×2 rib is not marked with two face loops and two reverse loops. Instead, it is marked as produced on the machine i.e. the inactive missing needles appear as blank squares.

- Improvement of the fabric's widthwise stability. A missed loop, creates a short connection between two adjacent wales and eliminates the accordion effect of the rib. Straight segments of yarn formed in the fabric, ensure that the stretchability of the structure is reduced. The result is a much more stable construction.

- Decrease of fabric width. Short connections between the wales, as shown in the previous paragraph, affect the fabric width. A large number of miss stitches in a course reduces the fabric width considerably.

- The production of jacquard structures. The main use of miss stitches, in a selected fashion, is for the creation of jacquard fabrics.

Almost two hundred years ago, Joseph Marie Jacquard, the son of a weaving master from Lyon, France, invented the patterning mechanism equipped with punched cards, that made his name immortal. Today, every elaborately coloured patterned effect in knitting and in weaving, bear his name. The original invention and perforated cards have long since been replaced.
In flat knitting, the jacquard effect is created when each course is produced of several coloured yarns according to a predetermined design. In practice, the machine knits each course in a sequence of operations as follows:

a. One yarn knits on selected needles while other needles miss.
b. The second yarn then knits on other selected needles which were missed during the previous operation.
c. The operation continues until all the needles in the course have been knitted with one of the yarns.
d. The following courses are knitted in the same way according to the design.

A segment of a two colour jacquard design is illustrated in the following figure showing that each of the yarns misses where the other knits. The long segments of yarn created by the yarn misses are call “floats”. They are present on the reverse side of the fabric and can in some cases cause snagging problems when the garment is worn.

- The use of the structural deformation. The structural deformation resulting from a missing sequence can be used as a patterning effect on the fabric. The miss stitches have to be arranged according to a predetermined design to create such a pattern. To increase the size and boldness of the deformation, the missing sequence can be repeated as shown in the following figure. The same needle is missed for two consecutive courses, the held loop is stretched even more and the deformation is greater.
The repeated missed sequence is limited by the properties of the yarn forming the held loop. The load is placed on this yarn and the number of misses possible depends on its tensile properties.

- Marking of garments. The different appearance of the missed loop can be used for the marking of cutting lines. Arm holes or a "V" neck lines can be defined on garments, during the knitting process. On longer production lines, garments can be code marked in a hidden place to allow machine recognition and trouble shooting during later production processes.

**The Tuck Loop or Stitch:**

The tuck stitches are the knitted structures in which certain loops are intermeshed with elements of two kinds: tuck loop and held loops. Tuck stitches can be weft and warp knitted, and are produced on machines equipped with any known types of needles.

A tuck stitch is composed of a held loop, one or more tuck loops, and knitted loops. It is produced when a needle holding its loop also receives the new loop which becomes a tuck loop because it is not intermeshed through the old loop, but is tucked in behind it on the reverse side of the stitch.

Its side limbs are therefore not restricted at their feet by the head of an old loop so that they can open outwards towards the two adjoining needle loops formed in the same course. The tuck loop thus assumes an inverted 'V' or 'U' - shaped configuration. Tuck stitch structures show a faint diagonal line effect on their surface.

In analysis, a tuck stitch is identified by the fact that its head is released as a hump shape immediately the needle loop above it is withdrawn, whereas a knitted loop would require to be separately withdrawn and a miss stitch would always be floating freely on the technical back.

The following figure shows a stitch created by a knitting sequence called "Tucking". The effect is created by an enlarged knitted loop with a segment of yarn tucked behind it. A comparison with figure of the miss stitch, reveals a similarity to the float stitch construction. The stretched loop appears in both miss stitch and tuck stitches.

The tuck stitch is formed, as suggested by its name, when the yarn is tucked into the structure by the needle, instead of being formed into a loop. The stretched deformed loop originated as a normal knitted loop which was held by the tucking needle while the other needles knitted an additional course.
A following macro photograph shows the actual yarn configuration of the tuck stitch effect. As with the miss stitch, the deformed stretched loop, robs some yarn from the adjacent loops thus reducing them in size.

An important features of the tuck stitch is that the tucked yarn is placed behind the stretched face loop, as shown again in the above figure, drawn from the reverse side. This is important when a yarn should not appear on the fabric face, as further explained in next tropics.

The Tuck stitch formation:

In the series of following diagrams, the forming procedure of a tuck stitch is shown. The different steps in the sequence are:

1. The previously formed loop is in the hook of the needle which now starts to ascend.

2. The needle’s ascent is stopped short of clearing position with the loop still placed on the needles latch.
3. A new yarn is fed into the descending needle. Since the new yarn is not pulled through the previous loop, it does not acquire a loop shape. Instead, it is simply placed in the hooks enclosure together with the previous loop. The adjacent needles have formed new loops during this sequence, so the previous loop held by the tucking needle is now stretched and deformed.

4. The needle now ascends to clearing position and both previous loop and tucked yarn drop under the latch.

5. The descending needle is fed with a yarn. The previous loop together with the tucked yarn slide under the latch, close it and slide over the hook.

6. The new yarn is pulled into knockover position and forms a new loop. Note that the tucked yarn is hooked between the two knitted loops.

"Tucking in the hook", described above, is the modern way of tuck stitch formation. There is another way for forming a tuck stitch, as described in the following series of diagrams. This sequence, called "Tucking on the latch", is described as follows:
1. The previous loop is held within the needle’s hook which now ascends to clearing position.

2. At clearing position, the previous loop is dropped under the latch. A new yarn is fed into the hook of the needle, which now starts to descend.

3. The descent is stopped short of knockover position with the previous loop still on the outside of the latch. The new yarn has not been pulled into the previous loop and has not acquired a loop shape.

4. The needle ascends again to clearing position. Both the previous loop and the yarn within the hook drop under the latch. A new yarn is now fed into the descending needle.

5. The previous loop and yarn slide under the latch, close it and slide outside of the hook. The newly fed yarn is in the hook’s enclosure.

6. The needle is pulled into knockover position while forming a new loop through the previous one. The yarn fed into the hook during the previous cycle assumes a tuck formation identical to the one described above.

Tucking on the latch (without cast off operation)
The sequence of tuck forming “on the latch” by restricting the movement to knockover, is not as reliable as the “tucking in the hook”. Loops may accidentally slip off the latch during the shortened descent and a normal loop may form instead of a tuck stitch. The method is used in older machines which are restricted by their raising cams arrangements.

For obtaining a tuck stitch on spring-bearded needles, the most widely used method consists in obviating the operation of pressing. Selected needles are not pressed during loop formation, and under the not pressed needle hook both the newly fed yarn and the old loop are slid. The not pressed needle does not perform the operation of old loop casting-off.

For manufacturing the tuck stitches, knitting machines with spring-bearded needles require special pressers. In some knitting machines with spring-bearded needles special pattern pressers are used. The needles have their individual pressers which can be switched in for pressing or switched off for tucking. The best example of such machines are the Cotton Patent machines; their pressers are made of a series of segments individually driven for knitting or tucking.

In warp- knitting machines with spring-bearded needles moving in unison (tricot machines), so called “cut pressers” are employed which are made of a steel or plastic bar with cut-outs at the pressing edge. The cut-outs can be covered in order to control the process of tucking. Compound needles form tuck or held stitches either without sinking or without pressing.
The notation of the tuck stitch:

A tuck stitch can be simulated in the various notation systems as shown in the following figure. In one notation system in squares (a), the tuck stitch is symbolized by a large dot regardless of the needle bed in which it is formed. If a dot is marked in a wale of a front needle, then it is produced by such a needle.

![Tuck Stitch Notation](image)

The German standard notation system in squares (b), uses a ‘V’ and an inverted ‘V’ shape to symbolize the tuck stitches. A ‘V’ marks a front tuck and a ‘N’ marks a rear tuck.

When the needle notation system is used, the yarn is marked as fed into the needle but without forming a loop. The above right figure is the notation of the tuck effect drawn in the previous figure.

The Properties and Use of the Tuck Stitch:

Tuck stitches are widely used in the production of Vee-bed flat knitted garments as well as in the production of cut and sew knit wear from circular knitting machine. They are used for the following reasons:

a. Fabric patterning. The different appearance of the tuck stitch, in comparison with the regular standard loop background, can be used for patterning. The stretched elongated held loop relaxes on leaving the knitting zone, forming a small buckle on the face of the fabric. When tuck stitches are arranged on the garment according to a plan, a design is formed. This however requires a needle selection system on the knitting machine.

To increase the effect, a needle can tuck for consecutive knitting sequences. The illustration in the following figure shows the arrangement of the yarn after two consecutive tucking operations. The held loop is further stretched and the needle has gathered three yarns within the hook before clearing. Consecutive tucking operations and the shrinking forces applied by the held loop, can create large knobs on the fabric plain.

The number of consecutive tucking operations is restricted by the tensile strength of the yarns in the held loop. It is also limited by the size of the needle’s hook in relation to the collective thickness of the yarn ends. While in older machine types four...
consecutive tucks have been possible, modern equipment can produce up to eight or even ten such consecutive sequences.

Each side of the head of a tuck loop is held by a sinker loop from the course above. When tucking occurs across two or more adjacent needles, the head of the tuck loop will float freely across between these two sinker loops, after which a sloping side limb will occur. Dependent upon structural fineness, tucking over six adjacent needles is usually the maximum unit before snagging becomes a problem.

b. Increasing fabric weight and thickness. The tuck yarn is added to the standard loop without a knitting sequence and no new loop is produced. A large number of tuck stitches can thus add to the weight and thickness of the fabric.

Such a structure is the "cardigan", illustrated in the following notation figure. While the front needle bed knits, the needles of the back bed tuck. In the following sequence, the procedure is reversed. In this way, one course is produced every two knitting cycles and the fabric advances only one course spacing while containing two yarn ends.

The cardigan fabric is therefore very heavy, bulky, insulating and is suitable for heavy outerwear garments.

c. Increasing fabric width. The principle described above also shows why fabric width increases as a result of a large number of tucks. This increase is caused by the presence of more yarn in the structure, and the restrictive forces applied by the tuck courses to the tendency of the rib to contract.

d. Insertion of problematic yarns. Not all yarns are able to be formed into the shape of a loop due to their mechanical properties. With tucking procedures, such yarns can
inserted into the fabric with only a minimum of bending stresses shows in the following figure. Note that while the central needle tucks, the rest of the needles miss. The fabric does not advance and the loop of the tucking needle is not stretched.

Every knitting machine is restricted by the thickness of the yarn which can be processed and turned into a fabric. Contrary to popular belief, the thickness of the yarn is not limited by the size of the hook.

It is limited by the size of the trick in the needle bed, into which it is pulled in the knockover position. Tucked yarns need not pulled into knockover position, as described before. Yarns which are much too thick for regular knitting can thus be inserted in the fabric by tucking.

e. Shortening of jacquard floats. As described in previous part, long floats can be formed on the reverse side of the fabric as a result of a jacquard patterning sequence. These floats can easily be pulled by such objects as a ring or a wrist watch, resulting in loop distortion on the fabric face and damage to the garment. To reduce the size of such floats, lessening the danger of snagging, tucks can be introduced along the float. In this respect, the tuck construction has two advantages:

- No loop is formed so no yarn in wasted.
- The tucked yarn is placed behind the face loop and does not interfere with the design.

The reverse side of a jacquard structure with long floats is illustrated in the following figure with a tuck stitch introduced into one float to show its advantages.

f. Garment marking. The different appearance of the tuck stitch, in comparison with the standard loop background, can be used to mark cutting lines in the garment
during the knitting process. Furthermore, the knitting machine can code mark the garment in an obscure place to allow machine identification for quality control during later production stages.

Successive tucks and floats on the same rib needle

The Drop or Press-off Stitch:

Dropped stitches are usually associated with knitting failures. They can however be employed to pattern a fabric, if used according to a controlled procedure.

The formation of a Dropped stitch:

The following figures show the procedure by which a stitch is dropped. The stages are:

1. The needle ascends to knitting position in which the loop within the hook clears the latch.

2. No yarn is fed to the needle which then descends. The loop slides under the latch, closes it and slides over the needle’s hook.

3. The needle is pulled into knockover position and the loop drops from it.

The notation of the dropped stitch:

A dropped stitch has no special notation symbol and is shown simply as a knitting needle. Sometimes however, the yarn simulated in the needle notation system is drawn as a broken line to suggest that contrary to normal procedure no yarn is being fed.
The Properties and Uses of the Dropped Stitches:

A drop stitch fault will result if a needle releases its old loop without receiving a new one, sometimes this technique is used to achieve a press-off on all needles in a set between garment length sequences. A drop stitch or press-off stitch is used very occasionally in flat knitting to cause certain loops in a plain structure to be much larger than the rest.

Knitting takes place on only one bed of needles and selected needles in the other bed pick-up loops which are immediately pressed-off by not receiving a new yarn. The yarn from the pressed-off loops flows into the adjacent loops in the other bed making them larger, giving the impression of a much coarser gauge.

Drop stitch wales are sometimes used to provide a guide for the cutting operation. A secure structure is only produced when a needle retains its old loop if it does not receive a new loop.

Previous chapters have shown that a dropped stitch creates a “Ladder” in the fabric by creating a chain reaction in the wale. To control the procedure and to be able to stop the ladder at a specified point, a special wale needs to be formed.

The patterning procedure with dropped stitches starts with a new wale being introduced into the fabric by a needle which previously was inactive. Several knitting sequences later, the same needle is programmed to drop its stitch. The chain reaction which develops, runs down the wale and stops at its root. The loops adjacent to the ladder increase in size, as shown in the above figure.
DESIGNS OF WEFT KNITTED FABRICS

As mentioned in the previous chapter there are only four knit structure families, the combination of which makes all the knitted fabrics and garments produced in weft knitting. To simplify explanations, all the basic weft knit structure families were described as being made only of basic knit loops. In reality however, other loop types exist which, together with the simple one, combine to enhance the patterning potential and the variety of knitted fabrics and garments.

All the knit structures excluding the basic structures are made of a combination of the three loop structures described previous chapter i.e. the standard knit loop, the missed and the tucked stitch. When tuck or miss loop or both tuck and miss loop are combined with the standard knit loop in case of plain or single jersey structure then it is called derivatives of single jersey structures. Similarly there is lot of rib based structures i.e. called derivatives of rib structure, interlock based structure i.e. called derivatives of interlock structure and purl based structure i.e. called derivatives of purl structure.

Decoration or ornamentation of plain knit or single jersey fabrics:

A single jersey fabric is ornamented without deviating from the true principles of plain structure as follows:

- The yarn vary in colour, raw material, types of construction and in thickness. As the fabric consists of yarn and yarn is made up of fibres or filaments the ornamentation can start from the fibre, filament stages. Fibre dyeing, yarn dyeing, fabric dyeing are some of the means by which attractive colours can be provided to fibres, yarns, filaments or fabrics to enhance the beauty of the fabric.

- Threads of different colours are combined in stripe form. If different dyed or contrasting colours are used at different feeds by supplying packages of coloured yarn on a multi-feed machine of a single jersey structure, a variety of horizontal stripes can be obtained on the surface of the knitted fabric. For casual T-shirt garments such horizontal coloured stripes are commonly used.

- By using fancy yarns. Instead of simple regular single yarn, fancy yarn such as slub, knop, mélange, loop, crepe yarn etc. can be carefully knitted in the fabric to give some interesting results.
• By using different twisted yarns (such as hard twisted yarn is produced crepon effect). In staple fibre yarns, twist is given to a group of fibres in S or Z direction to form the yarn. If some courses are knitted with S-twist followed by some courses of Z-twist then a zig-zag path of wale lines is created on the fabric surface.

• In plated single-jersey knit fabric the characteristics of one yarn are visible on the surface composed of the face loop stitches whilst the characteristics of the other yarn are visible on the reverse surface composed of the back stitches. Sometimes back side is considered as face side, if coloured or fancy yarn pattern appears attractive from the reverse side. It is common practice for sweater.

• By using extremely fine gauge for finer yarn or coarse gauge (sweater) for coarser yarn.

• For children garments two or four colour bright prints of animals, birds, boys, girls or some letters or funny messages are printed which attract the customers. For knit goods transfer printing is popular, although block printing is used.

**Single Jersey Derivatives:**

The structural modifications are used to a very great extent in designing plain-knit structures by modifying the order of knitting. The plain knit structures can be modified with the following alternatives.

- Knit loop and miss loop
- Knit loop and tuck loop
- Knit Loop, miss loop and tuck loop.

The following figure illustrates the notations of some simple tuck and float stitch single jersey fabrics.

1. **Cross Miss Design:**

Cross miss is a miss-knit single jersey structure. So one set of needle is used to produce this structure. The repeat of the structure completes on two courses. Knitting sequence for a repeat as follows:

```
  2  
  1
```

- First course: Knit on all odd number needles and miss on all even number needles.
- Second course: Miss on all odd number needles and knit on all even number needles.

2. Birds Eye or Double Cross Miss Design:

Birds eye is a knit-miss single jersey structure. So one set of needle is used to produce this structure. The repeat of the structure completes on four courses. Knitting sequence for a repeat as follows:

```
  4  ●  ●  ●  ●  ●
  3  ●  ●  ●  ●  ●
  2  ●  ●  ●  ●  ●
  1  ●  ●  ●  ●  ●
```

- First course: Knit on all odd number needles and miss on all even number needles.
- Second course: Knit on all odd number needles and miss on all even number needles. Similar as first course.
- Third course: Miss on all odd number needles and knit on all even number needles.
- Fourth course: Miss on all odd number needles and knit on all even number needles. Similar as third course.

3. Weft Locknit Design:

Weft locknit is a knit-miss single jersey structure. So one set of needle is used to produce this structure. The repeat of the structure completes on four courses. Knitting sequence for a repeat as follows:

```
  1  ●  ●  ●  ●  ●
  2  ●  ●  ●  ●  ●
  3  ●  ●  ●  ●  ●
  4  ●  ●  ●  ●  ●
```

- First course: Knit on all needles.
- Second course: Miss on all odd number needles and knit on all even number needles.
- Third course: Similar as first course knit on all needles.
- Fourth course: Knit on all odd number needles and miss on all even number needles.
4. Mock Rib Design:
Mock rib is a knit-miss single jersey structure. So one set of needle is used to produce this structure. The repeat of the structure completes on two courses. Knitting sequence for a repeat as follows:

- First course: Miss on first three needles and knit on second or next three needles.
- Second course: It is just opposite of the first course i.e. knit on first three needles and miss on second three needles.

5. Single Cross Tuck Design:
Single cross tuck is a knit-tuck single jersey structure. So one set of needle is used to produce this structure. The repeat of the structure completes on two courses. Knitting sequence for a repeat as follows:

- First course: Knit on all odd number needles and tuck on all even number needles.
- Second course: It is opposite of the first course i.e. tuck on all odd number needles and knit on all even number needles.

6. Double Cross Tuck or Polo Pique Design:
Polo pique is a knit-tuck single jersey structure. So one set of needle is used to produce this structure. It is a very popular structure to produce cut and sew knit wear. The prominence of the design appears on the back side of the fabric. The repeat of the structure completes on four courses. Knitting sequence for a repeat as follows:
- First course: Knit on all odd number needles and tuck on all even number needles.
- Second course: Knit on all odd number needles and tuck on all even number needles, which is similar as the first course.
- Third course: Tuck on all odd number needles and knit on all even number needles.
- Fourth course: Tuck on all odd number needles and knit on all even number needles, which is similar as the previous third course.

7. **Single Lacoste or Fred Perry Design:**

Single lacoste is a knit-tuck single jersey structure. So one set of needle is used to produce this structure. It is also a very popular structure to produce cut and sew knit wear. The prominency of the design appears on the back side of the fabric. The repeat of the structure completes on four courses. Knitting sequence for a repeat as follows:
- First course: Knit on all odd number needles and tuck on all even number needles.
- Second course: Knit on all needles.
- Third course: Tuck on all odd number needles and knit on all even number needles, which is opposite of the first course.
- Fourth course: Similar as second course knit on all needles.

8. Double Lacoste Design:

Double lacoste is a tuck-knit single jersey structure. So one set of needle is used to produce this structure. It is also a very popular structure to produce cut and sew knit wear. The prominence of this design near to the single lacoste fabric. The repeat of the structure completes on six courses. Knitting sequence for a repeat as follows:

- First course: Knit on all odd number needles and tuck on all even number needles.
- Second course: Same as first course i.e. Knit on all odd number needles and tuck on all even number needles.
- Third course: Knit on all needles.
- Fourth course: Tuck on all odd number needles and knit on all even number needles, which is opposite of the first course.
9. Simple Crepe Design:

It may be tuck-knit or miss knit single jersey structure. So one set of needle is used to produce this structure. The repeat of the structure completes on four courses. Knitting sequence for a repeat as follows:

- First course: Tuck on first needle and knit on all rest of the needles.
- Second course: Tuck on second needle and knit on all rest of the needles.
- Third course: Tuck on fourth needle and knit on all rest of the needles.
- Fourth course: Tuck on third needle and knit on all rest of the needles.
10. Cellular Blister or Popcorn Design:

It is a tuck-knit single jersey structure. So one set of needle is used to produce this structure. The prominence of the design appears on the back side of the fabric. The repeat of the structure completes on eight courses. Knitting sequence for a repeat as follows:

- **First course**: Tuck on first two needles and knit on second or next two needles.
- **Second course**: Similar as first course.
- **Third course**: Similar as first course.

- **Fourth course**: Similar as first course i.e. Tuck on first two needles and knit on next two needles.
- **Fifth course**: Knit on first two needles and tuck on second or next two needles.
- **Sixth course**: Similar as fifth course.
- **Seventh course**: Similar as fifth course.
- **Eighth course**: Similar as fifth course i.e. Knit on first two needles and tuck on second two needles.

11. Twill Effects:

It may be tuck-knit or miss-knit or knit-tuck-miss single jersey structure. So one set of needle is used to produce this structure. The prominence of the design appears on the back side of the fabric. The main features of this structure is that the diagonal line (twill line) appears on the fabric surface like as woven twill fabric. The repeat of the structure completes on several courses. The following figures show the knitting sequence for a repeat:
Double Jersey Derivatives based on Rib Structure:

A generic name applied to a range of knitted fabrics made on a rib or interlock basis, the construction of which is often designed to reduce the natural extensibility of the structure. The term is generally confined to fabrics knitted on machines of E10 gauge or finer and it may be classified as either non-jacquard or jacquard double jersey.

1. Double Piqué:

Double piqué is a double jersey fabric made on a rib basis, using a selection of knitted loops and floats. The two most important sequences are known as Swiss double piqué and French double piqué respectively, and the knitting sequences for each are shown in the following figure. Double piqué is also known as wevenit, rodier, and overnité.

**Swiss Double Piqué**

![Swiss Double Piqué Diagram]

**French Double Piqué**

![French Double Piqué Diagram]

a) **Swiss Double Piqué:** Knitting sequence for a repeat as follows –

- First course: Cylinder needles – all are produce knit loop.
  - Dial needles – odd number needles produce knit loop and even number needle produce miss loop.
- Second course: Cylinder needles – all are produce miss loop.
  - Dial needles – same as first course.
- Third course: Cylinder needles – same as first course.
  - Dial needles – odd number needles produce miss loop and even number needle produce knit loop.
- Fourth course: Cylinder needles – all are produce miss loop.
  - Dial needles – same as third course.

b) **French Double Piqué:** Knitting sequence for a repeat as follows –

- First course: Cylinder needles – all are produce knit loop
Dial needles – odd number needles produce miss loop and even number needle produce knit loop.
- Second course: Cylinder needles – all are produce miss loop.
  Dial needles – odd number needles produce knit loop and even number needle produce miss loop.
- Third course: Cylinder needles – same as first course.
  Dial needles – same as second course.
- Fourth course: Cylinder needles – all are produce miss loop.
  Dial needles – same as first course.

2. Half Cardigan Rib or Royal Rib:

It is a rib based structure in which a great number of tuck stitches are added to make the fabric heavy, wide and soft. From the below notation diagram it is clear that two knitting sequences are required to produce one repeat of this type of fabric.

A special effect is produced when one half of the cardigan repeat is substituted for a regular 1×1 rib structure. The new fabric is called a “Half Cardigan” and is produced according to the knitting notation system illustrated in the following figure. One side of the fabric, in this case the reverse side, is produced with tuck stitches and therefore looks like a “Cardigan”. The loops of the other side acquire a very rounded and attractive shape which is very typical for this structure.

![Knitting diagram](image)

The Knitting sequence for a repeat as follows –
- First course: regular 1×1 rib structure.
- Second course: tuck loop formed by the all needles of one bed and knit loop formed by the all needles of other bed.

3 Full Cardigan Rib or Polka Rib:

It is another variation of the 1×1 rib structure. In this case, even more tuck stitches are introduced which makes the fabric wider, heavier, bulkier and less flexible then the half cardigan or the usual 1×1 rib. Contrary to the previous example the full cardigan is symmetric on both sides. From the below notation diagram it is clear that
two yarns are inserted into the fabric in order to complete one full course i.e. loops on the one needle bed and loops on the other needle bed.

The two courses which make the “Cardigan” repeat are illustrated in the above needle notation system. The Knitting sequence for a repeat as follows –

- First course: tuck loop formed by the all needles of back bed and knit loop formed by the all needles of front bed.
- Second course: tuck loop formed by the all needles of front bed and knit loop formed by the all needles of back bed.

Because of the large number of tuck stitches, both Cardigan and Half Cardigan are very bulky, in comparison with other knit structures. They are sometimes very fashionable and are used for heavy outerwear such as sweater.

4. Half Milano Rib:

A weft-knitted rib-based fabric, consisting of one row of 1×1 rib and one row of plain knitting made on either set of needles. The appearance and characteristics of the fabric are related to the ratio of the course lengths of first (1) and second (2). The Knitting sequence for a repeat as follows –

- First course: regular 1×1 rib structure.
- Second course: plain structure, all needle of one bed is active and all needles of other bed is inactive.

5. Milano Rib:

A weft-knitted rib-based fabric. Each complete repeat of the structure consist of three components knitted in the sequences shown to give one row of 1×1 rib and one row of plain tubular knitting, the two component parts of tubular knitting usually being similar. The appearance and characteristics of the fabrics are related to the
ratio of the course lengths of two rows. The Knitting sequence for a repeat as follows:

- First course: regular 1x1 rib structure.
- Second course: plain structure, all needle of one bed is active and all needles of other bed is inactive.
- Third course: reverse of second course.

6. Roma Rib:

A weft-knitted rib-based structure. Each complete repeat of the structure consist of two components knitted in the sequences shown to give one row of 1x1 rib and one row of plain knitting. The Knitting sequence for a repeat as follows –

- First course: regular 1x1 rib structure.
- Second course: plain structure, all needle of front bed is active and all needles of back bed is inactive.

7. Lacoste Piqué:

Basically it is a derivatives of single jersey structure. This lacoste piqué is produced by using a selection of knitted loops and tuck loops. It can be produced on rib based machine, but it should be remember that for the production of this fabric one bed is active and other bed is inactive. In the following figure the front bed is active and back bed is inactive. The Knitting sequence for a repeat as follows –

- First course: all needles of front bed makes knit loop.
- Second course: odd number needles of front bed makes knit loops and even number needles of same bed makes tuck loops.
- Third course: same as first course.
- Fourth course: odd number needles of front bed makes tuck loops and even number needles of same bed makes knit loops.
8. Gaberdine or 2 × 2 Twill Fabric:
Gaberdine is a simple 2×2 twill double-blister fabric which is useful for fine-gauge men’s leisurewear. It has a four needle width repeat, with the dial needles all knitting the backing at every third (ground) feed. The following left figure shows a gaberdine fabric.

9. Poplin Fabric:
Poplin is a flatter structure. It is used for the same purpose of gabardine fabric. It is a type of single blister with a two needle width repeat. The above right figure shows the notation diagram of a poplin fabric.
10. Blister fabric:

A three-dimensional relief effect fabric generally made on a rib basis. There are two types of blister fabric, such as single blister and double blister fabric.

- Single blister: It is sometimes termed three-miss blister because each dial needle misses three feeders after knitting. It has one blister feeder course between each ground feeder course.

- Double blister: It has two blister feeder courses between each ground feeder course. This produces a more pronounced blister relief, with twice as many courses of blister loops to ground loops. It is heavier and has a slower rate of production than single blister. It is sometimes termed five-miss blister. Blister loops at two successive feeders may not necessarily occur on the same needles. They may be in one or more colours with a self-colour or a one or two-colour ground. All blister structures show only the ground loops on the back.

<table>
<thead>
<tr>
<th>Rib gating</th>
<th>Ground (■)</th>
<th>1st feeder</th>
<th>Blister (□)</th>
<th>2nd feeder</th>
<th>Ground (■)</th>
<th>3rd feeder</th>
<th>Blister (□)</th>
<th>4th feeder</th>
<th>Ground (■)</th>
<th>5th feeder</th>
<th>Blister (□)</th>
<th>6th feeder</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>D</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>C</td>
<td>D</td>
<td>C</td>
<td>D</td>
<td>B</td>
<td>B</td>
<td>B</td>
</tr>
<tr>
<td>First two rows of pattern graph</td>
<td>Row 2-feeders 3 &amp; 4</td>
<td>Row 1-feeders 1 &amp; 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

Single blister fabric

Double blister fabric
11. Relief Fabric:

A patterned rib-based fabric, the surface of which exhibits a characteristics relief or blister effect in which the number of loops in the relief portion is greater than in the surrounding area on the effect side and on the reverse side. The relief area may be of a different colour from the main ground and the ground may also be patterned. Two main types of structure are recognized: single relief or three-miss blister and double relief or five-miss blister. The latter has a greater preponderance of loops on the face of the fabric in the relief areas than the former. Also known as blister fabric or cloqué fabric.

Non-Jacquard Double Jersey Structures or Derivatives of Interlock Structure:

It produced mainly on the modified interlock machine. Various modifications to the basic interlock machine have been necessary in order to produce the new structures. Originally only alternate tricks were fully cut through to accommodate long needles so that mock eight-lock was achieved by knitting normal interlock with every third dial needle removed, now all tricks may be cut through and inserts placed in tricks under short needles.

Most interlock variation structures have six or eight feeder repeat sequences as only alternate needles in one bed are in action in a course.

1. Single Pique or Cross Tuck Interlock Structure:

It was one of the first to be produced, by placing tuck cams in the dial at every third feeder. The tuck stitches throw the fabric out approximately 15% wider than normal interlock to a satisfactory finished width of over 60", they break up the surface uniformity and help to mask feeder stripiness but they also increase fabric weight.

Single pique is a tuck-knit interlock structure. So interlock needle gating system is used to produce this structure. Long and short needles in dial and cylinder, long
needles facing short needles and vice-versa. The repeat of the structure completes on six feeders. Knitting sequence for a repeat as follows:

- First feeder: Knit on all short cylinder needles and tuck on all short dial needles.
- Second feeder: Knit on all long cylinder and dial needles.
- Third feeder: Knit on all short cylinder and dial needles.
- Fourth feeder: Knit on all long cylinder needles and tuck on all long dial needles.
- Fifth feeder: Knit on all short cylinder and dial needles.
- Sixth feeder: Knit on all long cylinder and dial needles.

2. Texi Pique Structure:

It is wider and bulkier and shows the same pique effect on both sides of the fabric. Texi pique is a tuck-knit interlock structure. So interlock needle gating system is used to produce this structure. Long and short needles in dial and cylinder, long needles facing short needles and vice-versa. The repeat of the structure completes on six feeders. Knitting sequence for a repeat as follows:
- First feeder: Tuck on all short cylinder needles and tuck on all short dial needles.
- Second feeder: Knit on all long cylinder and dial needles.
- Third feeder: Knit on all short cylinder and dial needles.
- Fourth feeder: Tuck on all long cylinder needles and tuck on all long dial needles.
- Fifth feeder: Knit on all short cylinder and dial needles.
- Sixth feeder: Knit on all long cylinder and dial needles.

3. Cross Miss Structure:

It is the knit miss equivalent of single pique but it is narrower and lighter in weight. Cross miss is a miss-knit interlock structure. So interlock needle gating system is used to produce this structure. Long and short needles in dial and cylinder, long needles facing short needles and vice-versa. The repeat of the structure completes on six feeders. Knitting sequence for a repeat as follows:

```
6  *  *
5  *  *  *
4  *  *  *  *
3  *  *  *  *  *  *
2  *  *  *  *  *  *  *  *
1  *  *  *  *  *  *  *  *  *
```

- First feeder: Knit on all short cylinder needles only and all dial needles remain idle.
- Second feeder: Knit on all long cylinder and dial needles.
- Third feeder: Knit on all short cylinder and dial needles.
- Fourth feeder: Knit on all long cylinder needles only and all dial needles remain idle.
- Fifth feeder: Knit on all short cylinder and dial needles.
- Sixth feeder: Knit on all long cylinder and dial needles.

4. Piquette Structure:

It is a reversible knit miss structure with a light cord effect. Piquette is also a miss-knit interlock structure. So interlock needle gating system is used to produce this structure. Long and short needles in dial and cylinder, long needles facing short
needles and vice-versa. The repeat of the structure completes on six feeders. Knitting sequence for a repeat as follows:

- First feeder: Knit on all short cylinder and dial needles.
- Second feeder: Knit on all long dial needles only and all cylinder needles remain idle.
- Third feeder: Knit on all short cylinder needles only and all dial needles remain idle.
- Fourth feeder: Knit on all long cylinder and dial needles.
- Fifth feeder: Knit on all short dial needles only and all cylinder needles remain idle.
- Sixth feeder: Knit on all long cylinder needles only and all dial needles remain idle.

5. Pin Tuck Structure:

Pin Tuck is a tuck-knit interlock structure. So interlock needle gating system is used to produce this structure. Long and short needles in dial and cylinder, long needles facing short needles and vice-versa. The repeat of the structure completes on six feeders also. Knitting sequence for a repeat as follows:

- First feeder: Knit on all short cylinder and dial needles
- Second feeder: Knit on all long cylinder and dial needles.
- Third feeder: Knit on all short cylinder and dial needles.
- Fourth feeder: Knit on all long cylinder and dial needles
- Fifth feeder: Knit on all short cylinder and tuck on all short dial needles.
- Sixth feeder: Knit on all long cylinder and tuck on all long dial needles.
6. Bourrelet Structure:

A non jacquard double jersey fabric made on an interlock basis which is characterized by horizontal ridges on the effect side (the surface of the fabric intended to be used outermost on a garment or other construction). The knitting sequence is generally a number of courses of interlock, followed by a number of courses knitted on one set of needles only.

Bourrelet fabrics have pronounced horizontal cords at regular intervals produced by knitting excess courses on the cylinder needles, the cord courses may be in a different colour to the ground courses. There may be half, more than half, or less than half the total number of feeders knitting the cord courses. Interlock rather than rib base bourrelet is usually preferred because it provides a softer, smoother more regular surface with less elasticity but it requires two feeders per cord row.

Bourrelet is a miss-knit interlock structure. So interlock needle gating system is used to produce this structure. Long and short needles in dial and cylinder, long needles facing short needles and vice-versa. The repeat of the structure completes on ten feeders. Knitting sequence for a repeat as follows:

- First feeder: Knit on all long cylinder and dial needles.
- Second feeder: Knit on all short cylinder and dial needles.
- Third feeder: Knit on all long cylinder and dial needles.
- Fourth feeder: Knit on all short cylinder and dial needles.
- Fifth feeder: Knit on all short cylinder needles only and all dial needles remain idle.
- Sixth feeder: Knit on all long cylinder needles only and all dial needles remain idle.
- Seventh feeder: Knit on all short cylinder needles only and all dial needles remain idle.
- Eighth feeder: Knit on all long cylinder needles only and all dial needles remain idle.
7. Jersey Cord Structure:

Jersey cord is an example of a Miss bourrelet. So it is a miss-knit interlock structure. Interlock needle gating system is used to produce this structure. Long and short needles in dial and cylinder, long needles facing short needles and vice-versa. The repeat of the structure completes on eight feeders. Knitting sequence for a repeat as follows:

- First feeder: Knit on all short cylinder and dial needles.
- Second feeder: Knit on all long cylinder and dial needles.
- Third feeder: Knit on all short cylinder and dial needles.
- Fourth feeder: Knit on all long cylinder and dial needles.
- Fifth feeder: Knit on all short cylinder needles only and all dial needles remain idle.
- Sixth feeder: Knit on all long cylinder needles only and all dial needles remain idle.
- Seventh feeder: Knit on all short cylinder needles only and all dial needles remain idle.
- Eighth feeder: Knit on all long cylinder needles only and all dial needles remain idle.
8. Super Roma Structure:

Super roma is an example of a tuck bourrelet, this one sometimes termed horizontal ripple fabrics, tend to be heavier and to have a less pronounced cord than the jersey cord, which are termed ‘Ottomans’ in the USA. It is a tuck-knit interlock structure. Interlock needle gating system is used to produce this structure. Long and short needles in dial and cylinder, long needles facing short needles and vice-versa. The repeat of the structure completes on eight feeders. Knitting sequence for a repeat as follows:

- First feeder: Knit on all short cylinder and dial needles.
- Second feeder: Knit on all long cylinder and dial needles.
- Third feeder: Knit on all short cylinder and dial needles.
- Fourth feeder: Knit on all long cylinder and dial needles.
- Fifth feeder: Knit on all short cylinder needles and tuck on all short dial needles.
- Sixth feeder: Knit on all long cylinder needles and tuck on all long dial needles.
- Seventh feeder: Knit on all short cylinder needles and tuck on all short dial needles.
- Eighth feeder: Knit on all long cylinder needles and tuck on all long dial needles.

9. Punto di-Roma Structure:

It has replaced double pique as the most popular non-jacquard double jersey fabric, it belongs to a group of structures which are reversible and have a tubular sequence of dial only and cylinder only knit. It has an acceptable weight and finishes with a width of about 70 inches.

It is an interlock based structure. Interlock needle gating system is used to produce this structure. Long and short needles in dial and cylinder, long needles facing short needles and vice-versa. The repeat of the structure completes on four feeders. Knitting sequence for a repeat as follows:

- First feeder: Knit on all short cylinder and dial needles.
- Second feeder: Knit on all long cylinder and dial needles.
- Third feeder: Knit on all both long and short dial needles and all cylinder needles remain idle.
- Fourth feeder: Knit on all both short and long cylinder needles and all dial needles remain idle.

10. Cortina Structure:

Cortina is the six feeder version of punto diroma, produced on interlock camming with run-through cams where missing is required. So it is a missknit interlock structure. Interlock needle gating system is used to produce this structure. Long and short needles in dial and cylinder, long needles facing short needles and vice-versa
The repeat of the structure completes on six feeders. Knitting sequence for a repeat as follows:

- First feeder: Knit on all short cylinder and dial needles.
- Second feeder: Knit on all long cylinder and dial needles.
- Third feeder: Knit on all short dial needles only and all cylinder needles remain idle.
- Fourth feeder: Knit on all long dial needles only and all cylinder needles remain idle.
- Fifth feeder: Knit on all short cylinder needles only and all dial needles remain idle.
- Sixth feeder: Knit on all long cylinder needles only and all dial needles remain idle.

11. Six course Punto di-Roma Structure:

It is a miss-knit interlock structure. So interlock needle gating system is used to produce this structure. Long and short needles in dial and cylinder, long needles facing short needles and vice-versa. The repeat of the structure completes on six feeders. Knitting sequence for a repeat as follows:

- First feeder: Knit on all short cylinder and dial needles.
- Second feeder: Knit on all long cylinder and dial needles.
- Third feeder: Knit on all short cylinder needles only and all dial needles remain idle.
- Fourth feeder: Knit on all long cylinder needles only and all dial needles remain idle.
- Fifth feeder: Knit on all short dial needles only and all cylinder needles remain idle.
- Sixth feeder: Knit on all long dial needles only and all cylinder needles remain idle.
### 12. Evermonde Structure:

It has a row of tuck stitches on one side after each tubular course which produces a slight ripple effect. It is a tuck-knit interlock structure. Interlock needle gating system is used to produce this structure. Long and short needles in dial and cylinder, long needles facing short needles and vice-versa. The repeat of the structure completes on eight feeders. Knitting sequence for a repeat as follows:

- **First feeder**: Knit on all short cylinder needles and tuck on all short dial needles.
- **Second feeder**: Knit on all long cylinder needles and tuck on all long dial needles.
- **Third feeder**: Knit on all both long and short dial needles and all cylinder needles remain idle.
- Fourth feeder: Knit on all both short and long cylinder needles and all dial needles remain idle.
- Fifth feeder: Tuck on all short cylinder needles and knit on all short dial needles.
- Sixth feeder: Tuck on all long cylinder needles and knit on all long dial needles.
- Seventh feeder: Knit on all both short and long cylinder needles and all dial needles remain idle.
- Eighth feeder: Knit on all both long and short dial needles and all cylinder needles remain idle.

**Weft knitted Jacquard Design:**

Weft knitted jacquard designs are built up from face loops in selected colours on a base fabric of either single jersey, 1x1 rib, or links-links (purl). The face loop needles are individually selected, usually each only once per pattern row, to rise and take one yarn from a sequence of different coloured yarn feeds on a knit or miss basis.

In two-colour jacquard, certain needles will be selected to knit colour A from the first feed and, at the next feed, there will be a negative selection with the remaining needles being selected to knit colour B. The face loops of two feed courses thus combine to produce one complete row of face pattern loops.

In three-colour jacquard, each needle will be selected to knit once and miss twice at a sequence of feeds, so that three feeder courses will produce one design row. The greater the number of colours in a design row, the lower the rate of productivity in design rows per machine revolution or traverse, assuming striping is not employed.

If striping is employed with jacquard selection, different colours can be selected at different design rows so that there are more colours in the total design than in one design row. For example, a four-feed machine with four-colour striping at each feed could knit four colours per design row but have a total of sixteen colours in the design depth.

**Single Jersey Jacquard design:**

A patterned single-jersey weft knitted fabric, usually made from two or more yarns of differing colour or texture to give a construction that consists essentially of knitted and float loops, but may incorporate tuck loops. The surface pattern is derived from the chosen arrangement of the yarns and of the knitted and float loops.

The inclusion of tuck loops into the construction eliminates long lengths of floating threads from the back of the fabric.
Single-jersey tuck jacquard – A patterned single-jersey weft knitted fabric usually made from two or more yarns differing in colour or texture in construction that consists of knitted and tuck loops. The surface pattern is derived from a chosen arrangement of the yarn and of the knitted and tuck loops.

The floats of single-jersey jacquard to some extent reduce the lateral extensibility of the garments and when continuous filament yarns are used in gauges of E 18 (npi) or less, the floats on the technical back can create problems of snagging. Single-cylinder sock machines may knit 1×1 float stitch jacquard, odd needles being selected for knit and miss whilst even needles knit at every feed, thus reducing the coloured yarn floats on the technical back to a single wale. The clarity of the coloured pattern area is only slightly impaired.

The following squared diagram illustrates part of a three-colour jacquard design, each face stitch being represented by a square. Using the running thread notation, provide a representation of the design for single-jersey knit / miss jacquard.

![Diagram of single-jersey knit / miss jacquard pattern](image)
Accordion Fabric:

It is a single-jersey jacquard fabric. A weft knitted plain-based fabric, showing a figured design in two or more colours, that is produced by knitting and missing, and in which tuck loops are introduced to eliminate long lengths of floating thread at the back.

In accordion fabrics, the long floats are held in place on the technical back by tuck stitches. They were originally developed using knit and miss pattern wheel selection, needles required to tuck (if not selected to knit) were provided with an extra butt in line with a tuck cam placed immediately after the pattern wheel selection.

There are three types of accordion fabrics, such as – straight accordion fabric, alternate accordion fabric and selected accordion fabrics.

**Straight accordion fabric:**

In straight accordion fabrics, every odd needle was of this type, so every odd needle tucked when not selected to knit. The following figure shows a repeat of the representation of two pattern rows for the straight accordion fabrics.

```
<table>
<thead>
<tr>
<th>II</th>
<th>A</th>
<th>C</th>
<th>B</th>
<th>C</th>
<th>C</th>
<th>B</th>
<th>C</th>
<th>A</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>A</td>
<td>A</td>
<td>C</td>
<td>B</td>
<td>B</td>
<td>C</td>
<td>A</td>
<td>A</td>
</tr>
</tbody>
</table>
```

Straight accordion fabric (Tucking on non-knitting odd needles)
Alternate accordion fabric:

Alternative accordion provides a better distribution of tuck stitches, odd needles had a tuck butt position in line with cams placed at odd feeders and even needles had another butt position for cams at even feeders. With both these types of accordion, tuck stitches can occur close together causing distortion of face loops and allowing unselected colours to 'grin' (a defect in a compound structure e.g. a double cloth in which one fabric can be seen through or 'grinning through' the other, as a result of bad cover. The term can be applied to compound woven and knitted structures including pile fabrics) through between adjacent wales onto the face. The following figure shows a repeat of the representation of two pattern rows for the alternate accordion fabrics.

```
II
A  C  B  C  B  C  A
I
A  A  C  B  B  C  A  A
```

```
6
C
5 II
E
O  O  O
B
4 A
E  E  E  E  O
C
3
O  O  O
B
2 I
E  E  O  O
A
1 O  O  O  O
```

O = odd needles and E = even needles

Alternate accordion fabric

(Tucking on odd needles at odd feeders and even needles at even feeders when non knitting)

Selected accordion fabric:

The selective accordion fabric is the third type of accordion. It is most widely used but it requires a three-step pattern wheel or other selection device which can select the tuck loops so that they are carefully distributed to create the minimum of stitch distortion on the face of the design. The following figure shows a repeat of the representation of two pattern rows for the selected accordion fabrics.
Double Jersey Jacquard Design:
It produced on the rib jacquard machine. Rib jacquard is a patterned rib-based fabric the surface of which is essentially flat and exhibits a figure or design in differing colour or texture. The patterned surface is derived from the chosen arrangement of yarns, and of knitted and miss or float loops. The back of the fabric may be either plain, striped, birdseye or ladder backing.

Rib jacquard designs are achieved by cylinder needle selection. The dial needles knit the backing and eliminate floats that occur when cylinder needles only are selected to miss. Tuck stitches are therefore unnecessary. On circular knitting machines, the selection is on the cylinder needles only and the dial needles knit the backing loops, whereas on flat knitting machines both beds may have selection facilities.

1. Reverse Jacquard fabric:
A rib-based fabric in which the design on the effect side is reversed on the other side by alternation of the two component threads between the two sides.
2. **Striped Backing for a Two Colour Rib Jacquard Fabric:**

The reverse side of a rib jacquard fabric characterized by successive courses of horizontal stripes of each of the yarns used to form the pattern. The effect is obtained by knitting on all the needles in the set opposite to that used to form the pattern.

![Diagram of striped backing]

3. **Three colour rib jacquard with Striped backing:**

With horizontally striped backing, all dial needles will knit at every feeder thus producing an unbalanced structure with more backing rows of stitches than pattern rows. In the case of three-colour jacquard, there will be three times as many backing rows as face pattern rows. This type of backing ensures that the maximum yarn floats are only across one needle space and there is thus little loss of lateral extensibility – a prerequisite for garment length and hosiery knitting. The following figure shows a representation of two pattern rows as rib jacquard with horizontally-striped backing.

![Diagram of three colour rib jacquard]

**Rib jacquard with horizontally striped backing**
The following figure shows a representation of two pattern rows as rib jacquard with horizontally-striped backing.

<table>
<thead>
<tr>
<th>II</th>
<th>A</th>
<th>C</th>
<th>B</th>
<th>C</th>
<th>B</th>
<th>C</th>
<th>A</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>A</td>
<td>A</td>
<td>C</td>
<td>B</td>
<td>B</td>
<td>C</td>
<td>A</td>
</tr>
</tbody>
</table>

Rib jacquard with vertically striped backing

4. **Birdseye Backing for a Three Colour Rib Jacquard Fabric:**

The reverse side of a rib jacquard fabric characterized by courses in which knitted and float loops of one colour alternate with knitted and float loops of another, within and between successive courses. For double jersey fabrics, birds eye or twill backing is preferred as this is a more stable structure which is better balanced and has a pleasing, scrambled-colour appearance on the backing side. It is achieved by knitting the backing on alternate needles only and arranging for each colour to be knitted by odd backing needles at one feed and even needles at the next. The optimum number of colours is usually three.
Birdseye backing for a three colour rib jacquard fabric
The following figure shows a representation of two pattern rows as rib jacquard with birds eye backing.

<table>
<thead>
<tr>
<th>II</th>
<th>A</th>
<th>C</th>
<th>B</th>
<th>C</th>
<th>C</th>
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<td>I</td>
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<td>C</td>
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</tbody>
</table>

O = odd dial (backing needles) and E = even dial (backing needles)

Rib jacquard with birds eye backing
SWEATER KNITTING
(Fully Fashioned Knitwear)

In traditional garment production, rectangular flat knitted panels are cut to the required shapes, which are then sewn together. When a panel has to be cut according to a marker, the amount of waste is considerable and profits are reduced.

Fully fashioning is the process whereby portions of a garment are shaped at the selvedges by progressively increasing or decreasing the number of loops in the width of the fabric. Such narrowing and widening produces the shape of a piece of garment that would otherwise be generated by cutting. Sweater is a typical fully fashion knitwear.

The advantages of the fashioning process are:

- A considerable decrease in waste in the subsequent production stages. When the raw materials used in the knitting operation are expensive like Lambswool, Angora or Cashmere, the process is more attractive. There is little or no cutting waste.
- A reduction of some of the production stations such as marking, grading and cutting. The labour cost in each country define the importance of this point. In areas where higher wages are paid the process become more attractive.
- The quality of a fashioned garment edge is much better then a cut edge. The edges of the garment pieces are sealed and not liable to fraying, so can be joined by simple non-bulky seams. With the correct making-up equipment, this method produces a higher class garment.
- The shape of the panel is more accurate when produced during the knitting operation rather then being cut later.

The disadvantages of the fashioning process are:

- A reduced machine productivity due to the need to transfer loops from one needle bed to the other.
- The final shape of the garment has to be designed before the knitting procedure can be started. This is too complicated for many knitters who are not prepared to be involved in these operations.
- A somewhat higher level of designing skills has to be exercised. The fashioning procedure has to be added to the regular patterning of the fabric.
- The making-up operation of a fashioned garment requires a different type of sewing machine to achieve a higher quality product.

Fully fashioned garments are usually associated with knitted outerwear of a particular classical type and with a particular type of machinery: the 'straight bar' or 'Cotton's Patent' knitting machine.
However, knitted underwear is made on a fully fashioned basis, although the quantity is now very small compared to that made in the 19th century.

Men’s heavy rib sweaters are also fully fashioned on hand flat knitting machines, as are fine gauge ladies suits and dresses.

Increasingly the fashioning capabilities of modern electronically controlled V-bed flat machines are being used for making fully fashioned garments with scope for embellishment using a wide range of patternings. Such a use, with savings of material and making up costs, will increasingly feature as a development of the stitch shaped industry.

This chapter mainly discuss with the sweater knitting technology. The Vee-bed flat knitting machine is widely used to produce sweater part.

The features of a Vee-bed flat knitting i.e. sweater knitting machine:

The main features of a Vee – bed flat knitting machine are listed below:

- Numerically these are the most important industrial knitting machines.
- The needles, mounted in beds opposed in an inverted “V” formation, are operated by cams in a reciprocating carriage.

![Automatic Vee-bed flat knitting machine](image)

- The hand flat machine is still widely used but most modern machines are powered. Machines are built with 1.5 to 20 needles per inch in widths from a few inches to 76 inch.
- Many are employed to produce collars and rib trimmings for garments made on other machines, but because of the almost unlimited patterning scope available with jacquard flat machines considerable numbers are used for the production of patterned fabrics and garment lengths. Automatic narrowing has been common on these machines for some time and models are now being offered with full fashioning capability.
- Their main disadvantage is low productivity compared with other types.
Most have a single knitting head or section but versions with 2 to 6 sections arranged side by side are produced.

- Arrangement of 2 sections back to back allows knitting to take place in one direction using 15 or more carriages that traverse over the front section and return over the back one: the resulting machine is thus a hybrid circular-flat machine.

The Manual Sweater knitting machine:
The manual sweater knitting machine consists of the following parts:

The frame:
The manual sweater knitting (flat knitting) machine is made up by a frame carrying the base; this structure supports all the needle beds and motions necessary for the knitting process. In the rear side of the machine there is a spool rack for storing the yarn spools.

The yarn unwound from the spool is picked up by the feeding system: a tensioner, which adjusts the feeding tension and a thread guide, driven by the machine carriage, which provides the needle with yarn at the proper time.

The tensioner is made up by a spring-load flexible arm, that lowers when the yarn tension increases, to feed a bigger quantity of yarn, and lifts up when the tension decreases.

The needle bed:
The following figures show the needle bed and the motions of a manual sweater knitting machine. The needles accommodated inside the grooves of the needle bed can be either in a knitting or in a non-knitting position and are moved by special springs, which is shown in the above yarn passage figure. Placed between the grooves in the upper part of the needle bed, the knock-over jacks (top most part of the trick wall) act as supports for the yarn fed during the stitch formation.
A spring securing bar and a needle securing bar are also attached to the needle bed to keep needles and springs in a correct sliding position.

The carriage:

The following figure shows the schematic diagram of the carriage of manual sweater knitting machine. It is made up of two metal plates linked by a stiff bridge (P); the plates work individually and simultaneously on the front and the rear needle beds.

The carriage carries out a double function and can be used:

- To select the needles and make them raise or lower to form the stitch;
- To select and drive the thread guides which feed the needles.

The plates include cam locks (F) bearing the drive and control systems of the needles, i.e. the cams. When the carriage moves right-wards or left-wards, the thread guides (B), (C), (D), (E) are locked.
individually by the corresponding pistons (A) on the upper part of the bridge, that are manually driven.

Brushes are also mounted on the carriage to ensure a smooth needle latch opening and grant a correct feeding of the yarn, which is shown in the following figure. As with all yarn carriers, the yarn carrier represented below is composed of the following elements:

- **A** – is the block which guides the yarn carrier on its guiding bar;
- **B** – is the support;
- **C** – is the feeder holder, fixed with a hinge to enable the yarn carriers to pass one another and
- **D** – is the feeder.

**The Cam-locks:**

The cam-locks are a cam system which gives the necessary working information to the individual needles; they include a fixed part, working as support, and movable cams, which can be divided into raising cams and lowering or knock-over cams. The raising cam includes a tucking cam and a looping cam.

Camboxes of a Sweater Knitting machine
The fixed or movable cams form a symmetrical channel where the needle butt slides; the needle moves downward and upward in the groove to form the stitch. The different parts of the cams are chamfered; their profiles are curvilinear to make the needle move smoothly.

The angle of inclination of the cams ranges between $40^0$ and $50^0$; these values grant an optimum running of the needle and avoid high pressures between metal parts during the motion and excessive tensions on the yarn during the downward stroke of the needle. The carriage allows three different work ways according to the needle stroke and to the positions of the raising cam:

- Knit stitch – when the needle carries out a complete stroke, reaching the maximum height on the looping plane.
- Tuck stitch – when the needle reaches the tucking plane and receives a new yarn while still holding its former loop, thus forming two loops in the one needle hook.
- Miss or float stitch – when the needle is not knitting and remains out of the knock-over plane.

**High-butt and Low-butt needles:**

The latch needle can have two different butt heights which make it a high-butt needle or a low-butt needle. The assembly of high-butt needles and low-butt needles on the knitting machine allows different selection and different manufacturing work ways, according to the positions of the tucking and looping cams.

![High-butt and Low-butt needles](image)

**The knitting action or Loop-forming process on Sweater knitting machine:**

The loop forming process in a sweater (two bed flat) knitting machine is illustrated in the following figure. It comprises the following operations:

- Clearing (on the needles 1 to 3)
- Yarn laying (on the needle 8)
- Yarn drawing
- Pressing
- Landing (on the needle 9)
- Joining (not shown in the drawing)
- Casting-off
- Loop forming (on the needle 10) and
- Drawing off (on the needle 11)
At the time of clearing, the needles move over a distance sufficient to make the old loop pass from the latch onto the stem. When this occurs, the old loops are retained from lifting together with the needles by the action of the force that draws-off the knitted fabric.

As the needles move down, they grasp the new yarn in consecutive order. To obtain casting of old loops C in the following figure on the new yarn, it is necessary that the needles be sufficiently lowered in relation to the knocking-over plane. The amount of needle lowering in relation to the knocking-over plane (sinking depth) determines the size of formed knitting loops.

All the movements necessary to accomplish the loop-forming process are imparted to the needles by the cams as they exercise their action on the needle butts.

**Fabric Take-down:**

Knitted fabrics require a special system to take them down while they are formed on the knitting machine. On manual flat knitting machines, after the first stroke of the carriage, a steel reed is fitted into the course; the reed is hooked using a steel wire, which is shown in the following figure.

Once the manufacturing cycle comes to an end the steel wire is removed and the reed released. The machine and the reed must have the same gauge; the holes in the lower part of the reed accommodate the weight-holder hooks to increase the tension on the fabric according to the specific needs.
Production of different Fabrics on Sweater knitting machine:

The descriptions which follow, relative to different types of classic fabrics, embrace the basic knowledge of every knitter. These descriptions are often illustrated by photos taken on a hand machine, as this type of machine is the most suitable for describing the basics of knitting.

The set-up:

The description of the principle of the formation of a stitch, shows that the needle carries the thread or a first stitch and explains how the latch needle makes a second stitch. The study of the set-up must enable one to understand how the first thread is laid in the hooks of the needles.

The start made by a set-up. The yarn is fed to the needles by the yarn carrier, passes from one needle to the other, i.e. from front to back then from back to front. This is the first row of the welt – a single row of yarn – and can be represented graphically as follows:

![Diagram of set-up row](image)

To put this first row in the hooks of the needles, it suffices to put the raising cams front and back into action, to adjust the lowering cams on an average position and to pass the carriage entraining the yarn carrier. Check the opening of the latches of all the needles.

The following steps are carried out for the set-up; those are shown in the figure below:

- Step – 1: The first row of the welt. The yarn passes alternately on the front and back.
- Step – 2: Over the set-up row from below and between the needle-beds the set-up comb is introduced and then through the eyelets of the set-up comb, the wire.
- Step – 3: The comb is thus suspended on the set-up row.

![Step 1, Step 2, Step 3](images)

The set-up row is generally followed by a welt – often composed of two or several rows of tubular knitting. The set-up and the circular rows constitute the welt. Each knitted article, unless it is cut,
commences by a welt. But the utilization of automatic flat machines impedes the use of a set-up comb because the various articles knitted follow one another without stopping the machine. In this case, they are separated one from the other, by a draw-thread or by partial press-off.

So that the first row of the welt is correctly executed, it is important that the yarn, in passing from one needle to the other, passes also from front to back and back to front. In effect, if this is not so, the first row is imperfect.

**Tubular fabric:**

This is also called circular knitting. It can be made on circular machines with one needle-bed or on flat machines with two needle-beds. In this latter case the tubular fabric knits a flat tube which takes its circular form after knitting. The following description gives tubular knitting made on flat machines with two needle-beds. The flat machines have, in regard to circular machines for instance, the important advantage of being able to produce tubular fabric of any diameter, due to the simple fact that one puts into action the needles on any width.

It can be interesting, in certain cases, - especially for trimmings - to not connect the selvedges of the fabric of the front to that of the back, thus producing tubular fabric open at one or both sides. To do this, knit two rows on the back needle-bed, then two rows on the front needle-bed, and so on. Now the liason will only be effected at one side, at the right or the left, depending on whether the start has been done from the right or the left. To obtain circular knitting open both sides, one must naturally use two yarn carriers, one on the back knitting always with the needles of the back needle-bed and the other on the front feeding the front needles. In this manner the thread of each yarn carrier feeds always the needles of the same needle-bed and the two pieces of fabric are not joined to one another. The ordinary welt of an article is knitted generally with 2, 4, or 6 rows of tubular knitting, which ensures a sound edge. In effect, tubular fabric is not very elastic.

The tubular fabric is composed of the joining up of two pieces of knitting on one needle-bed, one piece made on the front needle-bed and the other on the back needle-bed. They are connected one to the other by a common thread which passes from one needle-bed to the other at the two selvedges. This liason is not visible in the fabric, the gap between the needle-beds is designed so that the interstitch at the selvedges is equal to the other inter-stitches.
The following figures illustrate the cam plates of a hand sweater knitting machine arranged for the production of tubular fabric. Two raising cams, one at the front, one at the back, are out of action. Thus when the carriage travels from left to right, the back needles only will form a stitch. On the other hand, when the carriage goes from right to left, only the front needles form a stitch. In this manner, the lowering cams A and B are always inactive. They must therefore be fixed at a higher position than the other two so as to avoid any tension on the stitches. In the following right corner figure of cam-boxes the clearing or raising cam 1' and 2 set for tubular fabric.

**Single bed fabric:**

This is also called jersey fabric in spite of the term often being used to describe all sorts of other fabrics in different textures, generally in fine stitches, but where the sole common point is the single colour. As in the case of tubular fabric, the quality of the single bed fabric depends principally on the shape and polish of the jacks of the needle-bed, as well as the accurate setting of the lowering cams. These must be set at exactly the same height, i.e. on the same division. Irregular setting of the lowering cams causes the rows to be short and long. The fabric, in consequence, shows horizontal stripes.

Single bed fabric, which is shown in the following figure, is the expression employed for knitting on one needle-bed only, generally on the back. Its characteristics are the same as those for tubular knitting: light, little elasticity, and stitches formed very uniformly.

A fabric on one needle-bed is almost always preceded by a piece of rib fabric made on two needle beds with an ordinary welt. To pass to the single bed fabric, all the stitches of one needle-bed mus
be transferred by a hook to the needles of the other needle-bed. Generally from front to back. Various procedures of the transfer of stitches are described in the following section. It is however possible to commence knitting on one needle-bed without a rib welt. In this case, a set-up comb is placed between the needle-beds, as high as possible, in such a manner that the eyelets rest against the jacks of the needle-bed which will produce the knitting. In knitting the first row of the single bed fabric, the needles pass between the eyelets of the set-up comb, and the yarn taken is trapped. The above right corner figure shows the set-up comb, with its wire, can be used to commence single bed fabric without a welt. 

**Rib fabrics:**

**1×1 rib:**

Contrary to circular fabric or fabric on one needle-bed, all rib fabrics are made simultaneously on the two needle-beds. Thus the yarn passing from one needle to the other passes equally from front to back and back to front, as for the set-up row. It is owing to machines fitted with two needle-beds and to rib fabrics thus produced.

![Rib fabrics](image)

1×1 rib has the same appearance on both sides. It is a very elastic fabric in its width. Its elasticity not only depends on the texture of the fabric, but is also influenced by the stitch length and the type of yarn. 1×1 rib is characterized by the fact that all the needles of both needle-beds are in action. All the raising cams will therefore be in work and all the lowering cams must be set exactly on the same division.

**Cardigan Stitch or Full Cardigan Stitch:**

Cardigan stitch is a fabric of tucks. The tuck renders the stitch doubled. That is why tuck fabrics are often described by the terms “double stitch fabric” or “multi-stitch fabric” when the tuck is repeated. There are two ways of making a tuck, such as – tucking in the hook and tucking on the latch.

The general appearance of cardigan stitch is similar to that of 1×1 rib. The two sides are identical. However, the columns of stitches are wider apart. On the other hand, cardigan stitch can be recognized by the tucks, which between the column of the stitches, show small loops. Cardigan stitch fabric is thicker, heavier, than 1×1 rib.

The following left figure shows the row of cardigan stitch. The tuck is on the back. The descriptions which follow, concerning tuck stitches (cardigan stitch, half cardigan, nopps, repeated tucks) relate
to cardigan cam plates. The cardigan stitch is knitted on all the needles. The stitches tucked are produced on the back and front needle-beds alike. The drawings of the following figures represent the cam plates of hand sweater knitting machines and the raising cams are set for the production of cardigan stitch.

In cardigan stitch, the lowering cams can all be set on the same division. However, to ensure a normal appearance to the fabric, the tuck must be generally and as much as possible, shorter than the stitch. The lowering cams Nos. 2 and 4 in the above figure will thus be set to about the ‘flush jack’ position, whereas the lowering cams Nos. 1 and 3 occupy a normal position of formation. The above middle figure shows the carriage passes from left to right – the back needles form a stitch and the front needles form a tuck. The above right figure shows the carriage passing from right to left – the back needles make a tuck, whereas the front needles, previously tucked, form a double stitch.

The following figures show the camboxes of the manual sweater knitting machine. In the left corner figure, the stitch cams 6’ and 7 set for tucking. In the middle figure, the cam setting for continuous tucking in one needle bed. In the right corner figure, the cam setting for full cardigan stitch.

**Half Cardigan Stitch:**

This fabric results from a combination of 1x1 rib and cardigan. It is obtained by alternating a row of 1x1 rib with a row of cardigan stitch. Thus, one set of needles forms individual stitches at each row whereas the other forms double stitches. The cams of the cam plate represented at the below are set for the production of half cardigan stitch.
When the carriage travels from right to left, the front and back needles make a complete ascension and form a single stitch. This is the $1\times1$ rib row. When the carriage travels from left to right, the back needles make a second single stitch, whereas those of the front make a tuck. This is the cardigan row. The lowering cam No. 4 – which determines the length of the tuck – will be placed a little higher than the other one.

The right side of the fabric with the single stitches. It presents this characteristic that the stitches of one row predominate whereas those of the following row are almost invisible. The predominating stitches are relatively large compared with those of the preceding row. They give the fabric a certain appearance of pearl stitch, which sometimes the fabric is called.

**Needle drop design:**

The expression “rib fabrics” denotes fabrics in rib (executed on two needle-beds) by means of needle-beds with needles out of action, or idle. The most common of these – rib $2/3$ and rib $1/2$ - are mainly used for the bottom border of a pullover, a jacket, or for the cuff of a sleeve, that is for all the parts of an article which must be close fitting. As its name indicates, the $2/3$ rib is knitted with a needle field comprising 2 needles in 3 in action. In other words, one needle in 3 is out of action. In the same way, in $1/2$ rib, 1 needle in 2 is in action.

The following left and middle figures show the 2 in 3 rib ($2/3$). The $2/3$ rib is very commonly known as $2\times2$ rib, which is a classic example of a rib fabric. On each needle-bed 2 needles in 3 are in action. The inactive needle is situated in the centre of the needles in action on the opposing needle-bed.
Rib fabrics can naturally be in single stitches or tuck stitches, in just the same way as rib on all the needles. Thus, the 2/3 rib can be 2/3 cardigan or 2/3 half cardigan. Ribs are generally very elastic in their width, especially when in single stitches. This elasticity is the result of the spaces made by the inactive needles which thus give space to the closing up of the ribs.

The inactive needle can be:

- A low butt, or short. The rib will be knitted on the high butt needles or the long needles only. Most knitting machines are equipped with these two sorts of needles.
- Out of action. This solution is used for machines without jacquard and fitted with needles having a single height of butt. In this case, the inactive needle is pushed downwards to the base of the needle-bed. Its butt occupies a position which is below the bottom raising cams.

The 1/2 rib is composed of a needle in action alternating with a needle out of action. The 2/4 rib is composed of 2 needles in action alternating with 2 needles out of action. These two kinds of rib are also very popular. Their elasticity is even greater than with 2/3 rib. The above right corner figure show the rib 1 in 2 (1/2) and the below left corner figure show the rib 2 in 4 (2/4).

To pass form a rib to 1x1 rib, it is necessary between the two to make 2 rows of tubular fabric on all the needles. If not, unsightly holes will appear between the rib and the 1x1 rib on all the needles.

Rib 2/3 followed by 1x1 rib with, between the two, 2 rows of tubular fabric on all the needles, which is shown in the above middle figure. The same sample without the two tubular rows shows small holes between the 2/3 rib and the 1x1 rib, which is shown in the above right corner figure.

**Needle-bed Racking:**

During the process of loop formation, the needle-beds are stationary and the tricks of one are set between the tricks of the other. This is the knitting position, and the needles of both beds are able to knit simultaneously. One of the needle beds can be driven sideways a short distance to change the relative positioning of the needles. In this respect, the needle-beds of flat knitting machines are not stationary. All flat knitting machines are provided with a needle-bed racking system which is used for shifting one bed in relation to the other by means of a special cam placed on the machine’s side, whilst at the same time maintaining the needle-bed gap.
Racking can occur in both directions. This racking movement is measured by needle spaces, i.e. the bed can be moved number of needles. The needle-bed can also take different positions: racking over half needle or full needle.

The above left corner figure shows the normal position of the needle-beds. The first slot at the left is of the front needle-bed. At the right, the last slot is of the back needle-bed. The back needle-bed is displaced three slots, which is shown in the above middle figure. One says that it has been racked three needles.

The displacement of the needle-bed is generally provoked by the rotation of the racking wheel, shaped in steps each of which corresponds to the gauge of the machine. This rotation can be controlled by hand or automatically. In each case, the angular displacement of the wheel must be limited in a very precise manner to ensure that the crossing of the needles in ascension is maintained.

The racking is carried out for either of the following reasons:

- To position the tricks almost in alignment. This is needed to allow needles of one needle bed to penetrate the transfer springs of the needles at the opposite bed and facilitate loop transfer. Loop transfer and transfer position are described in the following section.

- One of the needle beds can be moved a few needles to one side and still be positioned in a knitting arrangement. The needles of one bed are between the needles of the other. This is carried out to assist the transportation of transferred loops to a new location or to distort the regular vertical arrangements of the wales.

Note that the racking of the needle beds can take place only when all the needles are in the resting position. This time is between the completion of one machine knitting cycle and before the commencement of the next. Any attempt to rack the needle bed while some of the needles are in the clearing position and the needles are intermeshed, will result in mechanical damage.

The racking motion allows the creation of inclined patterns (right-hand or left-hand) on the knit fabric. The following figures show the fabrics produced by the racking system.
**Stitch or Loop Transfer in weft knitting:**

A loop that is displaced after being formed so that it combines with an adjacent loop, or so that it appears in a different wale, is said to have been transferred.

The transfer of a full or part of a needle loop or sinker loop onto an adjacent needle, either in the same bed or in an opposing bed is called stitch or loop transfer. The stitch formed by this loop transfer is called loop transfer stitches.

**Objects of loop transfer:**

The object of loop transfer is to achieve shaping, produce a design, or change the stitch structure. Transferring is used to generate holes in the fabric to form lace-like effects. Transferring can be used to produce structural effects by inclining wales of both plain and rib fabrics. This is also used to produce cables by exchanging two or more groups of wales with one another. In addition, loop transfer is used in ladies’ stockings, when producing the double-thickness, plain fabric, in-turned welt. It also used in running-on and doubling rib loop fabric onto the needles of a straight bar frame to form the rib border of a garment part. Loop transfer is used when running the loops of two separate fabrics onto the points of a linking machine for linking these fabrics together.

**Loop transferring process:**

Loop transfer by hand-controlled points is a tedious and skilled operation, but automatic loop transfer requires a specific arrangement of specially shaped needles and / or transfer points. The
following description relates firstly to manual transfer, then to automatic transfer on the sweater knitting machine.

**Manual loop transfer or Transfer by hand:**

The transfer by hand is executed by means of a narrowing handle or transfer needle of which the size of the point varies according to the machine gauge. To transfer a stitch of one needle to a neighbouring needle by means of the narrowing handle is shown in the following figure and comprises the following steps:

- Fitting the transfer needle 1 on the hook of the knitting needle to be put out of action, and pulling this needle out of the needle bed in order to cast-off the loop C from the needle latch onto the needle stem (a);
- Transferring the loop from the knitting needle onto the transfer needle by pushing the knitting needle into the needle bed (b & c);
- Removing the transfer needle with the loop to be transferred, from the knitting needle and fitting the transfer needle on the hook of the knitting needle which is to receive the transferred loop (d & e);
- Displacing the transferred loop from the transfer needle onto the knitting needle in such way that both loops (the old loop C1 and the transferred loop C) remain in the knitting needle hook (f) on the open latch.

![Schematic diagram of Manual loop transferring process](image-url)
The above three photos are also show the steps of manual stitch transferring process by means of narrowing handle those are explained above.

Transfer of a back stitch to the front is shown in the following photo (1). The left hand manoeuvres the butt of the front needle and pushes it into the stitch held by the narrowing point. Similarly the following photo (2) shows the transfer of a front stitch to the back. The left hand manoeuvres the butt of the back needle and pushes it into the stitch held by the narrowing point.

Before operating with the narrowing handle, all the latches that are to be transferred or to receive a stitch must be opened. The knitting on one needle-bed is normally always preceded by a rib fabric. To pass to single bed, all the needles of one needle-bed must be transferred to the needles of the other needle-bed. This operation can be done with a single needle narrowing handle or, most rapidly, by means of a transfer comb, a sort of bar equipped with several narrowing points appropriate to the gauge. The descriptions and illustrations of the above right corner figure (a) to below right corner figure (d) show how to transfer all the stitches from the front to the back. As possible, this transfer must be preceded by a last row of stitches a little slacker on the front.

Open the latches of all the back needles. On the front, lift up the needles to be transferred. Lower the front needle-bed, which is shown in the above figure (a). Rack one of the needle-beds 2 needles so as to open the stitches to be transferred, then in these stitches, introduce the transfer comb from the front, which is shown in the below left corner figure (b). Lower the front needles. The stitches are held by the transfer comb, which is shown in the below middle figure (c). Then connect the narrowing points to the back needles and, in turning these over, slide the stitches into the hooks, which is shown in the following right corner figure (d).
Chain Stitch: when partial, it is executed during the knitting. It is also done by transfer of stitches with the narrowing point, as indicated by the following figures (1) to figure (4).

- Figure – 1: Over the section where the chain stitch will be made, transfer the stitches from the front to the back needles. On the front, leave or put back into action all the needles. Knit one row of rib and press-off on the front the loops thus formed.
- Figure – 2: Take the last but one stitch with the narrowing handle and transfer it on to the selvedge needle. Push this up until the end of the latch is between two stitches.
- Figure – 3: Lower the selvedge needle and draw out the narrowing point. The transfer stitch is passed through the selvedge stitch.

- Figure – 4: With the narrowing handle, put this new stitch on to the needle which has become empty and re-commence the operation with the neighbouring stitch.
The chain stitch prevents the stitches from running. At the end of an article, it is often done off the machine by means of a latch needle which does the work of the narrowing point. However, in the Knitwear i.e., Sweater Industry, linking machines avoid the need for a chain stitch and also stop the stitches from running.

The doubling operation for ribs of fully-fashioned articles: Certain types of frames used in knitwear automatically produce articles entirely shaped (fully-fashioned) in plain jersey stitch fabric. But they cannot knit the ribs at the same time, as they have only one row of needles. The users of such frames must use flat knitting machines with two needle-beds to produce the ribs which are then transferred to the needles of the frame by means of a special transfer bar.

Furthermore, experience has shown that, to meet the making up needs, the ribs must have a greater number of stitches than for the article itself. In consequence, at the end of the ribs, the number of stitches is reduced. This operation, called doubling, can be executed by hand, when the rib is picked on, or automatically on a stitch transfer machine, incorporating the possibility of transferring the stitches of the low butt needles only. In the previous right figure, the illustration shows a border knitted in 1x1 rib transferred to plain fabric after doubling. In effect, certain stitches (encircled) have been doubled by stitch transfer. It is in this way that the number of stitches of the rib is adjusted to those of the article knitted in plain.

Although it is slightly visible, the doubled stitch does not unfavourably affect the appearance of the fabric. The change between the rib and the plain is quite natural, there being no join that is so obvious with fabrics with sewn-on welts. Finally, the automatic doubling is more rapid and more uniform than doubling made by hand.

The following figures show the execution of a few classic samples with stitch transfer. 2/3 i.e., 2x2 rib border and following reverse jersey structure is shown in the following left corner figure. The finished shape of the 1x1 rib to 2/3 (2x2) rib to 1x1 rib fabric sample can be represented as shown at the following middle figure. Knitted in fine gauges, it is used for the manufacture of vests (underwear). The following right corner figure shows the close-up view of this fabric.
**Automatic loop transfer:**

The process of automatic loop transfers on V-bed knitting machines and the working mechanism taking part in loop transfers are shown in the following figures. For loop transfer an auxiliary element must be brought in action and it is the transfer unit. The latch needle has a recess, ‘a’ which accommodates the transfer unit for loop transfer. The process of loop transfer is fulfilled in the following steps:

- needle selection for loop transfer (a);
- rising the needle to such a position that the loop remains on the open latch (a);
- the transfer unit 1 lowers onto the needle recess (b);
- the needle rise, coupled with the transfer unit, and the transfer unit takes over the loop (c);
- the rising transfer unit releases the needle which lowers into the needle bed (d & e);
- now, the transfer unit is shifted by one needle spacing to the needle which is to take over the loop carried by the transfer unit (e);
- new needle takes the transferred loop over (e & f).

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**Loop transfer on bearded needles:**

On spring-bearded needles (e.g. Cotton Patent machines) removal and transfer of loops are performed by means of transfer needles (transfer points) which are attached to special bars. Such a transfer needle consists of a stem 1, a groove 2, a tip 3 and a butt 4. In the transfer needle groove
the hook of the spring-bearded needle is hiding during pressing by loop transfer. The tip of the transfer needle enters in the groove of the knitting needles pressed.

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Loop transfer on a cotton’s patent machine

a) Transfer needle positioned in front of a knitting needle, b)&c) Needle pressing, d)&e) Loop removal, f)&g) Separation of needles; transfer needle rack, h) Clearing, i) Needle pressing, j) Loop transfer onto a knitting needle, k) Second separation of needles, l) Transfer needle retreat.

The loop transfer is performed in the following ten steps:

1. positioning the transfer needle in front of the selected spring-bearded needle;
2. pressing the spring-bearded needle in the groove of the transfer needle;
3. loop removal from the spring-bearded needle onto the transfer needle;
4. separation of needles;
5. transfer needle rack;
6. clearing;
7. pressing;
8. loop removal from the transfer needle onto spring-bearded needle;
9. separation of needles;
10. transfer needle out of action.

Fabric narrowing and widening are performed with identical interaction of loop forming elements and transfer needles.

**Half loop transfer or Partly loop transfer:**

For obtaining the lace effects (lace holes) by loop transfer without loop removal from the spring-bearded needles, points or transfer needles with a cut-out are used. The loop transfer in this case comprises the same operations, but at the first pressing the needle hook is not pressed by the point as shown in the figure. As a result, the loop transfer process is effected without loop removal by the points.

The sequence of operations at the transfer of a half-loop is illustrated in the following figure (a – f).

Sequence of operations in half-loop transfer

The above right figure shows the position of the needle and transfer point with cut-out at first pressing.
Loop transfer on knitting machines with latch needles:

The process of loop transfer on circular knitting machines with latch needles is carried out by using needles of various special design. Most largely used in practice are two methods of loop transfer from one needle bed of the knitting machine to another.

The first method makes use of latch needles with a spreader. Between the spreader and the needle stem there is a clearance.

![Diagram of loop transfer using latch needles with spreader](image)

1-spreaders,
2-needle stem,
3-shoulder,
4-recess for the spreader tip,
5-cylinder needle loop,
6-dial needle.

Loop transfer using latch needles with spreader

The second method involves latch needles with side recesses and shoulders. The needle shoulder stretches the loop brought to the level of the head of the loop receiving needle in opposite needle bed, thus preparing the loop to piercing by the receiving needle.

![Diagram of loop transfer at needle bending](image)

1-needle shoulders,
2-cylinder needle loop,
3-side recesses of cylinder and dial needles,
A&B-direction of cylinder and dial needle bending

Loop transfer at needle bending

![Diagram of loop transfer in 1x1 rib](image)

Loop transfer in 1x1 rib
The sequence of loop transfer operations is as follows:

- Needle selection for loop transfer
- Bending the loop transferring needles towards their receiving counterparts with recesses, in the other needle bed – in circular knitting machines, or – in V-bed knitting machines – racking one of the needle beds for 0.5 needle spacing
- Bringing the loops on selected needles to the level of needles in the opposite needle bed
- Putting the transferred loops on the hooks of receiving needles
- Casting-off the loops from the needles transferring the loops onto the heads of receiving needles
- Opening the latches of needles which have cast-off their loops
- Bringing the needles into their initial position.

The properties and use of the Transferred Stitch:

Loop transfer is widely used in flat knitting for various reasons, some of which are described below:

1. **Changing from rib to plain**: Often, garments are produced with a rib welt, which provides elastic properties, and then continues as a plain construction to reduce thickness and weight. In these cases, all the loops participating in the production of the rib welt are transferred to one needle bed. The plain knit structure continues to knit on this single bed.

2. **Knitting purl knits**: To knit purl knit structures containing face and back loops within the same wales, loops should be transferred between front and rear needles.

3. **Patternning**: Transferred loops are widely used in fabric patterning. Wale distortion is one example, in which certain wales are moved from needle to needle which then continue to knit through them. The vertical lines of the wales are thus distorted. The most common example of this pattern procedure is the “Cable” illustrated in the following figure. Some wales are highlighted to clarify the effect.
4. **Shaping**: Sophisticated knitting machines are able to shape the garment rather than to produce only rectangular panels. Panel shaping requires needle selection and transferring ability, in which loops are transferred inward at the edges, to facilitate narrowing. Since the loops are transferred from one needle bed to the other, which is then racked to allow the return procedure, the efficiency and productivity of the machine is reduced. The profitability of the process should be considered by weighing together the raw material costs and the reduction in cutting operations, against the knitting efficiency and productivity.

**Types of Transfer Stitches:**

There are four main types of transfer stitches:

1. Plain needle loop transfer stitches – It is produced by transference of a loop from one needle to another in the same bed.
2. Fancy lacing stitches – It is produced by modification of the plain loop stitch.
3. Rib loop transfer stitches – It is produced by transferring a loop from one needle bed to the other.
4. Sinker loop transfer stitches.

**Openwork weft knitted fabrics:**

The stitch variant is obtained by transfer of needle loops on the neighbouring needles or by transfer of sinker loops on one or two needles of the wales to which the transferred sinker loop belongs.

This variant stitches obtained by needle loop transfer are often called lace stitches whilst sinker loop transfer produces the pelerine stitches. These stitches can be obtained in a plain stitch or a rib stitch knitted fabric. The lace stitches and pelerine stitches are employed to obtain openwork design effects or to impart new properties to the knitted fabrics.

- **Lace stitches:**
  
  In designs the plain loop transfer stitches is termed a lace stitch whereas in selvedge shaping it is termed fashioning. Lace stitches can be produced on weft knitting machines with spring bearded needles and latch needles. For obtaining a lace effect, the loops can be transferred into neighbouring wales either by removing the loops of needles on which they have been formed or without removing them from those needles.

- **Pelerine stitches (sinker loop transfer stitches):**
  
  The sinker loops can also be transferred onto both needles producing the loop wales to which the transferred sinker loop belongs to. Pelerine stitches can also be obtained in plain stitch and rib stitch knitted fabrics. The structure of a fabric with pelerine stitches obtained by transfer of sinker loops onto a single needle or onto two needles. Pelerine stitches can also be obtained by transfer of two, three or four sinker loops lying one above another in two, three or four consecutive loop courses.
Process of producing the pelerine stitches:

One of the needle beds – the dial or the cylinder is equipped with latch needles; the other needle bed is equipped with transfer jacks with butts, nibs, shoulders and bends. Transfer jacks in pairs are used, with right-hand bend and left-hand bend. One jack is used in case of sinker loop transfer on one needle (left or right respectively), or two jacks are used for sinker loop transfer on two needles (left and right).

Process of knitting the pelerine stitches:

The process of knitting pelerine (nipp) stitches is carried out in the following sequence:

- selection of sinkers (transfer jack) for loop transfer;
- advancing the transfer jack nibs to the line of knock – over plane of the needles in opposite needle bed (fig. b);
- grasping the sinker loop ‘H’ by transfer jack nib, and bringing the sinker loop to the level of needle hooks in opposite needle bed (fig. c);
- transfer the sinker loop ‘H’ on the needles of the opposite needle bed (fig. d); these needles are partly protruding from their grooves;
knitting process of the pelerine stitches

- retreat of the jacks to their initial positions; the sinker loop is laid on the open latches of the protruding needles of the opposite needle bed;
- bringing the needles with sinker loop to their initial positions.

Transfer of sinker loops can be performed in one, two, three or four consecutive loop courses, on the same needles.

Fancy lacing stitches:

The bearded needle sinkerwheel machine produced the largest range of fancy lacing stitches. Some are unique to it and have the term 'a jour' in their description, which implies a sequence of samples. A jour C or knupf – also termed filet lace, weft knitted net and knotted stitch – square apertures in an all-over effect that is popular for men's athletic underwear. On an E16 fine gauge machine, 1/18's cotton or 2/70 denier nylon might be used. A course of long loops is knitted and the two side limbs of every second needle loop 'B' are spread sideways onto the needle loops 'A'. The second is knitted with a short stitch length and tucking occurs on needles 'B' to make the aperture wider.

Another stitch, known as a jour B, has a twisted transferred loop, produced by deflecting the beard of the receiving needle across into the eye of the delivering needle so that, as the loop is pressed-off from the delivering needle, it twists over. The effect is achieved by using toothed lacing wheels with the upper wheel's teeth coupling two beards together; these teeth are arranged according to pattern requirements.

Purl stitch fabric:

The following sample illustrates the purely basic fabric of purl stitch machines. It comprises rows of
stitches, knitted alternately, back and front on all the needles. Thus, after each row of stitches, all the needles pass to the opposite needle-bed to knit the next row of stitches. Both sides of the fabric are obviously identical.

**Moss stitch:**

The stitch formation chart of moss stitch is illustrated in below. In this case uneven needle means odd number needle. In each row, all the needles pass from front to back or back to front, depending on whether they are even or odd (uneven). Moss stitch fabric is identical front and back. It is particularly used for knitting articles of a layette.

![Moss stitch chart](image)

**Double moss stitch:**

This fabric is a variation of the preceding sample. The stitch formation chart is illustrated in below.

![Double moss stitch chart](image)

**Tucked moss stitch:**

This fabric is also a variation of the preceding sample. The stitch formation chart is illustrated in below.
Plain and Purl Stitch:

As indicated before, purl stitch machines generally permit the execution of the majority of basic fabrics, in plain or in rib, with single or tucked stitches. In addition, as the needles can pass from one needle-bed to the other, purl stitch fabrics increase the variety of the sampling of these machines. The samples below, in purl stitch and plain, illustrate one of these sampling possibilities. The following three samples composed of plain and purl stitches have been knitted on a hand machine.

Links-links knit:

Links-links knits are based on the concept of superimposition, on the same column of plain stitches and purl stitches. These structured stitches were originally made on special machines featuring grooved flat and coinciding needle beds, equipped with special double-hook needles. Today, thanks to easier stitch transfer options, these structured stitches can be made quickly and safely on standard flat knitting machines.

The characteristic appearance of links-links designs consists in presenting alternated areas of purl stitches and plain stitches, often arranged so as to create a design motif. A classic example of links-links structured stitches is that shown in the (above middle figure) illustration, that is, the chequered design.
Plaited fabrics on purl stitch machines:

Plaiting is often utilized on purl stitch machines. This follows the same principle as plaiting. In rib fabrics, the plaited yarn does not appear. It remains contained at the interior of the fabric. On the other hand, in plain on one needle-bed, the plaited yarn appears on one side, i.e. at the front. One can thus obtain plain fabrics in different colours, depending on whether they are seen at the back or the front.

Fabrics in purl stitch are eminently suitable for this possibility, because they are composed, in principle, of a succession of rows knitted in plain, either at the front or the back. The plaiting enables therefore these plain rows to be in two colours. The two samples at the above (middle and right figures) are of identical texture, but the right one is plaited.

Cable design:

Other classic knitting structures that can be made thanks to stitch transfer are cables. In cable designs the vertical wales cross each other, have always been very popular in the sweater knitting trade. The basic concept consists in producing a series of plain stitch columns on a purl stitch base. After a number of rows, some of the stitches, corresponding to half the stitch columns in question, are transferred on the other stitch columns, while the stitches of the latter are transferred to the previous stitch columns. The stitches are thus crossed over and produce the classic cable effect.

The cables can be of various sizes. A large number of variations exist, from “two needle cable” in which two wales cross each other, to “twelve needles cable” where six needles switch places with another group of six to form a very wide design effect. The principle of wale crossing is illustrated in a simplified loop configuration diagram (below right corner figure) in which a “four needles cable” is drawn. The most common and classic cable design is the “six needles cable” which is shown in the following left corner figure. This size of cable is popular because although the effect is clear it is still in proportion with a garment. The only limit to this size is determined by the displacement achievable by the machine all in one go.
Aran or Diamond design:
Another very common knitting structure made according to the same concept as the cable is the aran. The procedures used are similar to those of the cable. The only difference is that the arms determined by the moving stitch columns are diverging rather than converging as is the case of the cable.

An example of diamond effect made using the aran technique is shown in the above right illustration, though naturally, the branches of the various arms of the cables and arans can be much more imaginative and complex.

The Welt:
A welt is an attractive and secure edge of a knitted article that helps to prevent laddering or unroving of a structure. It is formed either during the knitting sequence (usually at the start, and parallel to the courses) or as a later seaming operation during making – up. Seamed welts, which are made after the knitting process, may occur in any position in the fabric.

Types of welt:

There are the different following types of welt:

- **The inturned welt:** A welt consisting of a double fold of plain fabric made on a circular stocking machine. Sinker loops from one of the first few courses are retained while the welt fabric is knitted and are later intermeshed with alternate needle loops of a subsequent course. The inturned welt is used particularly for manufacturing ladies’ hose and sports socks on circular machines and some knitwear on cottons patent machines. Jacks or hooks collect the sinker loops of the third course or the set – up course and hold them, drawing the fabric away until sufficient has been knitted for the double – thickness welt.
• **The turned welt:** A welt that consists of a double fold of plain fabric and is made on a straight-bar knitting machine. All or alternate sinker loops of the first course are retained while the welt fabric is knitted and later intermeshed with the needle loops of a subsequent course.

• **Reverse welt:** A roll welt in which the plain courses are intermeshed towards the reverse side of the fabric. This welt is used particularly for stockings with turnover tops.

![Turned welt on latch needle](image1)

![Turned welt on bearded needle](image2)

![Accordion welt top](image3)

• **Accordion welt top:** An accordion top, welt and mock rib, can be produced on single-cylinder half-hose and sock machines, and on other machines using a single set of needles in a tubular arrangement. Elastomeric yarn is laid-in to odd-needles only for a few courses so that when the first plain course is knitted by the textile yarn, the straight contracted elastomeric yarn lies through its sinker loops, forming a neat roll edge. The elastomeric yarn is then usually inlaid on a two-tuck two-miss or a one-and-one basis at each course or alternate courses for a number of courses. As the elastomeric yarn relaxes, it causes alternate wales to be displaced into a mock rib configuration. Sometimes, the second course of textile yarn is knitted only on alternate needles.

• **Rib welt:** Most fully-fashioned and stitch-shaped underwear and outerwear garments, half-hose, and socks have ribbed borders containing a welt sequence that is produced by causing the sets of needles to act independently of each other after the 1×1 rib set-up course. When the rib border is to be knitted in 2×2 rib, the needle bed is either shogged to form a skeleton 1×1 rib needle arrangement or it is knitted on a normal 1×1 rib needle set-out followed by rib loop transfer to achieve 2×2 rib for the border.

Three types of welt are possible when needles are arranged in 1×1 rib set-out. These are:

1. The Tubular or French welt
2. The Roll or English welt
3. The Racked welt

1. **The Tubular or French Welt:** A welt made on a rib basis, in which the number of courses with loops intermeshed in one direction is equal to the number of courses with loop
intermeshed in the other direction. In making such a welt on a 1×1 rib, the first and last courses are knitted on both sets of needles and the intermediate courses consist of an equal number of plain courses on each set of needles. The tubular welt is the most popular welt because it is a balanced structure that is reversible, lies flat, can be extended to any depth and is elastic. Its only disadvantage is that it can become baggy during washing and wear unless knitted tightly. Apart from old cottons patent Rib Frames, most garment-length knitting machines can knit this welt. The split welt is actually a tubular welt knitted at the end of the garment sequence instead of at the beginning. It is used as an open tube for a collar or stolling, to fit over the cut edge of a garment to which it is then linked by a through stitch.

2. The Roll or English Welt:

A welt made on a rib basis, in which all the courses of loops except the first and last are intermeshed in the same direction towards the face side of the fabric. In making such a welt on 1×1 rib, the first and last courses are knitted on both sets of needles and the intermediate courses are knitted on only one set of needles. The roll welt is produced by knitting approximately four courses on one set of needles only whilst continuing to hold the setting-up course of loops on the other set of needles. It is bulkier and less elastic than the tubular welt and has the disadvantage of long held loops. This welt is knitted particularly on half-hose and links-links garment-length circular machines. A reverse roll welt is knitted for sleeves with turn-back cuffs and for turn-over top socks. To obtain this welt, the opposite set of needles (the bottom set of needles on half-hose machines) are caused to hold their loops so that the roll of the welt appears on the other side of the structure, but it is on the face when the fabric is folded over.

3. The Racked Welt:

The racked welt is neat and inconspicuous, rather like the set-up course of hand knitting in appearance, and is favoured for collars and other trimmings. It is not as elastic as the other two welts and is normally only knitted on V-bed flat knitting machines. It is produced by racking the needle bed by one needle space after the set-up course and retaining this arrangement.
Garment panel separation:

Knitted articles are often produced separately on single-cylinder machines, Cottons Patent machines and some flat machines. Others are knitted in continuous string formation on many flat and circular rib and purl machines because fabric tensioning is dependent on a continuous length of fabric between the needles and the take-down rollers. Also, there would be a danger of latches not being open at the start of a new garment sequence. If the string of garments is separated by cutting, there is a danger of either the welt being damaged or of unwanted yarn not being removed. For these reasons, some form of separation course is usually provided, normally in the form of a draw thread course, preceding the first course of the new garment.

Although the “hand flat” or manual sweater knitting machine can be re-threaded before the production of each panel, a continuous production is also possible. A special yarn can be knitted at the end of each panel so the following panel can use it instead of the comb.

In products which are later finished through a wet process, a dissolving thread can be inserted between panels. Separation is achieved without the need for an additional working stage. When no wet process is planned or the panels are to be separated at another stage, the dissolving yarn technique cannot be used. For these panel types, there is two principal methods of separating fabrics – separation by a draw-thread and separation by press-off – are dealt with below.

Separation by draw-thread:

The draw thread is usually a smooth strong yarn that may be knitted as a slack, plain tubular course to facilitate easy removal. It appears between the end of the piece and the commencement of the next piece, at the end of the protecting rows. The tubular draw thread course does not unravel accidentally during wet processing. The draw-thread must be followed by the set-up of the next piece (set-up and welt). To separate the two pieces, the thread must be cut and drawn out. To facilitate this latter operation, the draw-thread must be knitted at a slack tension. The draw-thread is particularly convenient for fabrics where the needle arrangement is the same at the end of one piece and the beginning of the next. For example, to separate articles commencing and finishing in 1x1 rib, to separate ribs knitted in 2/3 rib, etc.

The separating process is schematically shown in above, in the following stages:
The draw thread, knitted according to the special routine, is cut at the selvedges.
- It is easily pulled out through one selvedge.
- The panels are separated.

The separating sequence differs according to the knitting structure at the end of the completed panel and the rib construction of the next. Only some common procedures are shown in the below.

A separating draw thread is shown in the following left corner figure. It is inserted between a panel finishing in a 1x1 construction and a panel starting with a 1x1 rib. The sequence is based on the principle of knitting the draw thread in a plain construction. It is easier to pull out later. To change from 1x1 rib to a plain construction, two different methods can be used:

- All loops can be transferred to one needle bed.
- One needle-bed can be activated to press its loops off.

The manual machine is not always equipped to transfer loops automatically and manual transferring is time consuming. It is natural that the press-off technique is preferred. A press-off sequence should be well controlled and prepared to avoid laddering which is usually associated with dropped stitches.

![A draw thread from 1x1 to 1x1](image1)
![A draw thread from 2x2 to 2x2](image2)

**Separation by press-off:**

Another method is the press-off draw thread construction, which, although more expensive in time and yarn, tends to be more popular. The course preceding the start of the new garment is knitted in 1x1 rib and then one set of needles presses-off its loops, leaving a single plain course of extra long draw thread loops that can be quickly and easily removed. Prior to the press-off course, locking courses are produced by knitting three or more additional courses, only on the set of needles that are to press-off. These help to reduce tension in the structure after pressing-off and thus reduce the possibility of laddering back.

The draw-thread monopolises a yarn carrier which could be of greater advantage for something else. On the other hand, it cannot be used for separating two fabrics when some of the needles are eliminated. For example between 1x1 rib and 2/3 rib. In these cases, the pieces must be separated by press-off.
The separation by press-off consists of pressing off all or part of the stitches of one needle-bed. To avoid the stitches running to the bottom of the preceding piece, the press-off is always preceded by a few rows of single bed fabric.

To separate the two pieces, one must cut, then draw out the thread of the slack row. This can be made with a smooth and strong thread (mercerized cotton, nylon, etc.) to facilitate the separation of the pieces.

The separation by press-off enables the needle arrangement to be modified between the end of one piece and the commencement of the following piece. Change from 1×1 rib to 2/3 rib by press-off of all the needles. This is the most common change, used for all machines without stitch transfer or jacquard. This method is ideal between two fabrics during which certain needles must be eliminated. From 1×1 rib to 2/3 rib or 1/2 rib etc.

Two articles in 1×1 rib are separated by press-off

A draw thread from 1×1 to 2×2

A popular alternative to a draw-thread, employed on half-hose and sock machines, is to knit a number of courses in a soluble yarn such as alginate. The socks are separated by cutting, and the remaining courses of yarn are dissolved away during finishing to leave a neat edge to the welt.

Most garment-length machines using two needle beds have a butt arrangement of two long, one short for each bed, enabling 2×2 rib knitting after pressing off the loops of a 1×1 rib set-out and re-commencement of knitting on only long butts on each bed in turn.

Shaping during knitting:

In addition to facilities for garment-length sequence knitting, weft knitting provides unique opportunities for width-wise shaping during knitting, with the sequence being initiated and coordinated from the same central control mechanism.

There are three methods of width shaping as follows:

- varying the number of needles in action in the knitting width,
- changing the knitting construction, and
- altering the stitch length.
Shape formation (Fashioning):

Shaping by fully fashioning involves the movement of a small number of loops at the selvedge of the fabric. Such movement reduces or increases the total number of loops being knit. The term used in the industry for such movements are narrowing and widening, and collectively fashioning.

To alter the shape of the panel, the courses are widened by increasing the number of knitting needles or narrowed by eliminating needles at the selvedges. The two operations require different knitting procedures.

The Widenings:

Widening is the process of increasing the width of the knitted fabric produced, by increasing the number of working needles.

To widen the width of a knitted piece, gradually needles are added – thus stitches – at the selvedges. Generally, widening is done needle by needle. Special cases involve two needles at once being put into action. The angle at the widened selvedge depends on the frequency of the widenings in relation to the rows of knitting. Thus, widenings of one needle every two rows of stitches is more rapid than widenings of one needle every four rows.

To increase the width of the piece knitted by a stitch, it is sufficient to add a needle in action at the selvedge. The widening of a rib fabric requires, naturally, 2 supplementary needles, one at the front the other at the back, which is shown in the following left figure.

In order to improve the appearance of the selvedges, the widening, on a hand machine, can be done by a narrowing handle. This involves firstly putting a needle into action front and back. The take the stitch or stitches of the selvedge on a narrowing handle with one or more points, move the handle a needle towards the exterior of the fabric and hook on the stitches to the selvedge needle. To avoid the formation of small holes, hook up the last but one stitch that has been formed on the empty needle, by means of the narrowing point or work hook. The above right figure show ti
sample in 1x1 rib, has been widened as per the method explained now, by means of a 6-point narrowing handle. The widening done in this way takes much longer, but give a more regular appearance to the selvedges.

In widening, the movement outwards creates a space adjacent to the innermost needle of the group, where a new wale may start. The empty space, followed by the tuck loop formed at the next knitted course, leaves a hole in the fabric. It is usual in commercial practice to fill this hole by moving a previously knitted loop to commence the new wale. Such holes restrict the widenings to single needle only.

On flat knitting machines (e.g. V-bed knitting machine) widening can be performed in two ways:

- by putting in action the border needles (one needle on either side, in a loop course) and respectively extending the working range of the yarn carrier;
- by transferring the border loops on the needles just put in action (one needle from either side in a loop course) and extending the working range of the yarn carrier (for one or two needles just put in action, on either side, in a loop course).

Another way of widening is performed as follows:

1. Only one selvedge of the panel can be widened with each stroke of the carriage.
2. When a special twin carriage machine is used, two courses are knitted in each carriage stroke.
3. No transfer operations are required for widening and the course is increased simply by adding new active needles to the panel.
4. The newly activated needles are introduced on the side from which the carriage starts its traverse. When the carriage travels from right to left, needles can be introduced at the right selvedge. In this way, the new loops are secured in the needle’s hook.
5. To complete one cycle of widening on both sides of the panel, the carriage has to travel once in each direction thus knitting four courses.
The Narrowings:

This is the reverse of what takes place in widening i.e. narrowing is the process of lessening the width of knitted fabric produced, by decreasing the number of working knitting needles.

Narrowings by hand are executed by stitch transfer with a narrowing handle. To avoid doubling the last stitch of the selvedge, a narrowing handle with several narrowing points is used. The narrowing handle with several points is used in the same manner as a narrowing handle with one point. The narrowing handle takes as many stitches as there are points, and transfers these one needle towards the centre of the piece. The extreme selvedge needle loses its stitch and can be put out of action. The stitch doubled by the narrowing is towards the interior of the piece. The use of a narrowing handle with several points gives the article a highly finished appearance. The selvedge stitches remain parallel. This appearance characterizes narrowed articles, which is shown in the following left figure. The following right figure shows the single bed knitting, in 12 gauge, narrowed by means of a 6-point narrowing handle of 3 stitches at once.

The following left figure shows the 1×1 rib in 12 gauge narrowed on a typical automatic machine, first in double system (1 transfer every 4 rows of stitches), and then in single system (1 transfer every 2 rows of stitches). The following right figure shows the side of collar knitted in 1×1 rib in 12 gauge and narrowed on the same automatic machine.
When narrowing, the innermost loop of the group being moved combines with the loop adjacent to it. The figure represents two loops being moved by one loop space, thus losing one loop at the edge. It is possible on plain fabric to move the edge loops more than one needle space, losing more than one loop at the edge. In the fully fashioned industry these are known as ‘needle narrowings’ e.g. two needle narrowings where the outer group are moved in two needles. Such multi-loop narrowings produce small puckers where the loops combine. The number of loops in the group being moved varies from three to seven.

![A Single Needle Narrowing](image)

With finer fabrics tending to involve more loops than coarser fabrics.

On flat knitting machines (e.g. V-bed knitting machine) narrowing can be performed in two ways:

- by putting out of action the bordering needles and casting off their loops; at the same time the working range of the yarn carrier should respectively be decreased;
- by transferring the loops of the needles to be put out of action, on the neighbouring needles, in order to prevent unraveling of the loops; the working range of the yarn carrier should respectively be decreased.

Another way of narrowing is performed as follows:

1. To decrease the size of the course and the width of the panel, needles have to be deactivated at the selvedges. The loops held by these needles cannot be pressed-off (ladders can be formed). Instead, these loops have to be transferred inwards to active needles.

2. Loops cannot be transferred from needle to needle on the same bed. The operation involves the transfer of loops to the opposite bed; racking and then transferring them back to adjacent needles. The procedure is further complicated by the need to transfer in opposite directions at each selvedge.
3. Narrowing of both selvedges can be performed after each stroke of the carriage regardless of its direction. If the panel is symmetrical, identical operations are performed for each selvedge.

Fashioning is not restricted to plain fabric only; rib fabrics are increasingly the subjects of fully fashioning. Particularly suitable for shaping in this way are the cardigan fabrics containing tuck loops and broad ribs.

**Shaping Calculation or Fashioning Frequencies Calculation:**

**Example no.1:**

The measurements for the complete panel are required to calculate the widening / narrowing procedure. The following figure shows the measurements of a front panel as designed for the garment. These measurements are to be used as an example for the planning of the fashioning operation.

- The panel measurements have to be translated into wales and courses.
- This is carried out according to the course and wale quality of the fabric to be knitted by the knitting machine.

![Diagram of garment panel measurements](image)

- For this example, the fabric quality is 4 wales per centimeter and 5 courses per centimeter (plain knit on 6 gauge). The converted measurements are presented in the figure also.
- When the garment is produced, the elastic border is knitted first. It can be adapted from the standard programmes in the data bank. As the first fashioning process, the knitting width has to be widened from 160 wales to 180 wales. 20 widening operations are required \((180 - 160 = 20)\), or 10 operations on each selvedge of the panel.
The widening has to be completed during the knitting of 90 courses. If these available courses are divided by the number of widening operations, the result is 9. One extra needle has to be included in the knitting operation every 9 courses, on the right and on the left.

After the widening operation, the panel is knitted on the same number of needles for 10 centimeters or 50 courses.

The narrowing procedure follows and the number of active needles have to be reduced from 180 to 80. The narrowing takes place on both sides of the panel in a single routine. Traditionally, two needles on each side are eliminated each time so the width is reduced by four wales. The number of operations is \( \frac{180 - 80}{4} = 25 \).

Narrowing should be completed within 65 courses. These available courses are divided by the number of narrowing operations. 25 operations are required so 15 operations are carried out after every 3 courses and 10 operations after every 2 courses.

After the narrowing operations, the panel is knitted on the same number of needles for 2 centimeters or 10 courses.

Fully fashioned panel

A fully-fashioned panel, produced on a modern flat knitting machine, is shown in the above figure. In addition to the fashioning techniques, the panel is designed with protruding elements.

Example no.2:
Using the details shown in the figure below as an example, the following sequence is necessary in order to calculate the required fashioning frequencies from the dimensions of a garment part:

- Convert the length dimensions in each section to total number of courses by multiplying the length measurement by the courses per inch. Thus, \( 7 \times 20 = 140; 4 \times 20 = 80; 5 \times 20 = 100 \) courses.
- Convert the width dimensions at the start of each section to total numbers of needles by multiplying the width measurement by the wales per inch. Thus, \(16 \times 16 = 256\); \(18 \times 16 = 288\); \(8 \times 16 = 128\) needles.
- Calculate the total number of needles increased or decreased from one section to another by taking one total from the next.
- Divide the totals obtained by 2 in order to obtain the increase or decrease of needles at one selvedge. Thus, \(288 - 256 = 32\) needles. \(32 \div 2 = 16\) single needle widenings; \(288 - 128 = 160\); \(160 \div 2 = 80\) needles, \(80 \div 2 = 40\) double needle narrowings.

![Diagram](image)

**Measurements of a garment panel**

- There are 16 single-needle widenings occurring during the knitting of 140 courses; assuming the first fashioning occurs in the first course, there will be \(16 - 1 = 15\) fashionings in \(140 - 1 = 139\) courses; \(139 \div 15 = 9\) with a remainder of 4. Thus 4 fashionings must occur at 10 course intervals and the remaining 11 at 9 course intervals.
- Forty double-needle narrowings occur during 100 courses, again assuming the first fashioning occurs in the first course; \(99 \div 39 = 2\) with a remainder of 21. Thus 21 fashionings occur at 3 course intervals and the remaining 18 fashionings occur at 2 course intervals.

**Example no.3:**

To calculate and plan the widening / narrowing operations, the measurements for the complete panel are required. In the following figure the measurements of a sleeve are presented, in centimeters, to be used as an example.

- The next stage is to translate the panel measurements into wales and courses, according to the quality of the fabric that is knitted by the machine with the required yarn.
- Assuming for this example that the fabric quality is 4 wales per centimeter and 6 courses per centimeter, the converted measurements are calculated and presented in the following second figure.

- After the knitting of the elastic border, the first fashioning process is required and the knitting width has to be widened from 72 wales to 128 over the period of 192 courses. $128 - 72 = 56$ single widening operations are required or $56 \div 2 = 28$ on each side of the panel.

![Measurements of a garment panel](image1)

![Panel measurements converted into wales & courses](image2)

- If the available 192 courses are divided by the four courses required for each widening operation, the result is 48 cycles out of which only 28 are required. The twenty unnecessary cycles are spread among the required 28 so that the procedure is as follows:
  - 20 widening routines after each 8 courses (each two sequences).
  - 8 widening routines after each 4 courses (each sequence)

- After the widening operation, the sleeve is knitted at the same width for two centimeters or 12 courses.

- The narrowing procedure follows and the number of active needles have to be reduced from 128 to 32 over 144 courses.

- The narrowing takes place on both sides of the panel and is carried out in a single routine. Usually two needles on each side are eliminated so that each time the width is reduced by four wales.

- The required number of operations is $\frac{128 - 32}{4} = 24$. 
When the available 144 courses are divided by the shortest sequence between narrowing operations (2 courses or one carriage stroke) the result is $144 \div 2 = 72$.

Since only 24 operations are required, each can take place after 3 sequences $(72 \div 24) = 3$ or:

- 24 narrowing operations each after 6 courses (three carriage strokes).
- To complete the sleeve, the same width is kept for an additional 10 centimeters or 60 courses.

**Linking operation:**

A method of joining together the edges of a piece of fabric or fabrics by a single or double chain-stitch on a linking machine, in which one or more of the pieces of fabric is run on to the points on a loop-to-point basis and is therefore stitched through adjacent needle loops. Where none of the pieces of fabric are run on to the points on a loop-to-point basis, this is referred to as random linking. The joining together of two edges, usually knitted selvedges is also called cup seaming. The edges to be joined are positively fed to a sewing point by two cup-like wheels. Cup seamers have been used almost exclusively for the assembly of fully fashioned knitwear.

Linking machine, straight or circular, provided with grooved points spaced to receive loops, which are then joined together by chain-stitch.

**Linking machine:**

Linking machines have a common basic construction that consists of a circular “dial” containing grooved points that face radially outwards, which is shown in the following figure. It is on to these points that the fabric is placed. The diameter of the dial varies according to the particular make of the machine, and the spacing of the points varies between different gauges of the machine. The gauge is still specified in imperial measure as points per inch of circumference. For knitwear gauges are available from 3.5 points/inch to 24 points/inch.

The points remain static except in the sense that the dial revolves relative to the looping mechanism. The looping mechanism consists of two moving parts: the needle and the looper. These are carried in a supporting arm mounted internally on the dial plate, so that the looping elements are presented in the vicinity of the points. Two variations of the machine exist, one where the needle enters the work from the inside of the dial, and the other where the needle enters the work from outside the dial and the looper works on the inside.

**Principle of stitch formation:**

To complicate matters, two forms of needle exist: an eyed needle similar to those found on other seaming machines and a hooked needle similar to that used for hand crochet work.

**Principle of stitch forming action on linking machine equipped with eyed needle:**

Eyed needle; the needle is usually mounted so that it enters the work from the outside, sliding along the groove of a particular point. In doing so it carries the thread with it. Once through the fabric it
enters the previously formed loop held by the looper, which is shown in the following figure-a. The looper withdraws leaving the previously formed loop on the needle, which is shown in the following figure-b. As the needle starts to withdraw, the thread is trapped at the base of the needle, causing the loop formed on the looper side of the fabric to bell out, which is shown in the following figure-c. The looper now enters this loop and holds it while the needle withdraws, which is shown in the following figure-d. The dial now advances one point space and the whole cycle begins again, which is shown in the following figure-e. The chain is formed on the side of the fabric facing the inside of the dial, i.e. on the looper side.

Principle of stitch forming action on linking machine equipped with hooked needle:

Hooked needle; the crochet hook is usually mounted on the inside of the dial and enters the work along the groove in the point, as described before, but in the opposite direction. The thread is presented to the needle by a yarn carrier. This is a tube on Complett machines, and a small ring on
Mathbirk machinery. The thread enters the hook of the needle which withdraws dragging a loop through the fabric and through the previously formed loop. The needle retains the loop on its stem as the dial moves on one point and the cycle starts again.

The chaining again takes place on the inside of the dial. Both types of loop forming principles exist in reversed versions, with inside mounted conventional needles and outside mounted crochet needles. Uses and advantages are claimed for each version. For both needle types entering from outside the dial, there is a tendency for the work to be pushed back on the points, requiring less presser plate control.

Thread control is effected by two principal methods: a tension device usually of the spring loaded disc type, and a yarn take up device that controls slackness in the thread between the disc tension and the stitch forming zone. Most linkers also have fitted a yarn trapping device that acts when the needle is withdrawing on the conventional needle type. Linkers are used in the making up of knitted outerwear in operations where a loop for loop seam is required or where a seam is precisely located down a particular wale.

Examples of loop for loop seams are closing the shoulder seams of some types of fully fashioned garments or closing the toe on socks. An example of wale seaming for precision is the attaching of a pocket to the front panel of a cardigan.

By far the commonest use of linking machines is for attaching neck ribs to knitwear. The operator of the machine sits on a seat positioned so that the dial is just below eye level. The dial and the arm are free to rotate around the central support pillar, making it easier for the operator to progress the work on to the points. Sometimes two operatives run on work to the same dial, working on opposite sides of the machine. The bulk of the garment being seamed hangs down from the points, usually into an annular cup-shaped support tray. The drive to the machine is direct and not through a clutch, a foot switch turning the motor on and off. Speed of stitching is also controlled by a foot pedal.
Faults in circular knitting production can be caused in various ways and quite a few of them cannot be related to just one cause. The following explanations are expected to be helpful in trying to locate the causes of these faults easier.

**Reasons of fabric faults:**

- Yarn manufacturing faults
- Fabric manufacturing faults
- Fabric processing faults – dyeing, printing or finishing faults

**Sources of fabric faults:**

The sources of faults could be (in circular knitting machine, 80% faults comes from yarn)

- Faults in yarn and the yarn package
- Yarn feeding and yarn feed regulator
- Machine setting and pattern defects
- Machine maintenance
- Climatic conditions in the knitting plant

**Fabric faults:**

Knitted fabric faults are very different in nature and appearance and are often superimposed. The most common faults are:

- Broken ends, holes or cracks
- Drop stitch
- Cloth fall-out or pressed-off stitches
- Snagging or snags
- Tuck or double loop or stitches
- Bunching-up
- Vertical stripes
- Horizontal stripes
- Soil stripes
- Colour fly or coloured tinges
- Distorted stitches or deformed or tilted loops

**Holes:**

Holes are the result of cracks or yarn breakages. During stitch formation the yarn had already broken in the region of the needle hook. Depending on the knitted structure, yarn count,
machine gauge and course density, the holes have different sizes. This size can therefore only be estimated if the comparable final appearance of a comparable fabric is known.

Possible causes:

a) Yarn parameters
   - High yarn irregularity
   - Incorrect yarn input tension setting, yarn running-in tension is too high
   - Poorly lubricated yarns
   - Weak places in yarn, which break during stitch formation
   - Knots, slubs etc.
   - Yarn is too dry.

b) If the yarn is trapped between the cheek taper and the closing latch
   - Yarn damage

c) Too small stitches
   - Difficulty in casting-off of the stitches

d) Relation between cylinder and dial loop not correct; yarn feeder badly set; defective knitting elements.

Drop stitches:

These are the result of a defective needle. They also occur when a yarn is not properly fed during stitch formation, i.e., not properly laid-in the needle hooks. These are the unlinked knitted loops.

Possible causes:

a) Inaccurate insertion of the yarn into the needle hook;
   - Closed latch – a wale of dropped stitches will be produced until the latch is opened either by the operator or due to machine vibration.

b) Broken needle hook;

c) Due to high yarn twist and low fabric take-down-tension the knitted loop could fall out of the hook;
d) Improper setting of the yarn feed angle i.e. badly set yarn feeder
   • The yarn is not caught by the needle hook, Example – low yarn tension
     and high yarn vibrations
  e) Yarn feeder wrongly threaded-in;
  f) Dial loop length not properly related to cylinder loop length; the loop jumps
     out of the needle hook;
  g) Bad take-up;
  h) Very dry material;
  i) Insufficient yarn tension.

**Cloth fall-out or Pressed-off stitches:**

It is an area consisting of drop stitches lying side by side. They can occur either when a yarn is
laid-out or when it breaks without any immediate connection. Cloth fall-out can occur after a
drop stitch especially when an empty needle with closed latch runs into the yarn feeder and
removes the yarn out of the hooks of the following needles.

**Possible causes:**

a) Yarn breaks before the yarn feeder
b) Yarn package winding faults, poor package buildup;
c) Fibre fly block the yarn guides, feeders etc.
Needle marks or Vertical stripes:
Vertical stripes can be observed as longitudinal gaps in the fabric. The space between adjacent wales is irregular and the closed appearance of the fabric is broken up in an unsightly manner. Vertical stripes and gaps in the fabric are often the result of a meager setting, i.e., the yarn count selected is too fine for the machine gauge or the stitch size (course density) is not correct. Needles are bent, damaged, do not move uniformly smooth, come from different suppliers or are differently constructed.

Possible causes:

a) Twisted or bent needle hooks;
b) Stiff latches and needles;
c) Incorrect closing of the hook by the latch;
d) Heavily running needles;
e) Damaged dial and cylinder;
f) Damaged needle latch and needle hooks;
g) Damages on other knitting elements.

Horizontal Stripes:
These are caused by unevenness in the courses; they traverse horizontally and repeat themselves regularly or irregularly.

Possible causes:

a) Deflector in dial cam brought into tuck position.
b) Deflector not completely switched off. Needle can still grip the yarn and forms a tuck loop.
c) Yarn feeder badly set.
d) Differences in the yarn running-in tension.
e) Couliering not constant at all feeders.
f) Jerky impulse from fabric take-up.
Barre’ness:

Barre’ness is the periodic lateral irregularities

- **Structural Barre’ness:**
  Possible causes:
  - Individual yarns differ with respect to count, properties or structure;
  - Different course lengths in feeders.

- **Colour Barre’ness:**
  Possible causes:
  - Knitting of yarns which differ in colour;
  - Yarns dye differently during piece dyeing.

- **Shadow Barre’ness:**
  - Shadow like changes in the appearance of the fabric. Very difficult to detect and done by reflected light.

Bunching-up or Thick and Thin Places:

Visible knots in the fabric are referred to as bunching up. They appear as beads and turn up irregularly in the fabric. Can build up resulting in a “cloudy” appearance. More irregular the yarn, more pronounced is the “cloudy” appearance.

**Possible causes:**

a) Thick and thin places in the yarn;
b) Fabric take-up too weak.
Snags:

Snags mainly occur while processing filament yarns. The tendency towards snagging can be reduced by using yarns with a coarser single filament count, lesser crimp elasticity and higher twist.

During knitting all mechanical influences, caused by rough surfaces on yarn guide elements, yarn feeders, needles, fabric take-up, etc. have to be avoided. Even after knitting some snags can appear especially during fabric setting, if its storage and further processing has not been undertaken carefully.

Tuck or Double stitches:

These occur due to badly knitted or non-knitted loops. They are unintentional tuck loops or floats, also showing up as thick places or small beads in the fabric. At first instance they may also appear as a shadow when the fabric is observed against light.
Possible causes:

a) Fabric take-up is too weak, i.e., fabric take-up is insufficient, must be readjusted, has a one sided drag on the fabric or is not continuous.
b) The dial is set too high. The dial needles do not support the fabric, which is thus pulled up.
c) The course density or couliering is not set correctly.

The loops are too tight, e.g. with interlock. These loops are not removed from the needles.

Soil stripe:

Soil stripes can appear both in the direction of wales as well as courses. Soil stripes in the direction of the wales are solely caused by the knitting machine. In most cases they are so-called needle stripes; they occur when individual needles have been replaced or when the working of mechanical or automatic oiling or greasing devices is defective.

Stripes or soiled places in the direction of the courses were already present usually in the yarn, if not caused by a standing course as a result of machine stoppage.

Colour Fly:

Colour fly consists of single fibres, bunches of fibres or yarn pieces in varying colours. It additionally sticks on the yarn or is knitted into the fabric and is very difficult to remove.
The function of textile arithmetic is to record or determine all interrelationships which can be recorded in figure form. The calculations listed below will explain operations in production control and on circular knitting machines. At the same time, the calculations will serve as a basis for costing and cost accounting.

The equations for calculating the various machine parameters, such as system count and density i.e. feeding system, knitting speed and machine rpm, performance factor and efficiency level, will first of all be discussed below.

**System count:**

By a knitting system (functional unit), we understand on circular knitting machines a cam system or a number of cam systems with yarn feed, arranged in such a way that a course is formed on all needles in one cylinder revolution. In the case of individual needle selection or selected choice, they are the part courses equivalent to a full course.

**Influencing variables on the number of functional units:**

The variables influencing the number of functional units are

- Cylinder diameter
- The circular knitting machine operating principle (single-jersey, rib, purl)
- Possibilities (plain and structured knits, jacquard fabrics), and also
- Machine gauge.

**System density or number of systems / inch of nominal cylinder diameter:**

System density (SD) describes the number of system / inch of nominal cylinder diameter.

\[
\text{System density (SD)} = \frac{\text{No. of systems}}{\text{Nominal cylinder diameter, } d \text{ (inch)}}
\]

**Example:**

If the system count is 96 and the nominal cylinder diameter is 30", then

\[
\text{System density (SD)} = \frac{\text{No. of systems}}{\text{Nominal cylinder diameter, } d \text{ (inch)}} = \frac{96}{30} = 3.2 \text{ systems / inch.}
\]

On circular knitting machines today, system density lies between 0.4 and 4.8 systems / inch of cylinder diameter, depending on the machine model.
Knitting speed and machine rpm:
Cylinder operating speed on a circular knitting machine is also indicated as peripheral speed. By this, we understand the distance in m covered in 1 second from a point on the outer circumference of a disk. The peripheral speed is indicated in m/sec. and designated 'V'. Peripheral speed depends on

- The machine operating principle (single-jersey, rib, purl)
- The machine patterning units (jacquard or draw course unit)
- The type and construction of the circular fabric to be produced (e.g. single or double sided fabric), and
- The type and properties of the yarn to be processed (e.g. carded or combed yarn, natural or man-made fibre yarns)

The knitting speed is individually adjustable, and must be adapted to the individual influencing variables from case to case.

\[ V = \frac{\pi \cdot d \cdot n}{39.37 \times 60} \text{ m/sec.} \]

Where, \( \pi = 3.14 \)

\( d = \) cylinder diameter in inch
\( n = \) cylinder rpm
\( 39.37 = \) conversion factor from inch to meter
\( 60 = \) conversion factor from mins. to secs.

Example:
If the cylinder diameter is 30" and the cylinder rpm is 35 then

The knitting speed, \( V = \frac{\pi \cdot d \cdot n}{39.37 \times 60} = \frac{3.14 \times 30 \times 35}{39.37 \times 60} = 1.396 \text{ m/sec.} \)

Circular machine knitting speeds generally lie in a range between 0.8 and 1.8 m/sec.

The above equation can be simplified to some extent if the constant dimensions like \( \pi, 39.37 \) and 60 are combined as one factor.

\[ \text{Factor} = \frac{3.14}{39.37 \times 60} = 0.00133 \]

\[ \therefore V = 0.00133 \times d \times n \text{ m/sec.} \]

For calculating machine rpm from the knitting speed, the above equation is transposed as follows:

The machine rpm, \( n = \frac{V}{0.00133 \times d} \)
Example:
If the knitting speed is 1.63 m/sec and the cylinder diameter is 26", then

\[ \text{The machine rpm, } n = \frac{V}{0.00133 \times d} = \frac{1.63}{0.00133 \times 26} = 47.137 \approx 47 \text{ rpm} \]

Speed factor or performance number:

With the aid of the speed factor SF or the performance number \( L \), circular knitting machines with different system counts and operating speeds can be compared in productivity terms. The performance number \( L \) is calculated in accordance with the above equation as follows:

\[ L = S \cdot n \text{ courses/min.} \]

A circular knitting machine with 72 systems (no. of feeder) and an rpm of 25 per min. has therefore a performance number of

\[ L = 72 \times 25 = 1800 \text{ courses/min.} \]

The performance number 'L' indicates therefore the theoretical number of courses/min. produced by the circular knitting machine.

\[ \text{SF} = L = n \cdot S \text{ courses/min.} \]

Or, \[ n = \frac{\text{SF}}{S} \text{ per min.} \]

Example:

If the Speed factor, SF is 2520 courses/min and system count i.e. no. of feeder is 84, then

\[ n = \frac{\text{SF}}{S} = \frac{2520}{84} = 30 \text{ rpm.} \]

Performance and efficiency:

Performance or efficiency plays a decisive role in producing perfect productivity calculations and cost accounting data for all machines used in warp and weft knitting. By performance, we understand actual output expressed as a % of theoretical output. Performance \( N_E \) is also expressed by the Greek letter \( \eta \).

\[ \text{Performance, } N_E = \frac{\text{Actual output}}{\text{Theoretical output}} \times 100 \% \]

Due to various influencing variables, performance is always less than 100% or expressed as a decimal, less than 1.
Production calculation:

It has been expounded in the sections above that the output of a circular knitting machine depends on a series of different influencing variables. A wealth of machine data and data on the fabric to be produced is required for calculating production capacity.

In this respect the cylinder diameter \( d \) in inch, the gauge \( E \), the system count \( S \), the machine rpm \( n \), and the efficiency level \( \eta \) of the circular knitting machine must be known. The following data on the fabric to be produced must also be available:

- The construction (e.g. single-jersey, rib, purl etc.)
- The course density or courses / cm, and
- The weight per unit area in gm / m\(^2\).

Machine output:

The machine capacity or performance in running m/hr is calculated in accordance with the following equation:

Machine capacity, \( L = \)

\[
\frac{\text{Speed of machine in rpm} \times \text{No. of system or feeders on the machine} \times \text{efficiency} \times 60 \text{ minutes}}{\text{No. of feeders or systems per course} \times \text{courses per cm} \times 100} \text{ m/hr.}
\]

Example:

Calculate the length in meters of a plain, single sided or single-jersey fabric knitted at 20 courses / cm. on a 30" diameter 22-gauge circular machine having 108 feeds. The machine operates for 8 hours at 36 rpm at 87% efficiency.

Machine capacity i.e. the total length of the fabric in metres

\[
= \frac{\text{Speed of machine in rpm} \times \text{No. of system or feeders on the machine} \times \text{efficiency} \times 60 \text{ minutes}}{\text{No. of feeders or systems per course} \times \text{courses per cm} \times 100}
\]

\[
= \frac{36 \times 108 \times 87 \times 60 \times 8}{1 \times 20 \times 100 \times 100}
\]

\[
= 811.82 \text{ metres}
\]

Example:

Calculate the length in meters of a plain, single sided or single-jersey fabric knitted at 16 courses / cm. on a 26" diameter 28-gauge circular machine having 104 feeds. The machine operates for 8 hours at 29 rpm at 95 % efficiency.

Machine capacity i.e. the total length of the fabric in metres

\[
= \frac{\text{Speed of machine in rpm} \times \text{No. of system or feeders on the machine} \times \text{efficiency} \times 60 \text{ minutes}}{\text{No. of feeders or systems per course} \times \text{courses per cm} \times 100}
\]
Fabric width:

The fabric width (WB) in metre is calculated in accordance with the following equation:

\[
\text{Fabric width, WB} = \frac{\text{Cylinder diameter in inch} \times \pi \times \text{machine gauge}}{\text{Wales per cm} \times 100}
\]

Example:

If the cylinder diameter is 30", machine gauge is 32 and the wales per cm. is 14, then

\[
\text{The Fabric Width, WB} = \frac{30 \times 3.14 \times 32}{14 \times 100} = 2.153 \text{ metres.}
\]

Production capacity:

If the production capacity \( P \) of a circular knitting machine is to be calculated in kg / hr., it can be calculated in accordance with the following equation:

\[
\text{Production capacity, } P = \frac{\text{Running length in metre per hour} \times \text{Fabric width in metre} \times \text{Weight in GSM}}{1000} \ K g/\text{hr.}
\]

Example:

If the production in running metres per hour is 63.76, fabric width is 1.76 metres and the fabric weight is 160 gm/m², then

\[
\text{The production capacity, } P = \frac{63.76 \times 1.76 \times 160}{1000} = 17.95 \text{ Kg / hr.}
\]

Production example:

- Plain circular knitting machine:

  Values of circular knitting machine:
  - Machine diameter 30"
  - Gauge E 28
  - Number of feeders 96
  - Machine speed 35 rpm
  - Machine efficiency 85%

  Values of article:
  - Structure: plain (Single-jersey)
  - Yarn: cotton \( N_m \) 50/1 (\( N_e \) 29.6/1)
  - Course density 18 courses/cm.
  - Wales density 13 wales/cm.
  - Fabric weight 125 gm/m²

  Machine performance \( L \) in metre per hour = \[
\frac{n \times S \times 60 \times \pi}{\text{feeders / course} \times \text{courses} \times \text{cm} \times 100}
\]

  \[
  = \frac{35 \times 96 \times 60 \times 0.85}{1 \times 18 \times 100} = 95.2 \text{ m/hr.}
  \]
Fabric width, WB in metre = \( \frac{d \times \pi \times E}{Wpcm \times 100} = \frac{30 \times 3.14 \times 28}{13 \times 100} = 2.03 \text{ m} \)

Machine performance in Kg per hour = \( \frac{L \times WB \times \text{Weight in GSM}}{100} = \frac{95.2 \times 2.03 \times 125}{1000} = 24.157 \text{ Kg/hr.} \)

Example:

- **Interlock circular knitting machine:**

An interlock fabric comprising, in the simplest case, two part courses. These part courses complement each other to make a full course, and therefore two systems or feeders are required for producing one course.

The following data were assumed for the interlock fabric production:

**Example – 1:**

**Values of circular knitting machine:**
- Machine diameter 30”
- Gauge E 28
- Number of feeders 96
- Machine speed 31 rpm
- Machine efficiency 85%

**Values of article:**
- Structure: plain interlock
- Yarn: polyester dtex 76/1
- Course density 17 courses/cm.
- Wales density 14 wales/cm.
- Fabric weight 100 gm/m²

Machine performance L in metre per hour = \( \frac{n \times S \times 60 \times \pi}{\text{feeders / course} \times \text{X courses / cm} \times 100} \)

= \( \frac{31 \times 96 \times 60 \times 0.85}{2 \times 17 \times 100} = 44.64 \text{ m/hr.} \)

Fabric width, WB in metre = \( \frac{d \times \pi \times E}{wpcm \times 100} = \frac{30 \times 3.14 \times 28}{14 \times 100} = 1.88 \text{ m} \)

Machine performance in Kg per hour = \( \frac{L \times WB \times \text{Weight in GSM}}{1000} = \frac{44.64 \times 1.88 \times 100}{1000} = 8.39 \text{ Kg/hr.} \)

**Example – 2:**

**Values of circular knitting machine:**
- Machine diameter 30”
- Gauge E 42
- Number of feeders 108
- Machine speed 31 rpm
- Machine efficiency 87%

**Values of article:**
- Structure: plain interlock
- Yarn: polyester filament yarn dtex 50 f 88/1
- Course density 19 courses/cm.
- Wales density 23 wales/cm.
- Fabric weight 100 gm/m²

Machine performance L in metre per hour = \( \frac{n \times S \times 60 \times \pi}{\text{feeders / course} \times \text{X courses / cm} \times 100} \)

= \( \frac{31 \times 108 \times 60 \times 0.87}{2 \times 19 \times 100} = 45.99 \text{ m/hr.} \)
Fabric width, WB in metre \(= \frac{d \times \pi \times E}{W \times P \times cm \times 100} = \frac{30 \times 3.14 \times 42}{23 \times 100} = 1.72 \text{ m} \)

Machine performance in Kg per hour \(= \frac{L \times W \times B \times Weight \text{ in GSM}}{1000} = \frac{44.99 \times 1.72 \times 100}{1000} = 7.91 \text{ Kg/hr.} \)

- **Jacquard circular knitting machine:**

A two-colour jacquard fabric is to be produced, and the following machine and fabric data were assumed:

**Example – 1:**

**Values of circular knitting machine:**

- Machine diameter 26”
- Gauge E 20
- Number of feeders 60
- Machine speed 27 rpm
- Machine efficiency 80%

**Values of article:**

- Structure: two colour jacquard (two part courses for one course)
- Yarn: cotton yarn \(N_m\) 50/1 (80%), polyester filament yarn dtex 67 f 14 (20%)
- Course density 10.5 courses/cm.
- Wales density 16 wales/cm.
- Fabric weight 90 gm/m²

Machine performance \(L\) in metre per hour \(= \frac{n \times s \times 60 \times \pi}{\text{ feeders / course } \times \text{ courses / cm } \times 100} = \frac{27 \times 60 \times 60 \times 0.80}{2 \times 10.5 \times 100} = 37 \text{ m/hr.} \)

Fabric width, WB in metre \(= \frac{d \times \pi \times E}{W \times P \times cm \times 100} = \frac{26 \times 3.14 \times 20}{16 \times 100} = 1.02 \text{ m} \)

Machine performance in Kg per hour \(= \frac{L \times W \times B \times Weight \text{ in GSM}}{1000} = \frac{37 \times 1.02 \times 90}{1000} = 3.396 \text{ Kg/hr.} \)

**Example – 2:**

**Values of circular knitting machine:**

- Machine diameter 30”
- Gauge E 20
- Number of feeders 96
- Machine speed 23 rpm
- Machine efficiency 80%

**Values of article:**

- Structure: three colour jacquard
- Yarn: polyester dtex 150/1
- Course density 12 courses/cm.
- Wales density 11 wales/cm.
- Fabric weight 180 gm/m²

Machine performance \(L\) in metre per hour \(= \frac{n \times s \times 60 \times \pi}{\text{ feeders / course } \times \text{ courses / cm } \times 100} = \frac{23 \times 96 \times 60 \times 0.80}{3 \times 12 \times 100} = 29.44 \text{ m/hr.} \)

Fabric width, WB in metre \(= \frac{d \times \pi \times E}{W \times P \times cm \times 100} = \frac{30 \times 3.14 \times 20}{11 \times 100} = 1.7 \text{ m} \)
Machine performance in Kg per hour = \( \frac{L \times W \times B \times \text{Weight in GSM}}{1000} = \frac{29.44 \times 1.7 \times 180}{1000} = 9 \text{ Kg/hr.} \)

Example:

Calculate the production of a single-jersey circular knitting machine in kg/hr from the following data:

**Values of circular knitting machine:**
- Machine diameter 30"
- Gauge E 28
- Number of feeders 96
- Machine speed 35 rpm
- Machine efficiency 80%

**Values of article:**
- Structure: plain (Single-jersey)
- Yarn: cotton \( N_m \) 50/1 (\( N_e \) 29.6/1)
- Stitch length 0.25 cm

Production in Kg/hr = \( \frac{n \times s \times \left( \pi \times d \times E \times \text{stitch length in cm} \right) \times 60 \times \tau \times 0.4536}{100 \times 100 \times \text{Ne} \times 840 \times 0.9144} \)

= \( \frac{35 \times 96 \times (30 \times 28 \times 0.25) \times 80}{29.6} \times 0.00001112598 \)

= 21.22 Kg.

Example:

Calculate the length of fabric produced per shift at 75% efficiency of a knitting machine from the following particulars:

- No. of feeders 48
- Fabric open width 264 cm
- Stitch density 15
- Machine speed 20 rpm
- Machine diameter 30 cm
- Machine gauge E 14

Fabric width = \( \frac{\text{Total no. of wales}}{\text{Wales per cm.}} \)

Wales per cm. = \( \frac{\text{Total no. of wales}}{\text{Fabric width}} = \frac{d \times \pi \times E}{\text{WB}} = \frac{30 \times 3.14 \times 14}{264} = 4.99 \approx 5 \)

Again stitch density = wales/cm \times courses/cm

Courses/cm = \( \frac{\text{Stitch density \times Wales / cm.}}{\text{Wales / cm.}} = \frac{15}{5} = 3 \)

Length of fabric produced per minute = \( \frac{\text{courses per minute}}{\text{courses per cm}} = \frac{n \times s}{\text{cpcm}} = \frac{20 \times 48}{3} = 320 \text{ cm} = 3.2 \text{ m} \)
Length of fabric produced per shift at 75% efficiency = \(3.2 \times 60 \times 8 \times 0.75 = 1152\) m.

**Example:**

Calculate the courses / cm of a fabric producing 1152 metres per 8 hours shift in a circular knitting machine with the following particulars:

- No. of feeders 48
- Machine speed 20 rpm
- Efficiency 75%

Length of fabric produced per shift at 75% efficiency = \(\frac{\text{courses per minute} \times 60 \times 8 \times 0.75}{\text{courses per cm}}\)

Courses / cm = \(\frac{20 \times 48 \times 60 \times 8 \times 0.75}{1152 \times 100} = 3\)

**Weight per unit area and cover factor:**

Weight per unit area of fabric is an important property that is again related to a host of other properties. The weight is determined by two factors that interact: the loop size and the yarn size. The effect of the loop size is simple to express: if the size of the yarn remains constant, then increase of loop size produces a decrease of weight per unit area. The effect is an inverse ratio.

Stitch density is the most important one in defining knitted fabric properties and is directly related to appearance, weight per unit area, thickness, drape and many other factors.

The stitch length is the absolute quantity of any knitted fabric and is directly related to the stitch density. In general terms, for any knitted fabric, as the loop size increases the loop density decreases. For simple fabrics the relationship can be expressed in a single equation:

\[S = \frac{K}{l^2}\]

Where \(S\) is the stitch density, \(l\) is the loop length and \(K\) is a constant for the particular construction. A large amount of data and research work has been carried out relating the above expression to the characteristics of plain fabric, and definite values of \(K\) have been proposed. For other constructions, while the proposition still holds the situation is more complex and further study is required.

**Example:**

We know that, \(S = \frac{K}{l^2}\) and Let \(K = 20\)

- For a loop length of 0.4 cm, stitch density \(S = \frac{20}{0.4^2} = 125\) stitches/cm²

Length of yarn in 1 cm² of fabric = \(125 \times 0.4 = 50\) cm
• For a loop length of 0.8 cm, stitch density \( S = \frac{20}{0.8} = 31.25 \) stitches/cm²

Length of yarn in 1 cm² of fabric = 31.25 × 0.8 = 25 cm

So double the loop size means half the weight per square unit. Usually in knitted fabrics, for fabrics of a similar construction, as loop length increases so the size of yarn increases. Yarn sizes are themselves expressed not in terms of diameter but in weight per unit length.

In a knitted fabric, to maintain cover, as the length of loop doubles so the diameter of the thread must double.

Cover is a simple ratio of the area of a knitted fabric covered by yarn to the area covered by the gaps in between loops. It can be demonstrated that for a given knitted structure, if the cover ratio is maintained through a range of fabrics with different loop lengths, then those fabrics are related in characteristics of tightness / looseness and other physical properties.

This concept of cover leads to the property of ‘normality’ of a knitted fabric. A ‘normal’ fabric is one that is neither too tight and stodgy nor too loose and floppy. Lay observers given a range of fabrics of differing loop size and yarn size make surprisingly similar judgements on what ‘normality’ is in a knitted fabric intended for normal apparel.

There is a simple formula that can be used to express ‘cover factor’ or tightness factor, taking into account and abbreviating diameter of yarn, length of loop and loop density.

\[
\text{Cover factor (cf)} = \sqrt{\frac{\text{Count in tex}}{l}}
\]

For a particular value of cover factor we can obtain a range of fabrics having similar normality relationships. The calculation for weight/m² involves combining the equation for stitch density and the equation for cover factor:

Weight in gm of 1 m² of fabric, i.e.

\[
\text{GSM} = \frac{\text{CPI} \times \text{WPI} \times l(\text{mm})}{\text{Ne}} \times 0.9158
\]

\[
\text{GSM} = \frac{\text{CPI} \times \text{WPI} \times l(\text{cm})}{\text{Ne}} \times 9.158
\]

\[
\text{GSM} = \frac{\text{CPI} \times \text{WPI} \times l(\text{mm})}{\text{Nm}} \times 1.55
\]

\[
\text{GSM} = \text{CPI} \times \text{WPI} \times l(\text{mm}) \times \text{Tex} \times 0.00155
\]

\[
\text{GSM} = \text{CPI} \times \text{WPI} \times l(\text{mm}) \times \text{Denier} \times 0.00017
\]

In another form,

\[
\text{GSM} = \frac{\text{Loops/cm}^2 \times l(\text{cm}) \times \text{tex}}{10}
\]

As loops per cm² = \( \frac{K}{l^2} \)
Therefore GSM = \( \frac{K \times \text{tex}}{l \times (\text{cm}) \times 10} \)

As \( \text{Tex} = (cf \times l)^2 \)

Therefore GSM of a fabric = \( \frac{K \times (cf \times l)^2}{l \times 10} \)

The concept of the relaxed state for knitted fabrics is well recognized and documented. Quality control must ensure that before knitted garments are cut, the fabric is in a relaxed or near relaxed condition, i.e. that there will be little shrinkage of the fabric/garment when it is in the consumer’s possession. Relaxation tests can be carried out on fabric as a routine procedure, or as spot checks on suspect deliveries. There are British Standard procedures for relaxation testing and some of the large retail/wholesale purchasers have established tests of their own. Most test procedures involve agitation in aqueous solution followed by measurement under water, and/or spinning and tumble drying. They attempt to reproduce the conditions under which the garment will be laundered during usage.

**Relation between Yarn count and Machine gauge:**

Selection of machine gauge depends upon yarn diameter. Yarn diameter also depends on several factors such as yarn count, fibre type, yarn twist, yarn finishing etc. General practice of yarn count and machine gauge in different industries in Bangladesh given below:

<table>
<thead>
<tr>
<th>Yarn count used</th>
<th>Machine gauge</th>
<th>Yarn count used</th>
<th>Machine gauge</th>
</tr>
</thead>
<tbody>
<tr>
<td>16</td>
<td>18</td>
<td>28</td>
<td>22</td>
</tr>
<tr>
<td>18</td>
<td>20</td>
<td>28</td>
<td>25</td>
</tr>
<tr>
<td>20</td>
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<td>28</td>
<td>28</td>
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<td>24</td>
<td>30</td>
<td>22</td>
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<td>26</td>
<td>20</td>
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<td>34</td>
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<td>22</td>
<td>34</td>
<td>28</td>
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<tr>
<td>26</td>
<td>24</td>
<td>34</td>
<td>28</td>
</tr>
<tr>
<td>26</td>
<td>28</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The above values may differ, because it is the results of a research work. There is a relation between yarn in tex and machine gauge is given by a equation,

For single-jersey, \( G = \sqrt{\frac{1650}{\text{Tex}}} \) and for double-jersey, \( G = \sqrt{\frac{1400}{\text{Tex}}} \), where G is measured in needles per cm.

The yarn count to be used on a circular knitting machine depends largely on the pitch, and thus on the machine gauge. For any given machine gauge it can lie within a larger range, because on the same machine different yarn counts can be used, depending on the knitted structure, the desired optics (fabric appearance) and the fabric properties.
The following tables contain practical values of the average count of yarn to be used, depending on the machine gauge and several fabric types. The values in N\textsubscript{e} (converted from values in N\textsubscript{m}) refer to staple fibre yarns and those in dtex are related to filament yarns.

### Yarn count and machine gauge for Single-jersey

<table>
<thead>
<tr>
<th>Machine gauge E Needles/inch</th>
<th>Ne</th>
<th>Yarn count</th>
<th>dtex</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>2.5/2 - 7.0/2</td>
<td>660x2 - 550x2</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>3.5/2 - 9.5/2</td>
<td>550x2 - 400x2</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>5.0/2 - 12.0/2</td>
<td>470x2 - 330x2</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>7.0/2 - 14.0/2</td>
<td>400x2 - 260x2</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>9.5/2 - 8.5/1</td>
<td>330x2 - 235x2</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>10.5/2 - 10.5/1</td>
<td>280x2 - 200x2</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>14.0/2 - 12.0/1</td>
<td>235x2 - 150x2</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>8.5/1 - 14.0/1</td>
<td>200x2 - 235x1</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>10.5/1 - 16.5/1</td>
<td>150x2 - 200x1</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>12.0/1 - 19.0/1</td>
<td>250x1 - 167x1</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>14.0/1 - 23.5/1</td>
<td>200x1 - 150x1</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>18.0/1 - 28.0/1</td>
<td>167x1 - 122x1</td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>21.5/1 - 29.5/1</td>
<td>150x1 - 110x1</td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>23.5/1 - 35.5/1</td>
<td>140x1 - 100x1</td>
<td></td>
</tr>
<tr>
<td>26</td>
<td>26.5/1 - 41.5/1</td>
<td>122x1 - 84x1</td>
<td></td>
</tr>
<tr>
<td>28</td>
<td>29.5/1 - 47.5/1</td>
<td>110x1 - 76x1</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>36.5/1 - 59.0/1</td>
<td>100x1 - 67x1</td>
<td></td>
</tr>
<tr>
<td>32</td>
<td>41.5/1 - 71.0/1</td>
<td>84x1 - 55x1</td>
<td></td>
</tr>
</tbody>
</table>

### Yarn count and machine gauge for Interlock

<table>
<thead>
<tr>
<th>Machine gauge E Needles/inch</th>
<th>Ne</th>
<th>Yarn count</th>
<th>dtex</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>2/14.0/2 - 2/21.5/2</td>
<td>800x1 - 550x1</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>2/18.0/2 - 2/23.5/2</td>
<td>660x1 - 470x1</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>2/21.5/2 - 2/28.0/2</td>
<td>550x1 - 400x1</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>2/23.5/2 - 2/30.5/2</td>
<td>470x1 - 330x1</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>2/28.0/2 - 2/35.5/2</td>
<td>400x1 - 280x1</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>2/30.5/2 - 2/38.0/2</td>
<td>330x1 - 235x1</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>2/35.5/2 - 2/43.0/2</td>
<td>280x1 - 200x1</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>12.0/1 - 16.5/1</td>
<td>235x1 - 167x1</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>14.0/1 - 19.0/1</td>
<td>200x1 - 150x1</td>
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</tr>
<tr>
<td>16</td>
<td>16.5/1 - 21.5/1</td>
<td>150x1 - 110x1</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>18.5/1 - 23.5/1</td>
<td>122x1 - 84x1</td>
<td></td>
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<tr>
<td>20</td>
<td>21.5/1 - 26.0/1</td>
<td>110x1 - 76x1</td>
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<td>22</td>
<td>24.0/1 - 29.5/1</td>
<td>100x1 - 67x1</td>
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<td>24</td>
<td>27.5/1 - 35.5/1</td>
<td>84x1 - 55x1</td>
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</table>

### Yarn count and machine gauge for Fleecy

<table>
<thead>
<tr>
<th>Machine gauge E Needles/inch</th>
<th>Ne</th>
<th>Yarn count</th>
<th>dtex</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>2.5/1 - 9.5/1</td>
<td>720x2 - 622x1</td>
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<tr>
<td>14</td>
<td>3.5/1 - 12.0/1</td>
<td>620x2 - 500x1</td>
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<td>4.7/1 - 14.0/1</td>
<td>500x2 - 420x1</td>
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<td>16</td>
<td>6.0/1 - 16.5/1</td>
<td>383x1 - 360x1</td>
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<td>18</td>
<td>7.0/1 - 18.0/1</td>
<td>660x1 - 300x1</td>
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<td>20</td>
<td>8.5/1 - 20.0/1</td>
<td>500x1 - 280x1</td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>10.5/1 - 23.5/1</td>
<td>360x1 - 200x1</td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>14.0/1 - 26.0/1</td>
<td>300x1 - 167x1</td>
<td></td>
</tr>
<tr>
<td>26</td>
<td>16.5/1 - 29.5/1</td>
<td>250x1 - 150x1</td>
<td></td>
</tr>
<tr>
<td>28</td>
<td>19.0/1 - 35.5/1</td>
<td>200x1 - 122x1</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>21.5/1 - 41.5/1</td>
<td>150x1 - 110x1</td>
<td></td>
</tr>
<tr>
<td>32</td>
<td>23.5/1 - 47.5/1</td>
<td>122x1 - 84x1</td>
<td></td>
</tr>
</tbody>
</table>

### Yarn count and machine gauge for Fine Rib

<table>
<thead>
<tr>
<th>Machine gauge E Needles/inch</th>
<th>Ne</th>
<th>Yarn count</th>
<th>dtex</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>12.0/1 - 16.5/2</td>
<td>800x1 - 550x1</td>
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</tr>
<tr>
<td>14</td>
<td>14.0/1 - 19.0/2</td>
<td>660x1 - 400x1</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>16.5/1 - 21.5/2</td>
<td>550x1 - 330x1</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>19.0/1 - 24.0/2</td>
<td>470x1 - 280x1</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>21.5/1 - 27.5/2</td>
<td>400x1 - 235x1</td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>24.0/1 - 30.5/2</td>
<td>330x1 - 200x1</td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>27.5/1 - 36.0/2</td>
<td>260x1 - 167x1</td>
<td></td>
</tr>
<tr>
<td>26</td>
<td>30.0/1 - 38.0/2</td>
<td>200x1 - 122x1</td>
<td></td>
</tr>
<tr>
<td>28</td>
<td>33.5/1 - 41.5/2</td>
<td>150x1 - 90x1</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>37.5/1 - 45.5/2</td>
<td>122x1 - 76x1</td>
<td></td>
</tr>
<tr>
<td>32</td>
<td>41.5/1 - 53.0/2</td>
<td>100x1 - 67x1</td>
<td></td>
</tr>
</tbody>
</table>

### Relation between Yarn count and GSM:

From the research work it is try to find the following equations for the selection of yarn count to get required GSM equations vary for fabric types, fabric construction. List of equations are tabulated below:

<table>
<thead>
<tr>
<th>Name of fabrics</th>
<th>Equations</th>
<th>Name of fabrics</th>
<th>Equations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single-jersey</td>
<td>Ne = -0.141 GSM + 50.22</td>
<td>Single-jersey</td>
<td>GSM = 350.4 - 6.879 N\textsubscript{e}</td>
</tr>
<tr>
<td>Pique</td>
<td>Ne = -0.146 GSM + 57.16</td>
<td>Pique</td>
<td>GSM = 354.56 - 4.9716 N\textsubscript{e}</td>
</tr>
<tr>
<td>Double lacoste</td>
<td>Ne = -0.167 GSM + 64.36</td>
<td>Pique</td>
<td>GSM = 386.44 - 6.6737 N\textsubscript{e}</td>
</tr>
<tr>
<td>1x1 Rib</td>
<td>Ne = -0.123 GSM + 54.57</td>
<td>1x1 Rib</td>
<td>GSM = 437.66 - 7.9731 N\textsubscript{e}</td>
</tr>
<tr>
<td>Lycra 1x1 Rib</td>
<td>Ne = -0.119 GSM + 59.12</td>
<td>Lycra 1x1 Rib</td>
<td>GSM = 494.08 - 8.2839 N\textsubscript{e}</td>
</tr>
<tr>
<td>Lycra 2x2 Rib</td>
<td>Ne = -0.108 GSM + 56.62</td>
<td>Lycra 2x2 Rib</td>
<td>GSM = 519.05 - 9.1216 N\textsubscript{e}</td>
</tr>
<tr>
<td>Interlock</td>
<td>Ne = -0.206 GSM + 80.56</td>
<td>Interlock</td>
<td>GSM = 388.41 - 4.778 N\textsubscript{e}</td>
</tr>
</tbody>
</table>
Selection of yarn count for various GSM for different fabrics:

<table>
<thead>
<tr>
<th>GSM</th>
<th>Fabrics</th>
<th>Plain or Single-je rsey</th>
<th>Pique</th>
<th>1×1 Rib</th>
<th>Lycra 1×1 Rib</th>
<th>Lycra 2×2 Rib</th>
<th>Interlock</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td></td>
<td>36.12</td>
<td>47.66</td>
<td>42.27</td>
<td>47.22</td>
<td>45.82</td>
<td>59.96</td>
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<tr>
<td>120</td>
<td></td>
<td>33.3</td>
<td>44.32</td>
<td>39.81</td>
<td>44.84</td>
<td>43.66</td>
<td>55.84</td>
</tr>
<tr>
<td>140</td>
<td></td>
<td>30.48</td>
<td>40.98</td>
<td>37.35</td>
<td>42.46</td>
<td>41.5</td>
<td>51.72</td>
</tr>
<tr>
<td>160</td>
<td></td>
<td>27.66</td>
<td>37.64</td>
<td>34.89</td>
<td>40.08</td>
<td>39.34</td>
<td>47.6</td>
</tr>
<tr>
<td>180</td>
<td></td>
<td>24.84</td>
<td>34.3</td>
<td>32.43</td>
<td>37.7</td>
<td>37.18</td>
<td>43.48</td>
</tr>
<tr>
<td>200</td>
<td></td>
<td>22.02</td>
<td>30.96</td>
<td>29.97</td>
<td>35.32</td>
<td>35.02</td>
<td>39.36</td>
</tr>
<tr>
<td>220</td>
<td></td>
<td>19.2</td>
<td>27.62</td>
<td>27.51</td>
<td>32.94</td>
<td>32.86</td>
<td>35.24</td>
</tr>
<tr>
<td>240</td>
<td></td>
<td>16.38</td>
<td>24.28</td>
<td>25.05</td>
<td>30.56</td>
<td>30.7</td>
<td>31.12</td>
</tr>
</tbody>
</table>

Relation among GSM, stitch length and yarn count can be derived from the following equation:

\[ \frac{1}{GSM} \propto \frac{1}{\text{Yarn count (Ne)} \times \text{Stitch length}} \text{, when yarn count and stitch length both are variables} \]

\[ \therefore \text{GSM} = \frac{K}{\text{Yarn count (Ne)} \times \text{Stitch length}} \text{, where } K \text{ is a constant} \]

\[ \therefore \text{Yarn count (Ne)} \times \text{Stitch length} \times \text{GSM} = K \]

\[ \therefore \text{Stitch length} = \frac{K}{\text{Yarn count (Ne)} \times \text{GSM}} \]

Constant 'K' which can be derived as follows:

<table>
<thead>
<tr>
<th>Fabrics</th>
<th>Constant K values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single-je rsey or Plain</td>
<td>12068.509</td>
</tr>
<tr>
<td>Double lacoste</td>
<td>14855.2</td>
</tr>
<tr>
<td>1×1 Rib</td>
<td>16431.497</td>
</tr>
<tr>
<td>2×1 Rib</td>
<td>19005.333</td>
</tr>
<tr>
<td>Interlock</td>
<td>24013.8</td>
</tr>
</tbody>
</table>

These values are get from a research work. It may be changed. For getting more accurate results it needs more data from different industry.
Introduction to Warp Knitted Fabrics:

Warp knitted fabric is formed from a yarn system called “the warp”. All ends supplied from the same warp sheet normally have identical lapping movements because each is lapped by a guide attached to the same guide bar. The warp yarns, after forming loops in one course, pass into the following course, and, as a rule, the number of loops formed in the course is the same as the number of yarns in the warp. Due to this, loop formation in warp knitted fabric features the presence of links J connecting the loops in the adjacent courses. Depending on the method the warp yarn is layed on the needles, the loops are of the following types: Open loops (courses II and IV), closed loops (courses I and III), with one side links (courses I and III) and with two-side links (courses II and IV).

Beams supply the warp sheets in parallel form to the guide bars whose pattern control determines the timing and configuration of the lapping movements in the form of overlaps and underlaps. The needles intermesh the new overlaps through the old overlaps to form the intermeshed loop structure.

Part of the yarn, between the loops which connect the wales together, is referred to as the underlap. The two sides of the fabric are referred to as the technical face (the side on which the knitted loops are prominent) and the technical back (the side on which the underlaps are prominent).
Warp knitted curtain fabric

The Guides:

Warp guides are thin metal plates drilled with a hole in their lower end through which a warp end may be threaded if required, they are held together at their upper end in a metal lead and are spaced in it to the same gauge as the machine. The leads in turn are attached to a guide bar so that the guides hang down from it with each one occupying a position at rest midway between two adjacent needles, in this position the warp thread cannot be received by the needles and it will merely produce a straight vertical float.

The needles only receive the warp thread in their hooks if the guide bar overlaps across their hooks, or across the side remote from their hooks when the guide bar underlaps. All guides in a conventional guide bar produce an identical lapping movement at the same time and therefore have identical requirements of warp, tension and rate of feed, although the threads may differ in colour or composition from each other.
Overlap, that length of yarn in a warp knitted fabric that has been placed over the needle during loop formation.

Underlap, that length of yarn in a warp knitted fabric that connects two overlaps in consecutive courses.

The Guide Bar:

A bar running the full width of a machine and equipped with guides through which threads are passed so that the lateral motions imparted to the guide bars by the pattern control device are transmitted to the threads.

Each end of yarn from each warp is located in the knitting zone by passing through the eye of a guide. All the guides containing the yarns fed from a single warp, are connected to a guide bar, so that all of them move uniformly with it.

The individual guides are usually cast in 1 inch units – which in turn are fitted on the guide bars. The guides swing between and around the needles in order to warp the yarn around them to form a new loop. They also shog side ways to connect the wales into a fabric.

Each guide bar is normally supplied with a warp sheet from its own beam shaft to suit its requirements of threading and rate of warp feed for its particular lapping movement.

Occasionally, two partly-threaded guide bars may be supplied from the same full-threaded beam provided they make lapping movements of the same extent to each other whilst moving in opposite directions. The minimum number of guide bars and warp sheets for commercially acceptable structures is usually two.

Lapping movement of the Guide Bar:

When the needle bar is observed in plan view from above, it can be seen that the guides of a guide bar are required to execute a compound lapping movement composed of two separately derived motions. A swinging motion and a shogging movement act at right angles to each other in order for their threads to form overlap and underlap paths which are joined together around the needles.
The swinging motion is in an arc from the front of the machine to the hook side and a later return swing. It occurs between adjacent needles and is a fixed, collective and automatic action for all the guide bars as they pivot on a common rocker-shaft. It is derived in a similar manner to the needle and other element bar motions from the main cam-shaft and is adapted via levers, pivots and linkages. The two swinging movements produce the two side limbs when combined with the overlap shog. When the overlap is omitted the guides swing idly between adjacent needles and achieve no useful purpose.

![Swinging and Shogging mechanism of the Guide bar](image)

The sideways shogging movement which occurs parallel to the needle bar produces the underlaps and overlaps. The occurrence, timing, direction and extent of each shog is separately controlled for each guide bar by its pattern chain links or pattern wheel attached to a horizontal pattern shaft driven from the main cam-shaft but set at right angles to it at one end of the machine. The guide bars are shogged independently sideways parallel to each other along linear bearings which support them in the swinging frame assembly which is keyed to the guide bar rocker-shaft.

A shogging movement can occur when the guides have swung clear of the needle heads on the back or front of the machine. On the hook side it will produce an overlap and on the side remote from the hooks it will produce an underlap. The timing of the shog during the 360 degrees of the main cam-shaft revolution will thus determine whether an overlap or underlap is produced.

**The Pattern Mechanism:**

The shogging movement is initiated by varying the radius of the continuously-turning pattern shaft either in the form of different heights of pattern links which pass over a pattern drum attached to the shaft, or in the form of carefully-shaped solid metal circular cams, termed pattern wheels or pattern disks, attached to it.
An increase in height from one link to the next produces a thrust against the end of the guide bar shogging it positively into the machine, a decrease will produce a negative shog towards the pattern shaft as the result of the action of a return spring. A constant height will produce no shog and the guide bar will continue to swing through the same needle space. The periphery of the pattern wheel or chain track is scanned by a roller which is linked by a flexible ball-jointed push-rod to the end of a guide bar, the underside of the rod near the roller is supported on a slide which moves freely on a metal surface as shogging occurs.

The drive for the pattern shaft is obtained from the main cam-shaft via bevel gears and a universal joint to a worm which derives the worm wheel of the pattern shaft. The ratio of cam-shaft speed to the pattern shaft speed is usually 16:1, therefore $\frac{1}{16}$th of the surface of a pattern wheel would represent one course or knitting cycle.

The lateral movement of the guide bars is generated by the patterning mechanism, which is situated on the side of the machine. The patterning mechanism of a tricot machine is described as follows.

The mechanism is driven by the main shaft (1) via a belt (2), worm (3) and a worm gear (4). The pattern drum (6) is mounted onto the shaft (5) so that it rotates in a constant ratio to the speed of the main shaft.

A chain made of links of different heights is placed on the pattern drum. While rotating, the different chain links move the roller (9) and slide (8) so that the push rod (7) moves the guide bar and displaces it laterally. The roller and push rod are held against the pattern drum by springs.

Patterning mechanism of a tricot machine
A lateral gating adjustment to the position of the guides is carried out by changing the length of the push rod using the bolt (10). The pattern drum with its pattern chain can be easily replaced by a pattern disk, precisely pre-cut for a certain design. Although the disk can only be used for one lapping sequence, it has the advantage of a very accurate, smooth and high-speed performance.

Pattern wheels provide accuracy and smooth running at high speeds but they are only economical for long production runs of the common simple repeat structures; for fancy structures, frequent changes of pattern and long pattern repeats, the shogging movements are obtained by assembling a chain of re-usable pattern links.

Chain links:

The identically Y-shaped chain links are similar in appearance to a tuning fork with the fork end leading. The tail of the preceding link fits into the fork of the succeeding link and the links are held together by pins which are pushed through holes in the side of the fork and tail, the pins pass through all the tracks and chains and the ends fit into grooves in the serrated flanges of the pattern drum so that as the drum turns the chain links are advanced in unison, in correct timing.

The link is slightly arched to fit the surface of the pattern drum. In order to ensure that the wider side of the link takes the greater load when pushing the guide bars, the fork side is the leading part of the link when connecting a chain. Links are made to fit a certain machine gauge. To eliminate any confusion, the gauge is stamped on to the link, together with the height of the link in needle spaces.

To ensure smooth operation, the leading and trailing edges of the links are ground to produce a slope. The angle and length of the ground edge must be very accurately set, so that the shogging movement is correctly timed.

Too steep an angle moves the guide bar before the swing to the hook side has been completed. A long angle causes the guide bar to move later when the swing-back has already started. A badly timed shogging movement might cause the yarn to be cut between needles and guides and, in extreme cases, knitting elements can be damaged.

A grinding gauge is usually supplied by the machine manufacturer and the links must only be ground according to it. Pattern links are also available with preground edges to fit different chain arrangements. These links are designated by letters indicating the ground edge.

- ‘a’ – is an unground link.
- ‘b’ – is a link on which the fork is ground.
- ‘c’ – indicates a ground tail.
- ‘d’ – means that both fork and tail are ground.
A profile of a pattern chain

With direct transmission of the shogging movement from chain links to guide bar, as described, the exact distance shogged is the difference in heights between the two successive links. This method is employed on most high speed machines and on the ground guide bars of many multi-bar Raschels.

Chain link numbering commences with ‘0’ height and every guide bar chain sequence must contain at least one of these ‘0’ links because when the guide bar is on this link it will be in its nearest position to the pattern mechanism, during that particular lapping movement. Tricot links are numbered 0, 1, 2, 3, 4, 5, etc., and with direct shogging, each will be successively one needle space higher than the previous link, so that on a 28 gauge tricot machine, a ‘2’ link will be \( \frac{1}{28} \) th inch (0.9 mm) higher than a ‘1’ link which will be \( \frac{1}{28} \) th inch higher than a ‘0’ link. If a ‘1’ link is placed after a ‘0’ link, a one-needle space shog away from the pattern mechanism will be produced. If a ‘0’ link is placed after a ‘3’ link a three needle space shog towards the pattern mechanism will occur. If two links of the same height are placed next to each other, for example ‘3’ followed by a ‘3’ a shog will not be produced and the guides will remain between the same needle spaces.

It must be understood that a height of link, for example ‘0’, does not represent a fixed position between two needle spaces, it represents the nearest position each guide in a particular guide bar approaches the pattern mechanism during that lapping movement. When a guide bar is on a ‘0’ link, all guides in that bar will be in their ‘0’ position but each will occupy a different space between needles across the width. Likewise, two guides from different bars may occupy the same space between two adjacent needles and yet be at different heights of links at that point.

A chain notation is a list in correct sequence of chain link numbers spaced into knitting cycles for each guide bar necessary to produce a particular structure. The difference between the first two links is normally the overlap. It must be remembered that the links are joined together in a closed loop with the starting link for each bar joined to its last link. For this reason, underlap movements towards left and right tend to balance each other.
The number of links per course is fixed for each machine, a minimum of two is usually required with the overlap occurring between the second link of one course and the first link of the next. On tricot machines, a third intermediate link is often used so that the underlap is also spread between the second and third links giving it more time and coinciding more closely with the knitting cycle requirements.

Modern Tricot machines use 3 links for each knitting sequence. This is because the guides spend very little time on the hook side of the needles during the overlap; a much larger proportion of the knitting cycle is spent when they are on the front side. The 3 links per course movement distributes the time allocated for each shogging movement in a better way. One-third for overlap and two-thirds for underlap.

It must also be remembered that the overlap is in most cases only one needle space, while the underlap shog consists sometimes of several needle spaces. The fact that there are two links available for the underlap allows a long shogging movement to be distributed between them.

The Warp Beams:

To ensure uniform conditions of warp feed and tension, the ends are supplied from flanged beams attached to shafts which turn to unwind the warp sheet in parallel formation. For convenience of handling, a number of beams may be attached to a beam shaft to achieve the full width of warp sheet, for example, a warp sheet 76 inches wide might be supplied from a full width beam, two beams each 38 inches wide, or four beams each 19 inches wide.

![A modern Warping machine](image)

The width of the warp section has increased in order to decrease the number of flanges and the contact between flanges and yarn. Beam width can be up to 84 inches.

![Different beam sections accommodated by a modern warping machine](image)
Lapping Diagrams and Chain Notations:

Lapping diagrams are drawn around horizontal rows of points which represent needles in plan view, usually assuming the pattern mechanism to be on the right. As the guides position themselves in the spaces between needles, the positions between the vertical columns of points can be given chain link numbers commencing with '0' position which is to the right of the right hand column of points.

Provided the direction and extent of the overlaps are correctly indicated in the lapping diagram and chain notation, the underlaps will always be correctly positioned as each extends from the end of one overlap to the start of the next.

![Guide bar lapping movement notation](image)

![Chain notation (2 links per course)](image)

In the lapping diagram, the first overlap will be drawn in a curve over a point from space 1 to space 0 and the second from space 2 to space 3. The lapping diagram is completed by joining the overlaps together with underlaps and the chain is notated as 1 – 0 / 2 – 3 / where ' – ' represents an overlap and ‘/’ an underlap. Whereas the shogging movements are produced by the transition from one link to the next, the swinging motions occur whilst the push-rod roller of the guide bar is in the centre of a link so that no shog is produced.

When plotting a lapping diagram, a few basic rules must be observed:

1. When the fabric is composed of more than one guide bar, the lapping movement of each guide bar must be represented separately by one thread
2. The lapping diagrams of all bars, knitting the fabric, must be plotted from the same course, so that the relative lateral position of all is kept.
3. The numbers allocated for the spaces between the needles must always correspond to the position of the pattern mechanism. For machines with pattern mechanisms on their right side, which is more common, the spaces must be numbered from right to left, as for the above example. The spaces are numbered from left to right if the pattern mechanism is at the left of the machine.

For multi-guide-bar machines with two patterning mechanisms, one on each side, the lapping movement of each guide bar has to be analyzed regarding the position of the patterning mechanism operating it.
4. When mounting a chain on the pattern drum, special care must be taken to ensure that the position of the chain corresponds to the movement of the knitting elements. If the chain is placed one link forwards or backwards, the guide bar shogs its underlap on the hook side of the needle, wrapping more than one needle and causing, in some cases, damage to the knitting elements.

**Single-needle or Double-needle Overlaps:**

Overlap movements are normally across only one needle space as a double needle overlap would cause both the warp thread and the needles to be subjected to the severe strain of two simultaneous adjacent knock over actions, whilst different tensions on the two loops in the structure will adversely affect their appearance. The underlap between the double overlap loops has the appearance of a sinker loop. Only in a few Raschel structures is the double-needle overlap used and here the needles are less easily deflected and there are no knock over sinkers over which to draw the loops. A single full-threaded guide bar making a double-needle overlap will cause each needle to receive two overlapped threads at that course.

The greater the extent of the underlap in needle spaces, the heavier the fabric and the more horizontal the path of the thread as it crosses the structure.

**Basic Overlap or Underlap Variations:**

All guide bar lapping movements are composed of one or more of the following five lapping variations:

- a) Closed lap – an overlap followed by an underlap in the opposite direction.
- b) Open lap – an overlap followed by an underlap in the same direction.
- c) Open lap – only overlaps and no underlaps.
- d) Laying-in – only underlaps and no overlaps.
- e) Miss-lapping – neither overlaps nor underlaps.

**Basic Lapping Movements or Basic Stitches in Warp Knitting:**

Most warp knitted fabrics are produced by a few guide bars, each one knitting a simple and basic lapping movement, which are described in the following:
1. Pillar or Chain Stitch:

A pillar stitch which produces a vertical chain of consecutively knitted loops on the same needle from the same yarn. The chains may be connected together by other yarns or they may be entirely separate from each other.

A pillar stitch is formed when a needle is being lapped continuously by the same guide. Since the guide bar does not lap the adjacent needles, there are no sideways connections and no fabric is formed. For the same reason, it is very difficult to form a chain (pillar) construction on a tricot machine, unless at least one more underlap forming guide bar is employed. With no underlap to be held in the throat of the sinker, the fabric rides up with the needles and does not clear the hooks.

With Raschel machines, however, chain constructions can very easily be produced due to the downward pull of the take-up mechanism. Different net fabrics, constructed of chain lapping movements, are produced in great quantities by the Raschel industry.

The pillar lapping movement can be open, closed or can be a combination of closed and open laps. The more common open lap chain construction is formed when the guide laps the needle alternately from the right and the left. The chain notations, as derived from figure are 0 – 1 for the first course and 1 – 0 for the next.

To produce a closed lap pillar, the guide has to lap the needle continuously in the same direction and the chain notations are 0 – 1 for all courses. A closed chain construction is less common because the guide, while rotating around the needle in the same direction, may insert an undesired false twist into the yarn.

Constructions made with a combination of closed and open laps, as well as constructions of only closed laps, are usually produced in order to achieve a certain technological aim.
Having no sideways underlaps, the yarn consumption of a chaining guide bar is relatively very small. This, and the fact that the construction is very stable lengthwise, makes it very popular for the production of certain fabric types.

Pillar construction can easily be unraveled from the end knitted last by pulling on a free end of the yarn. Although usually a disadvantage, this characteristic is used in the production of lace edgings as a method of separating the bands after finishing.

2. Tricot Stitch or 1 and 1 Lapping Movement:

Tricot stitch is a stitch formed of one warp; the tricot loops are disposed in an alternate order in two adjacent wales. This tricot may be formed of closed, open or alternate closed and open loops; the links in tricot are seen on the back.

This lapping movement is formed by the guide lapping alternately two adjacent needles. It is also called a tricot lap, and the definition “1 and 1” implies an underlap of one needle space and one overlapped needle.

![Diagram of Tricot Stitch]

Although a fabric is formed by this lapping movement it has as with most single-bar fabrics, a restricted commercial value. As with pillar lapping, the 1 and 1 movement can be formed open or closed. The closed 1 and 1 structure is more popular. The chain notations for the closed lap construction are $1 - 2 / 1 - 0$ and for the open one: $2 - 1 / 0 - 1$. For tricot machines, the chain reads $1 - 2 - 2 / 1 - 0 - 0$ and $2 - 1 - 1 / 0 - 1 - 1$ respectively.

The guide bar producing a 1 and 1 lapping movement consumes more yarn than a chaining one, however, the amount is still relatively small. The construction is flexible, light and very popular in the production of two guide bar fabrics.

Tricot is a warp-knitted fabric knitted with two full sets of warp threads, each set making, a 1 and 1 lapping movement but in opposite directions. Additionally the term is
now used generically to cover all types of warp knitted fabric made on tricot warp knitting machines.

3. **Cord Stitch or 2 and 1 Lapping Movement:**

It differs from tricot in the length of links. It is knitted from a one warp system and the loops are formed by one yarn in turn in adjacent courses, every two wales \( (R_b = 3, R_H = 2) \). In the atlas derivatives of the cord type, the yarns from loops in every other wale in one direction over several courses, and then in the same order in the other direction. The smallest repeat of such an atlas in width is \( R_{b_{min}} = 5 \), and of the satin type atlas \( R_{b_{min}} = 7 \), and so on; \( R_{h_{min}} \) for an atlas of any type is equal to 4.

![Chain notation: 3-2/0-1](image)

Open 2 and 1 lapping movement or Cord stitch

By increasing the underlap produced by the guide bar by one more needle, a 2 and 1 structure is produced. The longer shogging movement causes the yarn to lie more horizontally in the fabric, thus increasing the widthwise stability. The guide bar consumes more yarn so that the fabric is heavier and has a better covering factor.

![Chain notation: 2-3/1-0](image)

Closed 2 and 1 lapping movement or Cord stitch

As before, the lapping movement can be open or closed, the closed one is the more popular. The chain notations for the closed lap structure are \( 2-3/1-0 \) and for the open one \( 3-2/0-1 \). For tricot knitting, the chain reads \( 2-3-2/1-0-1 \) and \( 3-2-1/0-1-2 \) respectively.
The 2 and 1 lapping movement is used in conjunction with the 1 and 1 lap for the production of the most popular tricot knitted fabric, namely Locknit.

4. Longer Reciprocating Lapping Movements:

By increasing the underlap shogging movement by one or more needle space, a 3 and 1 construction or satin stitch is formed and as with the other structures, it can be produced with closed (fig. a) or open (fig. b) lapping movement.

The chain notations for the closed lap structure are 3 - 4 / 1 - 0 and for the open one 4 - 3 / 0 - 1.

Satin stitch differs from tricot and cord in the length of links. It is also knitted from a one warp system and the loops are formed by one yarn in turn in adjacent courses, every three wales ($R_b = 4; R_h = 2$).

More yarn is used with the production of this lapping movement, widthwise stability is increased together with fabric weight and cover factor. With the construction of two-or more guide bar fabrics, this lapping movement is usually used for one of three purposes:

a) To increase stability
b) When produced on the front guide bar, the long underlaps floating on the technical back apply a bright and smooth appearance to the fabric.

c) When produced by the front guide bar, the long underlaps can be brushed to produce a pile effect on the fabric.

4 and 1 or longer lapping movements or velvet stitches are produced for similar purposes. Velvet stitch also can be produced with closed (fig. c) or open (fig. d) lapping movement. The chain notations for the closed lap structure are 4 - 5 / 1 - 0 and for the open one 5 - 4 / 0 - 1. The longer the underlap, the greater the weight, stability and
density of the fabric. Velvet stitch differs from tricot, cord and satin in the length of links. It has large link length compare to other. It is also knitted from one warp system and the loops are formed by one yarn in turn in adjacent courses, every four wales, \((R_b = 5; R_h = 2)\).

5. **Atlas Stitch or Lapping Movement:**

It is a stitch in which each yarn consecutively forms loops in a multitude of adjacent wales. In atlas there are loops with single-side and double-side links. The smallest stitch repeat is \(R_b = 3\) in width, and in height \(R_h = 4\). The graphical representation of yarn laying in this atlas is shown in figure. In high repeat multicourse atlas the links connect the adjacent wales first in one direction, and then in the reverse direction (to the initial wale).

Atlas stitch normally means Tricot Atlas. There are various types of Atlas –

- Tricot Atlas – 2 course Tricot Atlas, 3 course, 5 course Tricot Atlas, etc.
- Cord type Atlas
- Satin type Atlas
- Velvet type Atlas.

The lapping movements illustrated in figure are called atlas movements. The guide moves to one side for a few knitting cycles, lapping the needles on its way. After a predetermined number of courses, the guide reverses.

![Atlas structure](image)

**Construction of a Two course Tricot Atlas**

Atlas movements differ from one another by the number of courses in one repeat and by the type of lapping used (Open or closed). A typical atlas fabric (5-course tricot atlas) with a repeat of 10 courses is illustrated in figure.
Loop inclination, which is very prominent in a single-bar fabric, will take a different shape when an atlas movement is produced. With the production of all previously described fabrics, the loops incline once to the left and once to the right, according to the alternate movement of the guide bar. With the production of atlas, however, the guide bar moves for a few courses in the same direction, so that the loops incline during those courses in the opposite direction. In this way, the loops incline to the same direction for a few courses, thus creating horizontal stripes on the face of the fabric. Those stripes of different shading can be used for patterning purposes.

Atlas lapping is often used with the guide bars threaded with coloured yarns. With two bars moving in opposition, the threading arrangement produces, due to the atlas movement, diagonal or diamond shapes.

6. Two needle Overlap:

The guide can be shogged by two needle spaces on the hook side of the needle during an overlap. In this way, two needles are wrapped by each yarn and both will draw the loops simultaneously.

This lapping movement is usually produced in order to add body and stability to a single-guide-bar fabric.
The facts that two separate loops must be drawn from a relatively small amount of yarn and that one of the two has no access to the guide and warp cause a lot of stress to be placed on the yarns and the needles. Usually, when producing a two-bar fabric, with incorporated two needle overlap, the movement should be produced by the front guide bar. The yarns of the front guide bars float freely on the face of the fabric and, if necessary, can move more easily into the knitted loop.

Figure illustrates a construction in which chaining and two needle overlap are combined. As can be observed, each needle receives two yarns and horizontal connections between the wales are formed. The fabric has erect loops, is relatively stable and resembles the appearance of two-bar fabrics.

The chain notations for the structure in figure are \(2 - 0 / 0 - 2\) and for tricot machine with 3 links per course movement \(2 - 0 - 0 / 0 - 2 - 2\).
Introduction to Warp Knitting Machinery:

In the past, it was usual to distinguish between Tricot and Raschel, by the needle used in each machine type. Tricot machines were equipped with bearded needles, while Raschel machines only used latch needles.

With the production of modern warp knitting machines, however, the compound needle replaced the bearded needle in Tricot and penetrated into the Raschel sector as well. The classification of machines by the needle type is, therefore, no longer possible. An accurate definition can be made by regarding the type of sinkers with which the machine is equipped and the role they play in loop formation.

The sinkers used for Tricot knitting machines control the fabric throughout the knitting cycle. The fabric is held in the throats of the sinkers while the needles rise to clear and the new loops are knocked over in-between them.

In Raschel knitting however, the fabric is controlled by a high take-up tension and the sinkers are only used to ensure that the fabric stays down when the needles rise.

It is for this reason, that the fabric produced on a Raschel machine is pulled tightly downwards from the knitting zone, at an angle of about $160^\circ$ to the backs of the needles. On Tricot machines, high take-up tension is not necessary, and the fabric is pulled gently from the knitting zone at a right angle to the back of the needles.

Tricot warp knitting machine:
Main Features of The Tricot Warp Knitting Machine:

Tricot warp knitting machines have the following important features:

- In the past, Tricot machines mainly employed bearded needles with a presser bar.
- Tricot machines have a gauge expressed in needles per inch and chain link numbering 0, 1, 2, 3, 4, etc., generally with three links per course.
- Their sinkers, which are joined to each other at the front and back, never move clear of the needles as they combine the functions of holding-down, knocking-over and supporting the fabric loops.
- The fabric is drawn-away towards the batching roller almost at right angles to the needle bar.
- The warp beams are accommodated in an inclined arc towards the back of the machine with the top beam supplying the front guide bar and the bottom beam supplying the back guide bar.
- The warp sheets pass over the top of the guide bar rocker-shaft to their tension rails situated at the front of the machine.
- Mechanical attention to the knitting elements is carried out at the front of the machine as the beams prevent access to the back.
- As all the warp sheets are drawn over the rocker-shaft to the front of the machine it is easier to thread up the guide bars commencing with the back bar, otherwise the front warp will obscure this operation.
- The guide bars are therefore numbered from the back towards the front of the machine because of this threading sequence.
- The conventional tricot beam arrangement generally restricts the maximum number of beams and guide bars to four but this is not of major importance as the majority of tricot machines employ only two guide bars.
- The small angle of fabric take-away and the type of knitting action provides a gentle and low tension on the structure being knitted which is ideal for the high – speed production of simple fine gauge (28 – 40 npi) close knitted plain and patterned structures, especially two guide bar structures with both bars overlapping and underlapping.

Knitting Elements of the Tricot warp knitting machine:

The knitting elements are located on four different bars and produce the rows of stitches in a pre-determined, precisely coordinated and simultaneous series of movements. Every knitting element has its own corresponding movement.
The above knitting elements of the tricot warp knitting machine are described as follows,

- **The Needle:**

Modern Tricot warp knitting machines, apart from a small number, are constructed with compound needles. The bearded needle, which until recently dominated the field of tricot knitting, can still be found running efficiently and reliably in thousands of machines around the world. Its knitting action is, however, nonharmonic, and so imposed many limitations on the machine builders.

<table>
<thead>
<tr>
<th>Name of the Bars:</th>
<th>Knitting Elements:</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Sinker bar</td>
<td>1a. Enclosing knock-over sinkers</td>
</tr>
<tr>
<td>2. Compound needle bar</td>
<td>2a. Compound needle</td>
</tr>
<tr>
<td>3. Tongue or sliding latch bar</td>
<td>3a. Tongue or sliding latch</td>
</tr>
</tbody>
</table>

![Diagram of Tricot Needle](image)

The compound needle used today in the construction of Tricot machines. The needle is made of two separate parts; the main part of the needle, which includes stem, butt and hook, and the closing element which operates with a sliding up-and-down movement in a groove, cut into the stem of the main part of the needle.
The needles are set in tricks cut in the needle bed of the machine, while the closing elements, being cast in units half an inch long, are set in a separate bar. The casting of the closing elements is required to ensure perfectly accurate spacing between them.

- **The Sinker:**

The sinker is a thin plate of metal which is placed between each needle. The sinkers are usually cast in units, one inch long, which in turn are screwed into the sinker bar.

Different names are given to different parts of the sinker according to their operation. The neb of the sinker (1) and throat (2) are used to hold down the fabric, while the belly of the sinker (3) is used as a knocking-over platform.

- **Guides and Guide Bars:**

Each end of yarn from each warp is located in the knitting zone by passing through the eye of a guide. All the guides containing the yarns fed from a single warp, are connected to a guide bar, so that all of them move uniformly with it.

The individual guides are usually cast in one inch units which in turn are fitted on the guide bars. The guides swing between and around the needles in order to wrap the yarn around them to form a new loop. They also shog sideways to connect the wales into a fabric.
Tricot machines are produced with 2, 3, or 4 guide bars, an arrangement which requires the same number of warps to be used. Tricot machines with a larger number of guide bars are produced in very small numbers.

The knitting cycle or Stitch formation of the Tricot Warp Knitting Machine equipped with Bearded needles:

Following figures illustrate the stitch forming process on a one-bar warp knitting machine with spring-bearded needles: (a) clearing and beginning of yarn laying; (b) yarn laying; (c) completion of yarn laying; (d) underlapping; (e) pressing; (f) landing; (g) joining; (h) casting-off; (i) loop forming and sinking.

Stitch formation or knitting action of a Tricot warp knitting machine equipped with Bearded needle

Each warp yarn, when forming all kinds of stitches, must be laid in one needle. At the beginning of the loop forming process, the guide bar swings from the back of the needle to the front of the needle, while the needle stay at the top most position. As a result, each warp yarn passes in a spacing between two adjacent needles to the front face of the needle bed. After the guide bar
has passed between the needles, it shifts one needle spacing in front of the needles and passes again to the back of the needle bed as shown in figure (b). As a result, each warp yarn is laid on the needle hook. Yarn laying is completed when yarns arrive onto the needle stem. For this, the needles lift and the yarns pass onto their stems (figure-c). Only those portions of the yarn which run from the old loops to the guide needles are laid on the needles. For this, at the time of bar railing the centres of the guide holes must not pass below the upper point of the needle head.

After the yarn has passed from the hook onto the needle stem (figure-c), the yarn is underlapped, or brought under the needle hook. For this, the needles are lowered so as to bring the yarns under the needle hooks; the old loop retained in the throat of sinker approaches the needle hook (figure-d). As the yarn is underlapped, the tips of the needle hooks must be disposed between the sinker nibs; this ensures a reliable insertion of the new loop under the needle hook. Further, the presser presses the needles and closes (figure-e) the access under the hook to the old loop.

On further lowering, the old loops slip along the needles onto the hooks, i.e. the operation of landing is carried out. In order to reduce needle hook displacement along the press, the sinkers retreat and shift upwards the old loops as shown in figure (f). The needles continue to move down until the old loops join the new ones as shown in figure (g). The needles continue their descent, while the sinkers again shift forward. The old and new loops enter the sinker throats (figure-h and i). At this moment, the sinker nibs pass into the spaces between the adjacent warp yarn, at which casting-off and loop forming take place. The needles start moving upwards and the sinkers protrude still more forward, and help the needle in executing loop forming and draw-off.

Basic Knitting action of a Tricot Warp Knitting Machine equipped with Compound needles:

The knitting action of a Tricot warp knitting machine equipped with compound needles and two guide bars is schematically illustrated in the seven diagrams of the following figure. One knitting cycle being explained in the seven stages ‘a’ to ‘g’.

‘a’ can be regarded as the starting position, with the needles at the knock-over just after completing the production of the previous course. The sinkers move forward in order to hold the fabric in the throats. At the same time, the guide bars shog sideways to position the guides close to the needles to be wrapped during this cycle (0°).

In position ‘b’, the main parts of the needles start to rise so that the needle hooks open. The underlap shogging movement is now completed (60°).

In position ‘c’, the needles are in the clearing position with the previous loops lying on the stem of the needle. The closing elements rise slightly but do not protrude out of the grooves of the needles. The sinkers move backwards to relax the hold on the fabric. The guide bars start to swing the guides in between the needles on to the hook side (120°).
Position ‘d’ illustrates the guides in the extremity of the swing. The guides of both guide bars are now shogged, usually one needle space, on the hook side of the needles thus creating an overlap. The closing elements continue their upward movement inside the loops, resting on the needle stem (195°).

Stitch formation or knitting action of a Tricot warp knitting machine equipped with Compound needle

The swing-back and completion of overlapping is in position ‘e’. Since the guides swing out of the needle line, in a space adjacent to the one entered, the yarn is left wrapped inside the needle hooks. The sinkers move in, to tighten the hold on the fabric, while the main body of the needle starts to descend (255°).

In position ‘f’, the needles continue to descend. The rate, however, in which the two parts of the needle descend is not equal. The main body of the needle is gaining on the closing element, so that the hook is being closed. The previous loops rest outside the closed hook on the closing element, while the newly wrapped yarn is trapped within the closed hook. The sinkers now move backwards to position their bellies under the hooks. In the same position of the knitting cycle, the guides can start the new underlap shogging movement, which position them in front of the needles to be wrapped during the next knitting cycle (315°).

Figure ‘g’ shows the last step of current course production with the needles descending with their respective closing elements into the knock-over position. The guide bars are now in the midst of the underlap shogging movement (345°).
Raschel warp knitting machine:

**Main Features of the Raschel Warp Knitting Machine:**

Raschel warp knitting machines have the following important features:

- Raschel machines used latch needles together with a latch wire or blade.
- Raschel machines have a gauge expressed in needles per two inches (5 cm) so that for example, a 36 gauge Raschel will have 18 needles per inch.
- Their chain links are usually numbered in even numbers 0, 2, 4, 6, 8 etc., generally with two links per course.
- Raschel sinkers only perform the function of holding down the loops whilst the needles rise.
- Raschel sinkers are not joined together by a lead across their ends nearest to the needle bar so they can move away towards the back of the machine for the rest of the knitting cycle.
- The needle trick-plate verge acts as a fabric support ledge and knock-over surface.
- The fabric is drawn downwards from the needles almost parallel to the needle bar at an angle of 120 to 160 degrees by a series of take-down rollers.
- The warp beams are arranged above the needle bar centred over the rocker shaft so that warp sheets pass down to the guide bars on either side of it.
- The beams are placed above the machine so it is accessible at the front for fabric inspection and at the back for mechanical attention to the knitting elements.
- The guide bars are threaded commencing with the middle bars and working outwards from either side of the rocker shaft.
- The guide bars are numbered from the front of the machine.
- With the Raschel arrangement there is accommodation for at least four 32 inch diameter beams or large numbers of small diameter pattern beams.
- The accessibility of the Raschel machine, its simple knitting action and its strong and efficient take-down tension makes it particularly suitable for the production of
coarse-gauge openwork structures employing pillar stitch and inlay lapping variations and partly-threaded guide bars which are difficult to knit and hold down with the tricot arrangement of sinkers.

- Additional warp threads may be supplied at the selvedges to ensure that these needles knit fabric, otherwise a progressive press-off of loops may occur.

**Knitting Elements of the Raschel warp knitting machine:**

The knitting elements of the Raschel warp knitting machine are described as follows,

![Diagram of Raschel warp knitting machine elements](image)

The knitting elements arrangement of a Latch needle Raschel warp knitting machine

- **The Needle:**

Most of the modern Raschel knitting machines built today use compound needles. Many machines however, are still equipped with latch needles. Compound needles are set as in Tricot machines, into tricks which are cut into the needle bar, and both main part and closing element are driven separately to open and close the hook.

The latch needles, especially developed for those machines, are cast in units, one inch long. The latch of the needle depends for its knitting operation, on the yarn.
The loop within the hook opens the latch when the needle rises for clearing position and closes it when the needle descends for knock-over. A broken end (thus an empty needle) causes the latch to stay closed, so that no loops can be formed. Such a needle has to be manually opened in order to allow loop formation to resume. Raschel machines are constructed in different gauges ranging from 6 to 32 needles per inch.

- **Trick Plate:**

The loop formation in a Raschel machine, takes place on the upper edge of the trick plate. This bar can be considered as a needle bed, since the needles are placed in tricks cut into it. The top edge of the trick plate is designed to ensure perfect knock-over operation which is of utmost importance when producing a fabric with long underlaps.

![A section of the Trick Plate](image)

- **The Sinker:**

The sinkers, like the latch needles, are cast in units, one inch long placed in the spaces between the needles, they are used to ensure that the fabric stays down while the needles rise to form their next knitting cycle.

![Raschel Sinker unit](image)

It must be remembered that the Raschel machines depend greatly on fabric tension created by the take-up mechanism to ensure the clearing of the needles. The sinkers of Raschel machines are, therefore, only of secondary importance.
**The Latch Guard:**

A steel wire stretched across the whole width of the machine, parallel to the needles, is used as a latch guard. When the loops of the fabric clear the latches, the latter have sometimes the tendency to flick back and close the hooks of the needles.

![Latch guard](image)

A closed hook does not receive a new yarn and causes a fault in the fabric. The wire is placed on the hook side of the needles so that the flicking latches are stopped and forced down when the needles continue to ascend.

**Guides and Guide Bars:**

Raschel machines are usually equipped with a larger number of guide bars than the Tricot machines. These bars, numbering in some cases more than 70, allow the greater patterning capability of these machines.

![Pattern guide bar with a guide finger](image)  
![Three guide bars nesting in the same displacement line](image)

Two types of guide bars are used in Raschel knitting. The first type is similar to the one used with Tricot knitting, with guides cast in one inch units, fully threaded and used for the construction of the ground fabric. In most cases one to three such guide bars are used. The second type of guide bars are used to apply the pattern onto the fabric. These bars usually require only one thread for each patterning repeat, so that only a few yarns are threaded across the whole width of such a bar.
To decrease the weight and to allow a greater number of pattern bars to be assembled, these bars are designed as narrow, light-weight strips of metal onto which individual guide fingers are attached. Holes are drilled and threaded into the light-weight guide bars at regular intervals, so that the individual guide fingers, accommodating their yarns, can be fitted in any desired position.

These guide bars, although only partly threaded and containing only a few threads each, are shogged individually according to the pattern. Each of them, therefore, must be mounted in a separate sliding bracket and driven by a separate pattern chain. Being only partly threaded, they allow the machine builder to set them at an angle so that their guide eyes are set in the same displacement line. This principle is called “Nesting” and because the bars are set in groups (nests), each nest can be considered as one guide bar for the swinging movement.

As can be observed 52 pattern guide bars are placed in 13 displacement lines and so require a swing movement similar to 13 fully threaded guide bars. Before passing to the next point, it is important to note that “nesting” imposes restrictions on design. The guide fingers of the bars placed in a common nest should not, in any point of the pattern, cross each other’s path, or even come close enough to touch one another. Allocating a crossing lapping movement to two guide bars within the same nest, results in a damage to guides and needles. Raschel machines are sometimes equipped with tube guide fingers which are especially designed to be used with bulky and fancy yarns.

Two different types of guide bar assemblies are illustrated in the following figures (a) and (b). Figure (a) shows the knitting zone of a standard Raschel machine with six fully threaded guide bars. Figure (b) shows a similar machine with three fully threaded guide bars and six pattern bars in three displacement lines.
To increase knitting speeds, some machines are so designed as to allow only the front bars to complete the overlap movement before the needles start to descend. In this case, all other guide bars are capable of inlay only.

**Basic knitting action of a single needle bar Latch needle Raschel warp knitting machine:**

The movement of the knitting elements of a Raschel machine is illustrated in the following figures. It is important to note at this stage that Raschel machines are built with different knitting movements, according to the specific requirements of the product. The following explanation is only one example of such a knitting action.

a) The needles are at knock-over position just after the completion of the previous knitting cycle. The sinkers move forward to secure the fabric whilst the needle starts to rise from knock-over. The guide bars now produce the underlap movement.

b) The sinkers move further in and, in conjunction with the take-up tension, secure the fabric position. The needles rise through the previous loops to clearing position. The flicking latches of the needles are stopped by the latch guard mounted on top of the sinkers. The guide bars complete their underlap shogging movement.

c) The needles dwell at clearing position, with the previous loops resting on the stems under the latches. The guide bars swing between the needles to the hook-side. The sinkers start to retreat.

d) Some of the guide bars are shogged sideways perform the overlap, and then all guide bars swing out between the needles. The needles start to descend while the sinkers are at their rearmost position.

e) The guide bars have completed their swinging movement. Underlap movement now starts. The needles descend with the newly wrapped threads in their hooks. The previous loops close the needle latches.

f) Underlap shogging movement continues. The needles are sinking into the trick plate with the previous loops sliding on the latch outside the closed hooks. Completion of the knitting cycle.
The Knitting action of a Compound Needle Raschel Warp Knitting Machine:

The knitting action of Raschel machine equipped with compound needles is different from that of a Tricot machine. In the following series of figures, the loop formation sequence of a multibar Raschel machine is described and it is important to note the following points:

- The sinker bar is stationary,
- The guide bars do not swing, and
- The swinging movement is made by the needle bar, closing element bar and trick plate.

The sequence can be described as follows:

a) The needles are at knock-over position, after the completion of the previous course. Both parts of the needles, together with the trick plate, swing towards the back of the machine and position themselves under the sinkers. Underlap shogging movement is now carried out.

b) The needles rise through the loops of the previous course. The closing elements stay down so that the hooks are opened. The fabric stays down due to take-up tension and is secured by the sinkers.

c) The needles are in the clearing position with the previous loops resting on the stem. Underlap shogging movement is now completed.
d) The needle bar, closing element bar and trick plate swing to the front of the machine, so that the guides move in between the needles to the hook side. The ground guide bars are now shogged sideways to produce the overlap.

e) The needle bar, closing elements bar and trick plate swing back, so that the guides move between the needles to the back. The needles can start to descend when the ground bars are at the back. The closing elements stay up, so that the hooks are closed, trapping within them the newly wrapped yarns.

f) Both needles and closing elements descend simultaneously and maintain a closed hook. The old loops slide outside the closing elements. Needle bar, closing elements and trick plate continue their swinging towards the sinker. Underlap shogging movement can now start.

g) The needles draw the newly wrapped loops through the previous loops. The swing movement is nearly finished and the guide bars continue to shog the underlap lateral movement.
TWO FULLY THREADED GUIDE BAR STRUCTURES OR FABRICS

In order to reproduce a warp knitted fabric, it is necessary to obtain the information regarding its production. Many different data items are involved such as:

a) Information describing the knitting machine; number of guide bars, machine gauge, width of the needle bed and special attachments used.
b) Information concerning the type and count of the yarn threaded in each guide bar.
c) Lapping movement of each bar.
d) The run-in of each bar.
e) Threading information if the guide bars are not fully and uniformly threaded.
f) Fabric quality and weight.
g) The finishing process.

The above-mentioned information varies widely for different manufacturers and end-uses, so that there is no practical limit to the number of different fabrics that can be produced on modern warp knitting machines.

The single-bar structures are not suitable for most commercial applications. They are usually very unstable dimensionally and some of them will even split easily if only slightly damaged. Furthermore, most single-bar structures exhibit an unbalanced loop structure and loop inclination is very pronounced.

The bulk of the fabrics, manufactured today on tricot machines, are constructed by two fully threaded guide bars, fed from two separate warps and producing a different basic lapping movement. The relative movement of the two guide bars in combination with the magnitude of the shogging, determines the appearance as well as the properties of the fabrics.

Tricot Fabric or Full Tricot Structure:

The basic lapping movement of two fully threaded guide bars is the so-called tricot or double tricot. In figure the schematic lapping movement is illustrated with both guide bars knitting the same 1-and-1 lapping movement in opposite directions. Such a lapping movement produces a light-weight fabric since the underlaps are very short.

Although the fabric is commercially very attractive, it is only seldom used due to a major disadvantage; each wale of this fabric is connected only to the adjacent wales, so that the fabric splits very easily if a yarn is broken or a stitch dropped.
Providing that the yarn tension in both guide bars is properly balanced, the fabric — as in all fabrics of this nature — exhibits erect loops and the technical face resembles the face of a weft knitted fabric.

The chain notations for the production of this fabric, as derived from figure are:

Front bar: 1 - 0 / 1 - 2
Back bar: 1 - 2 / 1 - 0

As all modern tricot machines are equipped with a pattern mechanism which uses three chain links for each knitted course, the chain notations are:

Front bar: 1 - 0 - 0 / 1 - 2 - 2
Back bar: 1 - 2 - 2 / 1 - 0 - 0

Locknit Fabric:

The most widely produced warp knitted fabric is probably locknit. The lapping movement of its two guide bars is illustrated in the following figure. While the back guide bar shogs a 1-and-1 lapping movement, as in tricot, the front guide bar shogs two needle spaces.

The free-floating underlaps, superimposed on the technical back, contribute to a very pleasant touch and together with a considerable elasticity make the fabric most suitable for ladies,
lingerie. In addition, being the lightest non-splitting fabric, further helps to make locknit the most popular of all warp knits.

The locknit construction tends to contract widthwise on leaving the knitting zone, so that its final width may only be 2/3 of the needle bar width. The amount of shrinkage depends mainly on knitting conditions, yarn type, yarn tension, etc.

There is also a tendency in tricot fabrics to curl towards the technical back at the selvedges. This, however, does not represent a major problem, since most of these fabrics are made of thermoplastic yarns and are heat-set during finishing.

As a trend of the last few years, locknit fabrics which were traditionally produced on 28 gauge machines, are becoming more and more popular when knitted on 32 to 40 needles per inch. The yarn consumption of the two guide bars depends on fabric quality, machine gauge, yarn type, and knitting conditions. The chain notations for the production of locknit fabrics, as derived from figure are:

Front bar: $2 - 3 - 2 / 1 - 0 - 1$
Back bar: $1 - 0 - 0 / 1 - 2 - 2$

**Reverse Locknit Fabric:**

This fabric belongs to the other group of two fully threaded guide bar fabrics, namely the semi-stable and stable structures. In this group of structures, the longer underlaps produced by the back guide bar are locked under the short underlaps of the front guide bar and are restricted in movement. It is made with a longer underlap on the back bar and a shorter one on the front guide bar. Reverse locknit is considered only a semi-stable fabric and still shrinks considerably on leaving the knitting zone.

The lapping movements of both guide bars for the production of reverse locknit are illustrated in the figure and the chain notations as derived from it are:

Front bar: $1 - 2 - 2 / 1 - 0 - 0$
Back bar: $1 - 0 - 1 / 2 - 3 - 2$
Satin Fabric (Three-Needle Structure):

A fabric with the same lapping movement on the back guide bar and an increased lapping movement on the front bar is called a satin fabric. The lapping movement of this fabric is drafted schematically in figure and as can be observed, the front bar shows one needle space longer than in locknit. While the technical face is similar in appearance to locknit, the technical back is smoother and shinier due to the underlaps of the front guide bar which are longer and more parallel to each other.

Like all structures which are made with long underlaps on the front guide bar, this fabric shrinks considerably immediately after leaving the needles. At the same time the fabric is elastic and very comfortable to wear.

Chain notations for the production of three-needle satin fabric are:

Front bar: 1 – 0 – 1 / 3 – 4 – 3
Back bar: 1 – 2 – 2 / 1 – 0 – 0

Sharkskin Fabric:

The sharkskin fabric is constructed as a reverse version of satin. The loop structure shows the longer underlaps of the back guide bar locked under the short underlaps of the front guide bar. These trapped underlaps restrict the shrinking potential of the fabric which is therefore more rigid and more stable than those previously described.
The surface of the technical back is rough which is probably the reason for the name "Sharkskin". The lapping movements are illustrated in figure and the chain notations are:

Front bar: 1 – 2 – 2 / 1 – 0 – 0
Back bar: 1 – 0 – 1 / 3 – 4 – 3

**Four-Needle Structure:**

Fabric with longer underlaps on the front guide bar are also manufactured. Such is the four-needle satin with a 4-and-1 lapping movement as illustrated in figure. As for three-needle satin, this fabric exhibits a very smooth and shiny technical back due to the long parallel underlaps. Like all fabrics with free and long front bar underlaps, it shrinks on leaving the knitting zone and curls at the selvedges towards the technical back.

It must be remembered that the longer the underlap floating on the surface of the technical back, the heavier the fabric and greater the risk of snagging. The chain notations of this fabric:

Front bar: 4 – 5 – 3 / 1 – 0 – 2
Back bar: 1 – 0 – 0 / 1 – 2 – 2

A 4-and-1 movement of the back guide bar produces even higher stability and decrease shrinkage even further. This fabric is called four-needle sharkskin and the lapping movement is illustrated in figure. The chain notations of this fabric are:

Front bar: 1 – 2 – 2 / 1 – 0 – 0
Back bar: 1 – 0 – 2 / 4 – 5 – 3
Introduction to Warp Knitting Machinery:

In the past, it was usual to distinguish between Tricot and Raschel, by the needle used in each machine type. Tricot machines were equipped with bearded needles, while Raschel machines only used latch needles.

With the production of modern warp knitting machines, however, the compound needle replaced the bearded needle in Tricot and penetrated into the Raschel sector as well. The classification of machines by the needle type is, therefore, no longer possible. An accurate definition can be made by regarding the type of sinkers with which the machine is equipped and the role they play in loop formation.

The sinkers used for Tricot knitting machines control the fabric throughout the knitting cycle. The fabric is held in the throats of the sinkers while the needles rise to clear and the new loops are knocked over in-between them.

In Raschel knitting however, the fabric is controlled by a high take-up tension and the sinkers are only used to ensure that the fabric stays down when the needles rise.

It is for this reason, that the fabric produced on a Raschel machine is pulled tightly downwards from the knitting zone, at an angle of about $160^\circ$ to the backs of the needles. On Tricot machines, high take-up tension is not necessary, and the fabric is pulled gently from the knitting zone at a right angle to the back of the needles.

Tricot warp knitting machine:
Pile Fabrics or Loop raised Fabric:

Two-bar fabrics are frequently produced of finished as pile fabrics in order to improve their appearance or their thermal properties. A pile can be produced either by raising the long underlaps of the front guide bar or by producing pile loops according to a lapping movement or knitting conditions.

For brushed fabrics, the long underlaps produced by the front guide bar, are raised during the finishing process by rollers covered with card-clothing. The metal card rollers raise the pile gradually and after a few such stages, the pile is formed. A different amount of fibres can be broken to form varying effects.

It is also possible to shear the pile so that a velour effect is produced. The lapping movement of a typical brushed fabric construction is illustrated in the above figure. In this fabric, the lapping movements of both bars are carried out in the same direction. In this way the fibres raised out of the long underlaps of the front guide bar can be easily pulled with no resistance from the back guide bar underlaps. Furthermore, the threads of the back guide bar help to reduce the fabric width which occurs anyway during this mechanical treatment. The density and height of pile can be increased by increasing the front guide bar underlaps to four, five or six needle spaces.

Great quantities of brushed fabrics are made with triacetate yarns in the front guide bar and polyamide yarns in the back guide bar.

Another type of pile fabric is constructed with loop pile. One way to produce this type of fabric is to overfeed the yarn of the back warp, while knitting a reverse locknit construction. The excess yarn protrudes between the underlaps of the front guide bar and forms a pile on the technical back. This method of pile loop production cannot be controlled so that the distribution of pile loops may not be even.
Knitted Pile Fabrics

The production of pile knits has steadily grown in variety, importance, and volume. They are constructed as fleece, high pile, terry, and velour knits. Depending upon the type of construction, they are used for fur fabrics, rugs, and fashion apparel fabrics.

Fleece knit fabric:

Technically, fleece fabrics are not truly of a pile construction. Fleece fabrics are knitted so that, when finished, they will have a short to medium nap that has a soft, pleasant hand, will provide warmth and body, as well as moisture wicking and absorption, if desired.

The kinds of fibres used are dependent upon the use objective. They are used for such purposes as liners, active sportswear, outerwear, and plush toys.

Fleece knits can be made on circular knit machines in any one of three different types of construction. The machines may be complex, utilizing either spring or latch needles employing sinker-top, dial, cylinder, or dial/cylinder mechanisms. With this equipment, various effects can be produced.
Three thread fleece:

One type of fleece knit construction is the three-yarn system, where three yarns are fed sequentially from separate yarn positions around the cylinder of the machine. The first yarn is the backing or fleece yarn. The second and third yarns are the tie-in and ground yarns which are fed successively in a plaing relationship and knitted so that the fleece yarn is caught at predetermined intervals between them. This results in the fleece yarn being floated on the technical back of the fabric and held in place by the wales of plaied tie-in and ground yarns. The technique hides the fleece yarn from the technical face so that it will be exposed only on the back. The fleece yarn, which may be coarse spun and low twist, can thus subsequently be readily napped and given other surface finishes.

Two thread fleece:

Another type of fleece knit is the two-yarn system. One yarn, which provides the ground or body is knitted in either a single or double jersey construction. The second yarn, which may be coarser and heavier to accommodate subsequent napping, is the floating or inlay yarn that is tucked at predetermined intervals on selected needles. This is the most productive method of making fleece knits, but there is a disadvantage of “grin-through” to the technical face unless it is camouflaged by knitting design effects, such as a double lay-in.
Single thread fleece:

The third type of fleece construction is the one-yarn system. A single or plied yarn is knitted according to a predetermined pattern of knit and tuck combinations that would provide floats which are to be subsequently napped. Since the yarn must be strong enough and fine enough for knitting purposes, the use of coarse, low twist yarns are precluded. The use of only fine yarns as well as the resulting additional napping and other finishing costs makes this type of fleece more expensive.

High Pile Knit Fabrics or Sliver Knit Fabrics:

Both weft and warp knitting machines are used to produce imitation fur fabrics and rugs utilizing acrylic, modacrylic, polypropylene, or nylon as determined to be appropriate for the end product. The fabrics are similar in appearance to their original counterparts but are more flexible and have better drape. These fabrics are lightweight and easy to care for. They usually can be laundered and cold tumble-dried, unless the garment construction requires dry-cleaning. When the pile is crushed or distorted due to washing, packing, or storing, it should be combed or brushed with a soft or medium bristle brush.
Feeding-in of fibres into selected needles

High-pile circular knitting machine

The techniques for knitting high pile fabrics are quite complex. The slower and more common method uses a plain knit with heavy yarn for the background and a carded sliver for the pile. As the needles pull the ground yarn to form loops, they catch and draw the sliver through, causing the fibres to get locked into place as the stitch is tightened. Production runs from 5 to 11 yards (4.5 to 10m) per hour.
The production of sliver or high-pile furry fabrics on circular knitting machines is based on the plain technique, using latch needles and holding-down/knocking-over sinkers. Special equipment, a so-called carding device, is employed to feed-in fibres into the latch needles at each knitting feeder. Normally each carding unit consists of two feed rollers for the sliver, a carding roller and a doffer. The feed rollers draw in the sliver and present it to the carding roller, which has a much higher surface speed in relation to the feed rollers. As a result the fibres are stretched (laid more or less linear) and parallelised. The doffer takes over the fibres from the carding roller and combs them into the needles with specially shaped wires. At this fibre combing point the needle is in cleared position.

For the production of coloured or structure-patterned high-pile fabrics, or combinations containing colour and structure, the needles at each combing point are selected according to the pattern in order to obtain fibres of the corresponding colour. It can be seen that the combed-in fibres are processed together with the ground yarn during loop formation. The fibres protrude from the fabric base on the technical left side.

A faster method uses circular-knitting units operating on a cut loop and ground-yarn principle. Another technique is the cut-pile and ground-yarn method on a Rachel machine. High-pile fabrics can also be made on double-knit equipment to knit plain and Jacquard fleece with the aid of special devices including an inlay yarn carrier.

**Plush Fabrics or Knitted Terry Fabrics:**

Knitted terry fabrics are made of a variation of the jersey knit construction where two yarns are fed simultaneously into the same needles. The fabric is knitted by a plaiting technique which causes one yarn always to appear on the face and the other always on the back of the cloth. As the fabric is knitted, the face yarn is pulled out by small devices to form the loop pile, leaving the other yarn to serve as the ground. Knitted terry is produced in weights ranging in suitability for robes and beachwear to fashion apparel.

Circular knitted plush or terry is a fabric with yarn loops protruding from the fabric base on one or on both fabric sides. Most of the plush fabrics produced have one-sided loops. Plush can be
produced on plain or rib circular knitting machines. The most common method of production uses the plain circular knitting technique with combined holding-down / knocking-over sinkers for making one sided plush fabrics. The loops are actually enlarged sinker loops and they protrude from the fabric base on the technical left side.

![Face side](image1.png) ![Back side](image2.png)

The most important demands are a firm fixing of the plush loops in the fabric base and a very uniform loop length. The more uniform the loop length is, the less material is lost when the loops are cut to produce cut-pile fabrics. Therefore the base fabric should not be too loosely stitched. On the technical right side a precise plating of the plush yarn through the ground yarn is extremely important during the cutting process for cut-pile fabrics. In usage this pre-requisite is largely responsible for the firmness of the pile.

Single-sided plated plush or terry is a popular leisure and sports wear structure found in both fabric and sock form having the form fitting elasticity of single jersey. The elongated plush sinker loops show as a pile between the wales on the technical back as a result of having been formed over a different surface to that of the normal length ground sinker loops with which they are plated.

Terry knits tend to be more flexible, softer, and more absorbent than woven terry cloth. However, they are not as sturdy or durable. They do not hold their shape as well and they tend to snag, causing the loop yarn to pull and trail. Should such a pull occur, it should not be cut because it would cause a run. Rather, it should be drawn through to the back of the material.

**Velour Knit Fabric or Henkel plush Fabric:**

Knitted velour fabrics are constructed in the same manner as knitted terry. After the material is knitted, the loop pile is sheared at a uniform height and then brushed. So velour is achieved during finishing by cropping or shearing the loops in both directions, to leave the individual fibres exposed as a soft velvety surface whilst the ground loops remain intact. It requires a fine gauge structure and involves a considerable loss of cropped yarn. The bearded needle sinker wheel machine has long been renowned for this type of fabric construction. This produces a soft, suedelike surface that is somewhat like that of velvet. However, knitted velour is softer and has better drapability. It is used for such fashion apparel as men’s shirts and women’s dresses.
The Crochet Warp Knitting Machine

Features of a Typical Crochet Machine:
On crochet machines, the warp chains are separate from the weft inlay and it is the latter threads which join the chaining wales to each other. The crochet galloon machine, as developed by Sander and Graff and popularized by kholer, is essentially a highly versatile Raschel with the following unique features:

a) A single horizontal needle bar whose simple reciprocating action can be used to operate individually tricked latch, carbine or embroidery needles.

b) There are no sinkers, instead a fixed hold-back bar is fitted in front of the knock-over verge to prevent the fabric moving out with the needles.

c) The closed lap pillar stitches and inlay threads are controlled and supplied as separate warp and weft respectively. Each needle is lapped from below by its own warp guide which is clipped to a bar whose automatic one-needle overlap and return underlap shog is fixed and is controlled from an eccentric cam whilst its upwards and downwards swing is derived from a rocker shaft.
Knitting Elements in a Crochet warp knitting machine

d) The warp yarn is often placed low at the front of the machine. The weft yarn, which is often placed above and towards the back of the machine, supplies the carrier tubes clipped to the spring-loaded inlay bars fitted above the needle bar and shogged at the rate of one link per course from pattern chains around a drum at one end of the machine. There are usually up to two warp guide bars and up to sixteen weft inlay bars, which may be mechanically or electronically controlled.

e) Special attachments are available for producing fancy effects such as cut and uncut fringe edges, pile, braiding (equivalent to fall-plate) and snail shell designs.

f) Very approximately, the knitting widths of crochet machines may vary between 16 and 122 inches (400 mm and 3100 mm), in gauges often expressed in needles per centimeter between 2 and 10 (E 5 to E 24) and machines run at speeds between 200 and 350 courses per minute.

Needles used in Crochet Machine:

- **The patent or carbine bearded needle**: It (A needle similar in shape to a bearded needle but with the beard shielded by a shoulder on the stem. The needle may only be lapped in one direction for the yarn to pass under the beard. A presser is not necessary as the needle is self-acting, the shoulder passing the loop on to the beard. It is mainly used in crochet-type machines) is used for fine structures and has a sideways crimped beard placed in a permanently-pressed position. Although warp threads can only be fed into the beard from the left, the old overlaps are automatically cleared and landed by the movement of the needle. It is still the most frequently used needle, achieving speeds up to 2500 rpm. Reduced machine speed and high needle wear make its use uneconomical for knitting single end cotton yarns.
- **Embroidery or Lace needles**: They are carbine needles with pointed heads that can penetrate pre-woven structures to produce embroidery effects. The needles can be arranged for coarser gauges or for fancy set-outs, when the floating inlay threads may be cut to produce separated fringed edgings.

- **The compound needle**: It patented by Müller produces less stress on the yarn during loop formation so a wider range of yarns can be used, and compound needles last up to six times longer than bearded needles.

- **Latch needles**: It operate at uneconomic speeds and have a short life due to latch breakage.

**The knitting action of The Crochet Machine:**
The knitting action or stitch formation to produce one course of loops on a crochet machine equipped with latch needles consists of the following stages:

1. The weft inlay
2. Clearing the warp overlap
3. The warp overlap wrap
4. Warp knock-over and underlap

The essence of these stages consists in the following operations:

1. **The weft inlay**:
   Whilst the needle is withdrawn into its trick, during knock-over of the previous of warp overlaps, the weft inlay tube is lowered so that, as it traverses in an underlap shog, the weft is laid below the level of the needle and on top of the warp thread which extends from its head to the warp guide.

2. **Clearing the warp overlap**:
   The weft tube rises slightly on completion of its traverse movement to allow the needle to move out of its trick to clear its old warp overlap.

3. **The warp overlap wrap**:
   The warp guide rises between the needles and automatically overlaps from the left, lowering itself again on the right side of its needle.
Knitting action of a Crochet warp knitting machine

4. **Warp knock-over and underlap:**
The needle now retraces into its trick to knock-over the old overlap, whilst the warp guide is cammed under its needle to the start position for its next overlap thus completing the closed lap pillar.

**Products of the Crochet Machine:**

Crochet machines, with their simple construction, ease of pattern and width changing, and use of individual yarn packages or beams provide the opportunity for short runs on coarse-gauge or fine-gauge fancy and open-work structures and edgings or trimmings, as well as the specialist production of wide fancy fabrics or narrow elastic laces. Crochet machine finds widespread application in the production of various types of edgings or trimmings, so it is sometimes described as a “Trimming machine”. A range of crochet fabrics is illustrated in the following figure.

Different types of Crochet Fabrics
The Straight Bar Frame

The main features of a Straight bar frame:

The Straight bar frame is a special type of weft knitting machine. It has the following unique features:

- Straight bar frames is a specific type of machine having a vertical bar of bearded needles whose movement is controlled by circular engineering cams attached to a revolving cam-shaft in the base of the machine.
- The length of the machine is divided into a number of knitting heads (sections or divisions) and each head is capable of knitting a separate but identically-dimensioned fashion-shaped garment panel.
- The needles press their beards against a fixed pressing edge; loop formation prior to intermeshing is achieved by individually horizontally-moving loop-forming sinkers, and knock-over occurs when the needles descend below the knock-over bits.
- At either edge of each knitting head, a group of rackably-controlled points transfer loops to fashion shape the garment panel at the selvedges by widening or narrowing the knitting width. On completion of the garment panel, it is pressed-off the needles.

Knitting motions of the Straight bar frame:

The three directions of motion required for the knitting action are provided from two separate sources. The rotary motion of the cam-shaft produces the vertical and horizontal movement of the fashioning points and the needle bar. The sideways reciprocating movement for the yarn carriers and for introducing the sinkers in seriatim sequence via the slurcock is obtained from a coulier or draw cam attached to a shaft set at right angles to the main cam-shaft at the back of the machine, which oscillates a draw lever. A variable draw ensures that the stroke of the draw is related to the varying knitting width thus more courses per minute are knitted on narrower widths. Operating speeds of a hundred courses per minute can be achieved.

The knitting head of the Straight bar frame:

The following figure shows the cross-section of the knitting head containing the different elements:

A. Bearded needle, having a cranked end for location in the tricked and drilled needle bar.
B. Sinker, only one between every other needle space, with a reinforced back and at the front, a catch to sink the yarn around the needles, and a ‘neb’ to separate the old and new loops until knock-over.
C. Divider, occupying each remaining space, usually having the same shaped front as the sinker but with an extended tail at the back.

D. Knocking-over Bit, one directly beneath each sinker and divider, having a ‘throat’ for holding the loops and a ‘nose’ for knocking-over.

Knitting head of a Straight bar frame

E. Needle Bar, having a compound horizontal and vertical movement.

F. Striking Jack, fulcrummed at its lower end, each with its nose resting on a sinker back, and a ‘spring’ exerting pressure on its ‘tail’.

G. Catch Bar, extending the full width of the knitting head, having forward and backward, as well as vertical movement.

H. Yarn carrier, which traverses in alternate directions across the head from one course to the next, up to six carriers may be available. The carrier is connected to a reciprocating carrier rail by friction and when the carrier is arrested by its carrier stop, the carrier rail completes its full traverse, driven by the coulier cam by punching through the carrier friction.

I & J. Falling Bar, is a stop which cushions the advance of the sinkers and dividers.

**Knitting action of a Plain Straight bar Frame:**

The following figures show the movement of the knitting elements to produce one course of loops:

a) **Thread laying:**
The carrier moves across the knitting head laying the yarn on the noses of the sinkers and dividers and the beard side of the needles.
b) **Sinking:**
The slurcock (one for each knitting head) travelling behind the carrier, contacts the jacks and is shaped so that each jack in turn pushes its sinker forwards to kink a loop around every two adjacent needles.

c) **Dividing:**
The catch bar moves the dividers forwards collectively, whilst the needle bar tips slightly outwards to allow the double loops to be divided into equal sized needle loops around every needle.

d) **Pressing and e) Landing:**
The needle bar descends placing the new loops inside the hooks of the beards. The catch bar is now lowered so that the sinkers as well as the dividers are collectively controlled by it for the rest of the knitting cycle. They now start to withdraw. The needle bar moves towards the sinker verge causing the beards to be pressed. A further downward movement of the needle bar ‘lands’ the previous course of loops, resting on the knocking-over bits, on to the closed beards.

Knitting action or Movement of the knitting elements to produce one course of loops

**The drop-off:** As the needle bar moves away from the pressing-edge, the sinkers and dividers withdraw so that the newly-formed course of loops drops off their noses onto the knocking-over bits.

**f) Completion of knock-over:**
The needle bar descends to its lowest position. As the heads descend below the belly of the knocking-over bits, the old course of loops is collectively knocked-over.
**Holding-down:** As the sinkers and dividers move collectively forward to hold down the fabric, the needle bar rises to the thread-laying position. The catch bar is slightly raised to release the sinkers for individual movement at the start of the next course.

On coarser gauge machines it is possible to accommodate sinkers with reinforced butts between every needle space thus eliminating dividers and their action. Some machines have selvedge dividers with a lower forward ledge so that when the yarn carrier stops over one divider the next divider inwards from it will be the last to take that traverse of yarn which will slide into its specially-shaped lower throat and form a tight selvedge.

**The Fashioning action of the Straight bar frame:**

The fashioning action or loop transfer for either narrowing or widening is performed in following steps:

![Diagram of the Fashioning action of the Straight bar frame](image)

**The Fashioning action of the Straight bar frame**

a) The fashioning points or transfer needles descend and the needle bar tips backwards to clear them.
b) The needle bar moves towards the points causing the beards of needles engaged with points to be pressed and boxed or located in the grooves of the points.

c) The sinkers and dividers, which are collectively controlled by the catch bar, retire, and the needles and points descend together below the knocking-over bits so that the loops are cast-off onto the points.

d) The needles and points now rise and move clear of each other so that the points can make the sideways ‘fashion rack’ at the selvedge either by one needle for widening or by one, two or four needles for narrowing.

e) The needles and points now descend and the needles box with the points again so they receive the transferred loops. As the needles and points descend below the sinkers, the sinkers and dividers move forwards to hold down the loops.

f) Once the needles have slid up into the grooves of the points to receive the loops, the points rise to their high inoperative position. The needle bar rises causing the transferred loops to slip down onto the stems and the cam shaft is shogged back to the left again so that knitting can restart.
Netting or Net Fabrics

The main features of Net fabrics:

Netting is an open-mesh form of fabric construction that is held together by knots or fused thermoplastic yarns at each point where the yarns cross one another. There are several types of mesh; they are square, hexagonal, and octagonal. The range of mesh sizes is from coarse and open to fine and shear. Netting may be made of any kind of fibre and may be given a soft or stiff sizing. Net fabrics are relatively fragile and require care in handling and cleaning. Torn net fabrics cannot be satisfactorily mended because the repair would be apparent. If the sizing is water soluble, the fabric should be dry-cleaned.

Early nets were made by hand-knotting yarns at each point of intersection to produce a specific geometric pattern. Prior to 1809, nets were made by hand, but in that year a new machine produced knotted nets so like hand-knotted fabrics that few people could distinguish between them. The comparatively large mesh of knotted nets does not slip, spread, or distort during use. Knotted nets are used for hammocks and fishing nets.

In recent years most light weight nets have been constructed on either Tricot or Raschel knitting machines, so the yarns are only interlooped and not knotted. These knitted nets lack the stability of those constructed by knotting. Their primary use is in apparel, although some are used as decorative window hangings.

Types of Nets:

There is a variety of netting; some are produced under specific trademarks. Among the best known standard fabrics are noted here. These nets are classified as bobbinet, fishnet, filet, maline, or tulle.
- **Bobbinet**: It is a hexagonal mesh that may be very thin and transparent (bridal illusion) or fairly coarse and opaque (casement cloth), depending on the yarn count of the material used to produce it. Most bobbinet sold in the United States is produced in England and France.

- **Tulle**: It is a fine, stiff hexagonal net made from silk or nylon yarns. It is very similar to bobbinet but lighter in weight than bridal illusion; some references do not separate bobbinet and tulle. It is generally used for trimming or over draping of dress goods.

- **Fishnet**: It is a coarse open-mesh construction created by knotting the mesh in a manner similar to a fisherman’s knot.

- **Filet net** is made with a square mesh, and **maline net**, used in millinery, is a fine, very thin, diaphanous, open diamond shape with hexagonal holes.
Lace Fabrics

The main features of Lace fabric:

Lace is an open work fabric consisting of a network of yarns formed into intricate designs. Lace may be hand or machine made, and intricate patterns can be produced by either technique. Both narrow and wide lace fabrics are available. The edges of the fabric may be straight or curved.

It is an important trimming, for it is used for table cloths, curtains, handkerchiefs, dresses, and underwear. Lace consists of two elements:

- The pattern, flower, or group, which forms the closer-worked and more solid portion, and
- The ground or filling, which serves to hold the pattern together.

Parts of Lace Construction:

In identifying various kinds of lace, references have been made to their designs. These patterns are constructed of different parts, each having a particular designation.

- Bride, or Reseau: It is the fine yarn that forms the mesh which provides the sheer ground (background) between the prominent parts of the pattern.
- Cordonnet: It is the heavy yarn that outlines the pattern.
- Picot: It is a decorative loop used both in the pattern and on the edge of the lace.
- Toile: It represents the predominant parts of the pattern made by braiding, knotting, looping, or twisting the yarn.
Uses of Laces:

Lace is a decorative fabric used in apparel and home furnishings. Narrow laces are used for trims and insertions; wide lace fabrics are used for curtains, table cloths, and garments.

Laces are made in different widths for different uses. For example, a narrow lace with a scalloped edge is used for trimming a baby’s dress; a lace with slits or eyelets is so made that ribbon may be run through it.

There are seven major uses of laces:

1. **All-over laces**: An all-over lace is a fabric up to 36” wide with the design or pattern spread over the width of the fabric and repeated in its length. Many kinds of design motifs and colours are used. The fabric can be produced in widths of over one yard (1 m) that are devoid of scallops. The fabric is cut and sold from the bolt like woven dress goods. The dressmaker cuts it to pattern and makes it up into formal evening, dinner, and cocktail dresses and blouses.

2. **Flouncing**: Flouncing applies to laces 18 to 36 inches wide with a plain edge at the top and a scalloped edge at the bottom of the fabric. It is used for wide ruffles or flounces. Often these flounces are arranged in tiers to form a skirt.

3. **Gallon**: A gallon is a lace up to 18 inches wide with a scalloped edge at top and bottom. It may be used as an insertion between two cut edges of fabric, or it may be appliquéd to a fabric in bands or as a border.

4. **Insertion**: Insertion is a band of lace sewn between two pieces of fabric or on a single piece of fabric at the straight top or bottom edges. A variety of insertion is footing, which has a straight edge at top and bottom but no pattern. Footing is often used at the bodice or at the bottom hem of a slip.

5. **Beading**: Beading has slots through which ribbon may be run. These slots may be found in edgings or galloons but are much more common in insertions.

6. **Edging**: An edging is a lace never more than 18” wide that is straight at the top and scalloped at the bottom. It is sewn to the edge of a dress, gown, blouse, handkerchief, or lingerie.

7. **Medallion**: A medallion is a lace in a single design that can be appliquéd to a fabric ground for ornamentation. It is sometimes used in the corners of napkins, or towels or as an ornament for a dress, blouse, or lingerie.

Quality and Care of Lace:

The quality of lace is determined by several factors. If it is made by hand, it is considered better than machine made. But the workmanship and the intricacy of the design are important. The kind of yarn (such as linen versus cotton), the fineness of yarn, and the closeness of the mesh are very significant.

The yarns used in lace are fairly tightly twisted to withstand the manipulations required to produce the material, so modern machine-made lace is less delicate than it appears. Lace
can snag easily. Whatever the quality, the construction of lace requires some care in handling to prevent snagging and pattern distortion. The material is quite open; thus, dimensional stability may be a problem in laundering and dry cleaning. Lace should either be laundered by hand or dry cleaned, depending upon its nature. If it is to be laundered, lace should be either washed by hand squeezing suds through it without rubbing or by putting it into a mesh or cloth bag and machine washing at a gentle cycle. Properly heat-set nylon and polyester lace can be handled with minimal difficulty. Ironing or pressing should be done carefully by placing a cloth over the lace to avoid tearing.

As was just indicated, lace is important in both clothing and home furnishings. The International Fabricare Institute suggests to consumers the following guide lines for the wear and care of clothing containing lace:

1. Laces snag and tear easily; even your jewelry can snag delicate lace. For this reason, extreme care must be used when wearing lace. Laces are difficult to mend and the mend is usually visible.
2. Lace clothing should have ample side and under arm seams which are well bound. Narrow seams will pull out with strain in wear.
3. Unfinished or machine-stitched button holes fray readily.
4. Protect lace, especially silk lace, from perspiration, deodorant, and antiperspirant damage, as this may weaken the fibres.
5. Lace garments should be folded and placed in drawers to relieve points of strain.

Types of lace:

The two main types of laces are “real” or handmade, and machine made. Linen thread is usually used for real lace and also expensive laces, but cotton, rayon, nylon, silk or other yarns are now used for various qualities and types and also for machine lace.

The former is softer, more irregular in mesh and pattern, and more expensive. Handmade laces are created by manipulating a single yarn or group of yarns with bobbins, needles, and hooks to produce intricate stitch formations. The major classifications of handmade laces are bobbin lace (pillow), needle point lace, crocheted (including Duchesse), embroidered lace, darned (including some filet lace), knotted, tatting.

Handmade laces have always been highly prized as trimming for apparel and as decorative pieces for the home. Unusually beautiful and intricately designed laces are retained in families as heirlooms and are displayed in museums as works of art. Today, such laces as needle point, bobbin, darned, crocheted, and knotted are duplicated so expertly by machine that the average consumer is not able to determine whether a lace is machine-made or handmade.
a) **Handmade Lace or Real Lace:**

1. **Bobbin Lace:**
   Sometimes called pillow lace, the lace design is drawn either on a pillow or on a paper that is placed over the pillow. Small pegs or pins are stuck into the pillow along the design, and a large number of small bobbins of thread are manipulated around the pegs or pins to produce the lace. A number of threads, each on its own bobbin, are interlaced by twisting and plaiting around the pins to produce the motif in a mesh construction. As the lace is completed, the pins are pulled out and the lace is removed from the pillow. Making pillow lace requires great skill and dexterity, for as many as three hundred bobbins may be needed to make some patterns.

![Chantilly lace](image1)

![Cluny lace](image2)

There are several varieties of bobbin lace. Because of its exquisite large, clothy design, "duchesse" is the queen of the bobbin laces. Duchesse lace was originally from Bruges, Belgium. It has a tape like structure. Other bobbin laces are Binche lace, Chantilly lace,

![Val or Valenciennes lace](image3)

![Torchon (Beggar’s) lace](image4)

Cluny lace, Honiton lace, Lille lace, Maltese lace, Mechlin, Torchon (Beggar’s) lace, and Valenciennes lace.
2. **Darned Lace:**

It has a design darned by a chain stitch onto a mesh background. When made by hand, the design of darned lace is sewn with thread and needle passed in and out of a mesh net. There are two principal types of darned lace.

3. **Needle point Lace:**

The design for needle point is drawn on parchment stitched to a backing of stout linen, and the lace is made by filling in the pattern with button hole stitches. When the lace is completed, the parchment is removed. Needle point lace is made entirely with a sewing needle and thread. A design is drawn on paper, thread is laid over the design, and the thread is then sewn in place with button hole and blanket stitches.
The motifs are of birds, flowers, and scrolls or spiral decorations. There are several types of needle-point lace:

- **Alençon Lace** - has a solid design with a cord outline on a sheer hexagonal ground. It is delicate but durable.
- **Milan Lace** - is a tape lace with a needle point mesh and a loop (picot) edging.
- **Rose point Lace** - is a Venetian needle point lace having a delicate floral and scroll pattern with a cord outline.
- **Venetian Lace** - has floral designs joined by irregularly placed connections (bridges) of loops and looped edges.

4. **Crocheted Lace:**
When handmade, this is made with a crochet hook, to form a series of loops, each one of which is finished with a fine stitch, working usually with specially twisted cotton thread. It originated in Ireland as an imitation of Venetian needle point. It is a comparatively inexpensive heavy lace. Irish crocheted lace (not necessarily made in Ireland) is typified by a rose or shamrock design that stands out from the background.

5. **Tatting Lace or Knotted Lace:**
This is made by twisting and knotting thread by means of a small shuttle. When made by pass in a shuttle in and out of loops in a thread, it is called tatting. It is
identified by a circle like motif and picots around the edge of the motif. Clover leaf and wheel designs are the most popular, but other patterns are also made.

Macramé Lace – it differs from other laces in texture and appearance. It is generally made of heavy yarn knotted into relatively large designs. The following figures show the basic macramé knots and some variations. Unlike most other laces, it is used for such purposes as women’s hats, hand bags, belts and vests.

Filet Lace: characterized by a flat, geometrical design, this lace may be either crocheted or darned. It is very common for household use, particularly for doilies, runners, antimacassars, set, and table cloths. It may also be used for dress trimming.
b) Machine Made Lace:

Nearly all the laces classified as "real laces" can be duplicated by machine with slight variations and simplifications.

Machinery for making looped net was invented about 1764. But the forerunner of the present lace machine, the bobbinet machine, was patented by John Heathcote in the early 1800s and was later modified by several other inventors, one of whom was John Levers, whose name has come down to us via the levers machine we now use. In 1813, John leavers developed his first lace machine and by 1837 the principle of the Jacquard loom punched card system was incorporated into the leaver's machine. Since then, several other lace making machines have also come into prominence.

Many of the laces available today are produced on raschel knitting machines or by embroidering a sheer base fabric. Knitted lace is predominant in the market. The name of a lace may derive from the city in which is originally produced or by design features that characterize a particular style. Some of the more common names are Alençon, Brussels, Chantilly, Cluny, Schiffli, Valenciennes, and Venetian.

A lace pattern is usually identified or described in terms of the ground mesh, the pattern parts, the basic stitches, and the construction technique used.
1. Leavers Lace:
The leavers lace machine can produce the most intricate patterns from any type of yarn into fabrics up to ten yards wide. It is a huge, complex machine that takes an operator two to three weeks to thread. Very thin, round, brass bobbins containing up to 300 yds each are individually conveyed by carriages moving back and forth from one warp to another. As each bobbin is moved to a predetermined position, it swings between the warp yarns and wraps its yarn around one warp before it is moved to another. Since there are about 20 bobbins per inch, very intricate designs are possible. The fabrics can be fairly expensive. Leavers lace is used to a great extent in the dress industry.

2. Nottingham Lace:
The Nottingham machine originated in Nottingham, England. It also utilizes swinging brass bobbins but produces a flat lace that is coarser than leavers lace. Its large overall patterns are used for such purposes as table cloths.

3. Bobbin Lace:
The Bobbin machine employs the braiding principle. The lace produced has a fairly heavy texture, with an angular appearance and a uniform count. Bobbin lace lacks the fine texture and flowing lines of the laces produced by other machines.

4. Raschel Lace:
Knitting machines can be constructed to make lace resembling levers and crocheted laces. The Raschel machine, which has its needles set horizontally instead of vertically as for knitting, can produce at high speed inexpensive lace fabrics of manmade filament yarns.

5. Ratine Lace:
It is a machine made lace that has a ground of heavy loops resembling that of terry cloth.

6. Schiffli Lace:
Although the schiffli design closely resembles lace, it is produced by an embroidery technique on the Schiffli machine developed in St. Gall, Switzerland. It is produced now by Swiss descendants from St. Gall living in the northeastern part of New Jersey, around Union City.

The machine was named Schiffli, which means “little boat”, because of the shape of the shuttle. It employs 682 to 1020 needles to produce fine and intricate designs in appliqués and embroideries on all kinds of fabrics, particularly sheer fabrics such as batiste, lawn, and organdy. The pattern is controlled by punched cards similar to those used in the Jacquard loom. The finished material looks like expensive handwork but costs much less. The fabrics produced range from narrow trimmings to widths of up to 15 yards (14 m), including pile construction.
NONWOVEN FABRICS

Nonwovens are flexible, porous products consisting of one or more fibre layers. The separate fibres may either be preferentially oriented in one direction or may be deposited in a random manner. They are bonded by chemical, thermal or mechanical processes into textile products. Nonwovens are mainly planar structures. This relatively young branch of the textile industry has expanded enormously after the second world-war because of the high production rates and the resulting cost savings.

Contemporary nonwoven fabric dates to the early 1930s. At that time, a few textile companies began experimenting with bonded materials as a way of utilizing cotton waste. The first commercial production of the products now called nonwovens began in 1942 in the United States in an effort to produce fabric directly from fibres. The market for nonwoven products has experienced tremendous growth and has potential for more.

Nonwovens may be classified as either disposable or durable goods. Disposable, or nondurable, nonwovens include such one-time use products as diapers, medical dressings, household wipes, and disposable protective clothing. Durable goods are used for apparel interfacerings, automobile headliners, road underlayments, and carpets.

Manufacture:

The basic sequence of steps in manufacturing contemporary nonwoven fabrics is as follows: Preparation of the fibre → web formation → web bonding → drying → curing → finishing.

For films, the chemical solution is prepared and extruded, or cast, as a film.

Raw Materials:

Polyester is the most frequently used fibre in the United States; olefin and nylon are used for their strength, and cotton and rayon are used for absorbency. Some acrylic, acetate, and vinyon are also being used.

Fibres are selected on the basis of their properties and expected performance in end uses. New, first-quality fibres are preferred over reused or reprocessed fibres. Both staple and filament fibres are used, and it is possible to blend fibres of different lengths as well as fibres of different generic groups. The selection of fibres depends on the product proposed, the care typically given it, and the expected or desired durability. As in the manufacture of all fabrics, the cost of the fibres used is important, as it in turn influences the cost of the final product.
Web Formation:

Web formation is the creation of a loosely joined sheet structure by laying down fibres in one of several techniques including, but not limited to, dry-laid and wet-laid webs, spunbonding, and casting films. Both staple and filament fibres are used to form the web, which is usually too weak to be used without additional processing.

I. Dry-laid web:

A dry-laid web is formed by a process similar to that used to produce a card sliver in spinning. Fibres can be separated by suspending them in an air stream and blowing them onto a belt or by using a mechanical card to form a uniform web on a moving belt. The fibres may be somewhat parallel to each other in a random web; they can be made perpendicular by alternating layers of fibres at right angles; or the web may have a parallel fibre arrangement similar to that of a combed yarn web. Fibre bonding is achieved either through the use of a binder or adhesive or by the inclusion in the blend of heat-sensitive fibres, which soften and fuse with other fibres, helping to seal the final fabric.

II. Wet-laid web:

A wet-laid web is formed by depositing an aqueous suspension of fibres onto a screen belt or a perforated drum. It permits manufacturers to use very short fibres, even those less than ½ inch long. Wet-laid webs are formed quite rapidly and can be less expensive than other nonwovens if waste fibre is used.
This is similar to the process of making paper. The fibres are suspended in water to achieve a uniform suspension. This flows over the moving screen. When the water filters out, the fibres remain in the form of a wet web. The remaining water is squeezed out and the fabric is dried. Further bonding may be achieved with rollers. A bonding agent, such as thermosensitive fibres or an adhesive, may be incorporated in the suspension to bind the web together as it dries. Alternatively, following formation the web can be sprayed with a binder, which seals the fibre together once the web dries.

III. Direct-laid web:

In the direct laid process, webs are made directly from fibres spun from molten polymer. The two direct-laid processes are spunbonding and melt blowing.

a. Spunbonding:

This method is used for man-made filament fibres that melt under heat, such as polyester. Spunbonding is a process by which fabrics are produced directly from a thermoplastic polymer such as polyester, nylon, polypropylene, or polyethylene. The molten polymer is extruded through a spinnerette, cooled slightly in the air, and laid on a moving conveyor belt to form a continuous web. As the web cools, the fibres bond.

The pattern of the spun-bonded fabric and arrangement of the fibres can be varied in several ways. The spinnerette can be rotated to deliver filaments in different patterns and arrangements; a jet of air (a controlled stream of air) can be introduced to tangle the filaments; the conveyor can be moved at variable speeds to collect different quantities of filaments at selected locations; and applying an electrical charge to make the fibres loop and crimp.

Spunbonded fabrics are strong because of the filament fibres and are not easily torn. They are used for a wide variety of products ranging from apparel interlinings, carpet backing, furniture and bedding to bagging and packing material. Spunbonded fabrics may be used in geotextiles to control erosion or in constructing road. Some
spunbonds made from olefins are used as a tough, especially durable substitute for paper in wall coverings, charts, maps, tags and the like.

![](image)

Web forming by the Spunbonding method

Fabrics made by this process include Mirafi 140, made from nylon and polypropylene; Celestra polypropylene; Reemay polyester; Tyvek polyethylene; Typar polypropylene; Bondtex polyester; Cerex nylon; and Bidim polyester.

b. Melt Blowing:

Melt blowing also forms fabrics directly from fibres, but it differs from spunbonding in that molten fibre filaments are attenuated and broken into short lengths as they exit from the spinnerettes. In this process, the molten polymer is forced through a spinnerette into a high-velocity air stream. The impact of the air breaks the filament into short fibres, which then collect on a moving belt to form a web. Cool air distributes the fibres onto a moving screen. As the fibres cool they bond, forming a white, opaque web of fine fibres. Because the fibres in meltblown nonwovens are fine, the fabrics make good filter materials.

![](image)

Web forming by the Melt blowing method

Specialty products can also be made by layering spunbonded and meltblown fabrics or by entrapping absorbent fibres or other materials within the meltblown structure.
IV. Film Fibrillation or Extrusion process:

There is another method of fabric construction that does not start with a fibre but with a plastic film. This film is extruded from a melted polymer (a chainlike structure from which man-made fibres can be derived) through a slotted die as a film rather than as fibre filaments. The film is embossed and then is stretched biaxially oriented, to the point where it opens into a netting of fibres. The mechanical embossing produces a weakened area in the film so that stretching the film along both axes creates openings in the film – a nonwoven net. The form of the netting is controlled by the embossing pattern. Hercules Incorporated makes such a net fabric, which it calls Delnet.

![Diagram of Film Fibrillation or Extrusion process]

Web Bonding:

After the web is formed, bonds between the fibres must be strengthened and stabilized. Webs are bonded by one of the following processes:

1. Chemical bonding, with either latex or chemical reagents
2. Thermal or heat bonding, with either hot air or a calender
3. Mechanical bonding, by either needle punching or hydroentanglement

1. Chemical Bonding:

Bonding may be achieved by applying an adhesive material to the web and then setting the adhesive. This, in essence, “glues” the fibres together. Latex adhesives, in which the adhesive substance is suspended in water, are most often used. The fabric web is passed through a bath in which it is impregnated with the latex, and then dried.

When adhesive is applied to the surface of the fibre web, it tends to make the fabric stiff and more rigid. Also, fabrics exhibit the characteristics of the adhesive material on the surface rather than those of the original fibre. To overcome this disadvantage, adhesives may be imprinted onto the surface in selected areas. The printing patterns are developed carefully to ensure that adequate bonding takes place among fibres to maintain fabric strength. Such fabrics are less rigid and have better drapability and a more pleasant
surface texture than do those that have been completely coated by an adhesive.

Instead of adhesive bonding, fibres may be solution bonded by spraying a mixture of chemicals and water onto the surface of the fibres. When subjected to heat, the water evaporates and the chemical vaporizes, dissolving a small amount of fibre, usually where one fibre crosses another. When the dissolved fibres resolidify, bonds are formed that hold the fibres together.

In most instances the web is coated with a heat-activated substance. When the web is heated, the substance forms a spot-weld effect at points of contact between fibres. Any solvents that are present evaporate at higher temperatures, leaving behind a structure of fibres sealed together at the weld points. Because no extraneous material is left on the fabric, these materials are softer and have better draping properties than those bonded with adhesives.

Binder and adhesives used in making nonwoven fabrics include acrylic latexes, polyvinyl acetate copolymers, polyvinyl chloride copolymers, nitriles, ethylene vinyl chloride, and vinyl acetate-ethylene. Their singular characteristics produce different properties in nonwoven fabrics.

2. Thermal Bonding:

Thermoplastic fibres may be bonded by heat. The application of heat causes the fusing together of heat-sensitive fibres, which effectively fastens them together. As in bonding
with adhesives, heat may be applied in a pattern to provide sufficient bonding for durability and to allow greater flexibility and softness in the end product. Nonwovens can also be formed with a small percentage of binder fibres of lower melting point than the predominant fibres. When the web is heated, the binder fibres melt, providing the necessary adhesion.

Heat and pressure can be applied to bind fibres into a web. The two common thermal bonding methods are calendaring and air heating. In air heating, hot air fuses fibres within the web and on the surface of the web to make high-loft, low-density fabrics. The hot air is blown through the web in a conveyorized oven or sucked through the web while it is passed over a vacuumed porous drum. In the calendaring process, the web is drawn over and between heated cylinders to produce strong, low-loft fabrics. Spunbond and meltblown nonwovens thermally bond when the molten filaments harden after extrusion. Passing the spunbonded or meltblown fibre webs between heated cylinders called calendar rolls bonds fabrics more completely. Design effects can be produced if these cylinders have patterns embossed on their surfaces. Heat can also be applied to webs by infrared radiation or ultrasound.

![Air bonding process](image1)

![Calendar bonding process](image2)

3. **Mechanical Bonding:**

Mechanical bonding is the oldest method of producing nonwovens; it entangles fibres to impart strength to dry-laid webs. The most common mechanical methods are needle punching, spunlacing, also called hydroentangling and stitch bonding.

1. **Needle Punching:**

In needle punching, barbed needles are punched vertically through the web to hook and entangle tufts of fibres. Needle-punched nonwovens resemble felt in appearance, but they are made primarily from fibres other than wool. Characterized by high density combined with some bulk, they are available in weights from 50 to 285 grams (1.7 to 10 oz) and in thicknesses from 15 to 160 mils.

Two basic steps are involved in the construction of needle-punching nonwovens:
The fibre web, or batt, prepared by either carding, garneting, or air-laying techniques, is fed into a machine with specially designed needles. The fibre web moves on a substrate between a metal bed plate and a stripper plate; the needles punch through the plates and the fibre web, reorienting the fibres so that mechanical interlocking or bonding occurs among the individual fibres.

![Basic principle of needle punching](image)

The substrate may be filaments, a scrim, or some other form. Placement of the substrate in the middle of the fibre web improves the strength and structural integrity of the finished needle-punched fabric.

The strength of needle-punched fabrics also depends on the fibre arrangement within the webs. If fibres are placed parallel to each other, the finished fabric will have good strength in that direction but will tend to be weak in the opposite direction. If the fibres are in a random arrangement, strength is equal in all directions. A two-step process first tacks the web with 30 to 60 punches per square inch (4.7 to 9.3 per square cm) and then punches with 800 to more than 2500 penetrations per square inch (125 to 390 per square cm). The higher number of punches is used for fabrics such as blankets, which are expected to be subjected to considerable handling during use and care.

The properties of needle-punched fabrics depend on the length and characteristics of the fibres, the physical properties of the web, and the techniques used to produce the web. Most needed fabrics lack any structural pattern because the needles punch and intermingle the fibres in such a random way that the fabric surface appears uniform.

**Needle-punched fabrics produced with a modified needle bed and needles that penetrate beyond the surface to form loops on the back can be made to resemble loop pile, velour, or velveteen. The loops either are left uncut or are cut and brushed to give the surface appearance of the pile-woven fabric.**

Needle-punched fabrics frequently are found in carpeting and other floor coverings, wall coverings, blankets, padding material, insulation materials, industrial fabrics, and fabrics for vehicles.
II. Hydroentangling:

In hydroentangling, or spun lacing, the fibrous web is subjected to high-velocity water jets to entangle the fibres, causing them to curl and knot around each other. These materials are produced without a binder, resulting in lightweight, soft, and drapable spun-laced fabrics. The Nexus fabrics by Burlington, available in several patterns that can be dyed or printed, best typify this group. Some of these fabrics are washable; others are dry-cleanable. Fabrics range in weight from 0.7 to 2.2 ounces per square yard and in thickness from 3.5 to 25 mils. Typical end uses include quilt-backing fabrics, mattress pad ticking, and substrates for coated fabrics of various types, interlinings, curtains, table coverings, and selected items of apparel. Although most of the spun-laced fabrics on the market are made of polyester, it is possible to use other fibres. Nexus, Sontara, and Polyspun are examples of polyester spun-laced products.

Spunlacing is often used in making kitchen wipes. The wipes have a regular pattern of holes surrounded by tightly entangled fibres. Many wipes are also adhesively bonded for increased wet strength.

III. Stitch bonding:

For the stitchbonding technique fibre webs are stitched through to hold the fibres together. Maliwatt fabrics are fibre webs that have been stitched together. The resulting fabrics are used as lining fabrics, furnishing fabrics, insulating materials, base fabrics for tufted goods, and in industrial and geotextiles. Malivlies fabrics, used in felts, packing materials, insulation materials, and utility textiles, are created by forming stitches from the fibres of the web itself. No additional yarns are required.

Other branded processes are kunit and multiknit. Kunit fabrics are formed by feeding a web of fibres into a machine where a type of compound knitting needle forms knitting stitches from the fibre web. These stitches hold the web together and form a fabric that may have either a plushlike, furlike, or flat appearance. Uses include linings for clothing and shoes, plush for toys, automotive interior fabrics, acoustical and thermal insulation, packaging material, and base fabrics to which coatings may be applied. In the multiknit
process, two fabrics formed by the kunit process are united into a double-sided, multilayered fabric with knitting stitches made by a compound needle with a sharp point that can penetrate both fabrics. Applications include insulation materials, garment interlinings, base materials for molded textile composites, and as a replacement for foam in car and furniture upholstery.

![Stitch bonding process](image)

**Finishing:**

The final stage in the manufacture of nonwovens is finishing, which includes drying, curing, embossing, printing, and dyeing. Hot – air ovens, infrared lights, rollers over heated cans, or high – frequency electrical equipment can provide the drying action, which also removes any solvents remaining in the fabric. Many of these finishes are similar to those used for standard woven or knitted fabrics.

**Care:**

Care of nonwovens depends on several factors, including the fibre used, the thickness and direction of fibre lay in the web, the adhesive system used, and the finishes and colours applied. Obviously, the care procedures for durable products will differ from those for disposable products. Procedures for discarding disposable diapers and medical products are now regulated in some municipalities.

**Important economic advantages include:**

1. no weaving or knitting processes and preparatory stages to those processes;
2. no mechanical spinning process, since nonwovens are made from carded fibre webs, pneumatically made fibre webs or fibre webs made on paper machines;
3. (very) high production rates, for example up to more than ten meters per minute for dry-laid nonwovens and up to several hundreds of meters per minute for wet-laid nonwovens;
4. savings of labour force and machinery;
5. production of cheap articles, and also dispensable items (one time use) such as nappies, briefs, towels, napkins, aprons, blankets, industrial clothing etc.
Characteristics of Nonwoven Fabrics:

The particular set of properties that a nonwoven fabric may have is dependent upon the combination of factors in its production. The range of characteristics is wide.

The appearance of nonwoven fabrics may be paperlike, feltlike, or similar to that of woven fabrics. They may have a soft, resilient hand, or they may be hard, stiff, or boardy with little pliability. They may be as thin as tissue paper or many times thicker. Nonwovens may be translucent or opaque. Their porosity may range from high, free airflow to minute to impermeable. Their strength may range from low tear and burst strength to very high tensile strength. They may be fabricated by gluing, heat bonding, or sewing. The drapability of nonwovens varies from good to none at all. Some nonwovens have excellent launderability; others have none. Some may be dry-cleaned.

Nonwovens are engineered to provide particular properties suited to desired end uses. For example, diapers can be constructed of two different layers of nonwoven fabrics: an outer layer composed of a wetting-agent treated polyester that will permit rapid fluid penetration, but with minimal lateral wicking, and an inner layer of absorbent rayon. Thin, high-filtration nonwoven fabrics for surgical masks can be composed of microdenier fibres; thick, fluffy, insulating nonwovens for ski jackets can also be made of microdenier fibres. Research continues in order to achieve or perhaps exceed certain properties of conventionally constructed cloth.

Uses of Nonwoven Fabrics:

The use of nonwoven products continues to expand. The many uses of nonwovens may be classified as disposables, durable consumer goods, and industrial materials. All these areas are making increasing use of this kind of merchandise because of its low cost and its suitability for many needs.

Disposable nonwovens are essentially made for one-time use; but some, such as dust cloths, may be laundered and reused a few times. General applications include personal hygiene products, such as diapers and sanitary napkins; medical products such as surgical gowns and drapes; surgical and industrial masks, bandages, wipes and towels; bibs and even costumes for special events. They have recently become popular for lightweight "fun" cloths that can be washed a number of times.

Durable nonwovens have wide applications. Consumer durables include both household goods or home furnishings, such as for draperies, furniture upholstery, mattress padding, towels, table cloths, blankets and carpet backing and clothing or apparel, such as for caps, linings, interlinings, interfacings and the reinforcement of other fabrics.
The many industrial uses include filters, insulation, packing materials, roadbed stabilization sheeting or road-building materials geotextiles and roofing products.

**Specialty Nonwoven Products:**

**Fusible Nonwovens:** A fusible nonwoven fabric is any nonwoven fabric with a heat-activated adhesive resin coating. More than half of the interfacings used in apparel construction are fusibles. They are placed between garment layers to provide body, shape, support, additional strength, and foundation. Heat and pressure, applied for a specified time, activate the resin to bond the interfacing to the shell fabric.

Fusible interfacings have some disadvantages. They sometimes produce a stiff or boardy hand; differential shrinkage between the fabrics being joined may produce a rippled garment; and separation of the two fabric layers may occur when improperly applied interfacings are cleaned.

Other special nonwoven products are film fabrics, coated fabrics artificial suedes and leathers etc.
TEXTILE DYEING, PRINTING AND FINISHING

Textile Finishing:

Textile finishing comprises all fabric processes, which are not included in fibre production, yarn production, and fabric formation. Finishing effectively means to improve or to beautify the material.

Importance of Textile Finishing:

Normally a raw fabric direct from the weaver or knitter cannot be used as such to make consumer products; various processes are required before it is suitable. For example, various substances, such as sizes or lubricants may have been added to the yarns as part of the manufacturing process. These, together with any soiling must be removed and faults may have to be rectified. An important function of the finishing is to enhance the appearance of fabrics by colouration, pressing, embossing, etc. Another aspect is to impart to the textile properties, which it would not normally possess; its handle and drape can be modified and it can be given better easy-care performance. The question of environmental conservation has a large impact on the finishing sector. Liquors used for colouration and finishing cannot be discharged to waste without some purification. The same is true of discharge gasses, such as solvent vapours.

Finishing at different stages in Textile production:

Finishing is most efficiently carried out on fabrics. However, there are times when a finishing process must be performed at some other stage. For example, in order to make colour-woven fabrics, either the loose fibre or the yarns must be coloured.
Preparatory Process or Pre-dyeing Treatments:

Preparation or the pre-dyeing stage includes a series of operations that prepare the textile product for subsequent finishing treatments such as dyeing, printing, and finishing. Any processing aids which may have been applied during spinning, weaving, or knitting must be removed. These might be spinning oils, waxes, sizes, etc. Any natural or adventitious contaminants must also be removed so that the fabric has the required purity for the following processes. Thorough preparation is a prerequisite for good results at the finishing.

These operations vary according to the type of fibre on which they have to be carried out, to the structure of the textile product (staple, top, sliver, yarn, fabric) and also depend on the subsequent treatments to be carried out, which may change according to various factors such as market demands, customer requirements, staff experience, and availability of machines.

The pre-dyeing stage includes for example desizing, singeing, mercerizing, scouring, and bleaching. Each process varies according to the processing conditions and the above-mentioned specific situations. Some of these processes (for example bleaching and mercerizing) can be considered either preliminary operations or finishing treatments; this depends on the type of the downstream processes to be carried out on yarns or fabrics.

Waxing

Waxing serves to lubricate the yarn, reducing to a minimum its coefficient of friction with the parts with which it comes into contact. This operation is normally carried out on yarns destined to be processed on knitwear machines, on which smooth running of yarns is essential.

Waxing is carried out on the winding machine, which is equipped with a positive-drive adjustable waxing system that guarantees constant waxing of the yarn; there is also control device that stops the machine should the wax run out.
Singeing:

With this treatment fuzz and fibre ends are burnt off in order highlight the fabric weave. It is generally carried out on gray pieces and the residues are removed by a further washing process. An oxidizing flame, which does not leave any trace of sooty residue on fibres, is used to carry out this operation.

The flame can be perpendicular to the fabric, and only rarely tangential; the fabric is positioned at a distance of 1.5 to 4mm from the end of the flame and the machine is equipped with a suction device under the fabric, which attracts the flame and concentrates the heat on the fabric. The fabric speed can range from 60 to 120 metres per minute. The singeing process with perpendicular flame is the most common one, while the process with tangential flame is used for fine fabrics (light singeing).

Singeing is carried out rarely on knitted fabrics and frequently on yarns and woven fabrics. Instead of the traditional singeing process, it is possible to apply an enzymatic treatment (for cotton and lyocell fabrics), for example with cellulose, which uses chemical agents to corrode the fibre surface and remove the fuzz from the fabric.

Normally singeing is done to those knitted fabrics which will be mercerized later. A typical singeing machine has a detwisting unit, two types of brushes, eight gas burners, a cigger, felt rollers and other necessary units like suction duct, feed and delivery rollers etc. The fabric is singeing in tubular form and on face side only. The detwisting unit removes twist during fabric feeding in machine. Between two types of brushes one is heavy brush and another one is light brush. The brushes raise the hairy fibres. The cigger can be extended in circumference and by this it opens the tubular fabric in full circumference. In this state the eight burners situated at 2cm apart from all sides of fabric surface burn the hairy fibres. The fabric is passed through the fire ring about 70 to 80 m/min. This is a gas singeing machine.

Singeing is also done at yarn stage. For the yarn singeing it is an operation carried out in order to eliminate yarn hairiness. The singeing system consists of a package-to-package winder and a gas burner. The yarn is passed through the flame, which singes the protruding fibres that cause the
hairiness. It runs at a rate of 400 to 1000 m/min. The machine must, in order to obtain even singeing, maintain a constant yarn speed and an even flame.

The singeing system, in addition to normal machine control devices, also has a fly fibre evacuation system and a flame temperature control system. Since this operation reduces the weight of the yarn, even by as much as 5-6%, the yarn count will also be modified, and this must be borne in mind when designing the yarn.

Desizing:

This treatment is carried out on woven fabrics to remove the sizing substance from the warp. The size must be totally eliminated since the fabric must absorb the liquor of subsequent processes homogeneously.

Since amylaceous sizes are generally used for cotton yarns, it is possible to apply amylolytic enzymes (enzymatic desizing), which carry out a biological degradation process of the starch, transforming it into soluble by-products which can be then eliminated by washing. The enzymatic process depends on the quantity of enzyme molecules per gram of fabric, while the thermal stability of the enzyme depends on the bacteria strain from which it originates. The amylases only react with starch molecules and do not affect the other glucose polymer (cellulose), since they attack the 1.4 alpha-glucoside bond of starch and not the 1.4 beta-glucoside bond of cellulose.

This reaction makes the use of amylases profitable (when applying starchy sizes) compared to other desizing agents such as alkali and oxidizing agents (oxidizing desizing), which attack both starch and cellulose.

The oxidizing desizing process is used to remove non-starchy sizes that do not dissolve in water or to eliminate starchy sizes combined with polyvinyl alcohol (this treatment is carried out before the singeing process). This last treatment requires accurately controlled operating conditions to solubilise only sizes and avoid any possible fibre degradation. Enzymatic desizing can be carried out in discontinuous systems (jigger) but semi-continuous or continuous techniques are more frequent after the pad-batch wetting of the fabric. The most frequently used processes are pad-roll and pad-steam. If the size is water-soluble, it can be eliminated by hot washing.

Scouring:

On cotton fibres, this treatment removes fatty and pectic substances, softening motes and preparing the material to absorb the subsequent treatment agents. Scouring is usually carried out in soft water additivated with textile auxiliaries such as absorbing agents, detergents, emulsifying agents, caustic soda and/or Solvay lye and sequestering agents. Alkali makes the fibre swell and enhance the action of surfactants. This treatment can be carried out on filaments, yarns and fabrics.
Instead of the traditional scouring process, it is also possible to carry out an enzymatic scouring process (bioscouring) to remove non-cellulosic material from cotton fibres, to make them more easily wettable and enhance the subsequent absorption of finishing liquors.

The scouring process applied to synthetic fibres removes oils, lubricants and anti-static substances, dust, contaminants and can be carried out on yarns and fabrics (when warp yarns have been bonded, the treatment is called debonding). It is carried out by means of surfactants, detergents and emulsifying agents.

Scouring is usually carried out by means of continuous or discontinuous systems, with the same machines used for downstream treatments; temperature, processing time, pH, concentration of reagents, depend on the fibre and on the machine used. Incomplete scouring processes usually originate dyeing and printing defects due to different degrees of wettability and to inconsistent affinity for dyes of the material.

**Bleaching:**

Bleaching treatments are applied to eliminate any impurity and obtain a pure white tone, to prepare substrates for low-density dyes or prints and to level off undesired tone variations. Bleaching agents mainly used for cellulosic fibres are sodium hypochlorite and hydrogen peroxide. They both require the addition of sodium hydroxide in the bleaching liquor to make it alkaline it by favouring the formation of the bleaching ion, which in the first case is the hypochlorite ion and in the second one is the perhydroxyl ion.

When using hypochlorite the pH must range between 9 and 11 and the temperature must not exceed $30^\circ$C. In fact, as far as the pH is concerned, pH values below 4 give rise to the formation of chlorine while pH values ranging between 4 and 9 give rise to the formation of hypochlorous acid: these chemical substances affect the fibre negatively and do not perform a bleaching action. After the bleaching with hypochlorite it is necessary to carry out an antichlor treatment. Fibres must be treated with hydrogen peroxide, which completely removes the chlorine and avoids the formation of chloramines, which, in drying machines, could generate HCl dangerous for cellulose. With hydrogen peroxide, in the presence of alkali, little motes can be eliminated and the autoclave scouring can therefore be avoided. The optimum temperature ranges between $80^\circ$ and $90^\circ$ C and the pH between 10.7 and 10.9. Hydrogen peroxide at a concentration of 1 – 2 vol can be used also for silk after degumming, with a pH of 8 – 9, at $70^\circ$ – $80^\circ$ C for 1 – 2 hours.

From an environmental point of view, hydrogen peroxide is more suitable than hypochlorite since it has a lower impact on the environment and effluents can be decontaminated with simpler operations. It is recommended to add sequestering agents to the bleaching liquors. Another bleaching agent used in textile processing is sodium chloride (suitable for synthetic fibres) that takes advantage of the oxidizing action of chlorine dioxide generated as a result of the hot acidification of the solution of this salt. Unfortunately, chlorine dioxide is a toxic substance and attacks stainless steels; therefore it is necessary to work in hermetically closed units equipped with suction systems with resistant materials such as stoneware.
Bleaching operations can be carried out on yarns, woven fabrics and knitted fabrics with continuous and discontinuous process in circulating liquor machines (autoclaves, jigger, paddle wheel, jet, overflow), semi-continuous (pad-batch, pad-roll). Continuous bleaching can be carried out on knitted fabrics using a J-box. The products to be used on the fabric are applied by means of suitably positioned mangles; the fabric is introduced in the machine where it remains for the time necessary to complete the bleaching process.

Temperature, speed, pressure and pH are controlled automatically. It is also possible to carry out optical bleaching using substances that do not perform a chemical action on the fibre but obtain a whitening effect by means of an optical compensation process of physical nature. These substances release a blue light compensating white and grey, and giving a dazzling white effect. For example an optical bleaching on wool can be carried out after chemical bleaching, using 0.2 – 0.6 g/l optical bleaching agent at pH 4 – 5 for acetic acid, at a temperature of 50° - 60°C for 30 minutes.

**Mercerising:**

This is a typical treatment for cotton yarns and fabrics, which improves the fabric luster and wettability, ensures a covering effect for dead cotton, improves dimensional stability and dyeing efficiency.

This treatment is carried out using caustic soda, which determines the contraction and swelling of the fibres; they become translucent and increase their tensile strength, but reduce their flexural and torsion strength. The bean-like section of the fibre becomes first elliptic and then circular, allowing a better reflection of light with a consequent increase of luster. The treatment is usually carried out under tension, with caustic soda at 28° – 30° Be(bom)' (approx. 270 – 330 g/l). If the concentration is lower than 24° Be'(bom), the treatment is called causticization and aims at enhancing the dyeing liquor penetration into the fabric.

The liquor temperature usually ranges between 15 – 20°C and its uniform absorption is assured by adding mercerizing wetting agents stable in alkaline environment. Once the operation has been carried out, alkalinity must immediately be neutralized by means of a diluted acid solution. From a chemical point of view, alkalicellulose is the first material to form; the next material, which forms after repeatedly water washing is hydrocellulose, which is more reactive than natural cellulose.

Cotton wetting entails shrinkage of the material, which must be kept under tension, to avoid a fuzzy and woolen appearance. Mercerising is carried out on yarns, fabrics or open or tubular knits. As far as yarns are concerned, before the mercerizing process in special machines, they undergo a singeing treatment to remove the fuzz and end fibres - which could otherwise prevent the perfect reflection
of light after mercerizing. There are two different types of machines to be used for woven fabrics: a chain system and a cylinder system.

**Chain mercerizing**: with the chain mercerizing process the fibres achieve perfect brightness thanks to optimum tension control. This system runs slowly and allows no flexibility when the width of the fabric varies.

**Cylinder mercerizing**: this is a more compact and faster system compared to the previous one; cylinder mercerizing does not allow the contraction of the warp because the fabric is drawn in on the cylinders. The contraction of the filling yarns is also prevented thanks to the tension produced by the simultaneous action of the cylinders and of the fabric wetting. Cylinder mercerizing machines are also used for flat knits.

Mercerising process can also be carried out on tubular knitted goods: after the wetting process, the fabric is left reacting in a padding mangle. The withdrawal of the fabric width is controlled by means of an adjustable ring spreader while the withdrawal of the fabric length is controlled by “slowing down” the fabric before the final squeezing. The sodium hydroxide concentration is brought down to approximately 4⁰ Be’ by means of a circular shower. The fabric is then washed, neutralized and rinsed.

A typical mercerizing process for tubular knitted fabric as follows. The mercerizing machine has a detwisting unit, a water trough, a sodium hydroxide liquor trough, swelling unit, four washing units and a neutralizing unit. The detwisting unit removes twist from fabric during feeding. In water trough required water is supplied for caustic. In sodium hydroxide trough required amount of caustic is come from a central reservoir. The central reservoir store caustic at particular concentration. There is also a chiller which maintains the caustic temperature. The swelling unit has some dancing rollers which control the fabric tension. After swelling unit the fabric enters into first washing unit and then second washing unit. Each washing unit has cigger which extends the fabric circumference as washing can be done very well. The cigger widths are kept same for first and fourth and same for second and third. But the temperatures are kept different for the all four washing units. Before entering third and fourth washing units the fabric is passed through neutralization padder. Here acetic acid is used and impregnation temperature is kept 70⁰C.

Another well-proven mercerizing agent is liquid ammonia, which has to be applied for very short times (about half a second). There are very few systems based on liquid ammonia due to the difficulties connected to the use of liquid NH₃.

Engineers have recently developed continuous mercerizing cycles and machines for combined mercerizing and bleaching process.
1-Entry, 2-Wetting with sodium hydroxide, 3-Exposing, 4-Spreader, 5-Stabiliser, 6-Exit, 7-Neutralisation and bleaching.

Continuous mercerizing and bleaching system for tubular knitted fabrics

**Heat Setting**

This operation is crucial for fabrics made of synthetic fibres (PE, PA, elastomers), for triacetate, and partly for PAC fibres (setting), since it grants excellent dimensional stabilisation and creaseproof properties, maintained till the fabric is exposed (by air blowing) to temperatures exceeding the heat setting one (after being treated with water at a temperature above the second order glass transition temperature, i.e. 80-85°C for acrylics).

Heat setting is carried out on gray fabrics (scarcely applied), on scoured fabrics (frequently applied) and on dyed fabrics (scarcely applied). The process grants excellent dimensional stability and good crease-proof properties. As far as operating conditions are concerned, the fabric must be treated in accurately controlled moisture and temperature conditions.

<table>
<thead>
<tr>
<th>Fibre</th>
<th>Min T. °C</th>
<th>Max. T. °C</th>
<th>Time (in seconds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polyester (PE)</td>
<td>170</td>
<td>210</td>
<td>15 – 50</td>
</tr>
<tr>
<td>Polyamide PA 6.6</td>
<td>170</td>
<td>210</td>
<td>15 – 40</td>
</tr>
<tr>
<td>Polyamide PA 6</td>
<td>160</td>
<td>180</td>
<td>15 – 40</td>
</tr>
<tr>
<td>Triacetate</td>
<td>160</td>
<td>180</td>
<td>15 – 40</td>
</tr>
<tr>
<td>Acrylic (PAC)</td>
<td>160</td>
<td>180 – 200</td>
<td>15 – 40</td>
</tr>
<tr>
<td>Elastomers</td>
<td>170</td>
<td>180 – 200</td>
<td>15 – 40</td>
</tr>
</tbody>
</table>

Machines used: stenters.

Fluctuating temperatures inside the stenter cause a consistent variation of crystallinity in the fibre structure, which leads to different affinity for dyes. The moisture in the fibre produces soft hand, but variable moisture percentages in the different fabric sections create the above mentioned defect (variable crystallinity). Too low temperatures do not allow a good setting while too high
temperatures and too long setting times cause yellowing (PA and elastic fibres), stiff hand (acrylics), and loss of elasticity (elastic fibres).

The presence of combustion gas (NOx) produces a yellowing of the elastomers. The heat setting process carried out before scouring could fix the stains on the fabric or make the scouring process more difficult due to the modification of the lubricating products (cracking with emission of polluting gas). Heat setting after dyeing could lead to the sublimation of disperse dyes (if not accurately selected).

Decortication (only for polyester)

This treatment is aimed at providing a silky-smooth hand to polyester fabrics (till a few years ago this process was also used to obtain microfilaments by increasing the fibre fineness), a lustrous effect and an enhanced drapability. The best results can be obtained with fabrics produced with coarser yarns.

The open-width decortication process can be carried out on jiggers or beam dyeing machines; rope decortication is performed on jet or overflow systems (batch systems). Decortication is carried out after scouring and heat setting; it is better to carry out a heat setting treatment also after the decortication process.

Operating conditions applied: the process is carried out at a temperature varying from 90-95°C to 120-130°C for 20-35 minutes, with 30-50 g/l of NaOH 36°Bé. Once the process has been completed, the fabric is washed and neutralised. Processes and machines used: open-width process on jiggers or beam dyeing machines (batch systems) or special tensionless open-width continuous machines.

Elastic Fabrics

For elastic fibres, treatments depend on the chemical composition, which can be extremely variable. As far as the fabrics containing segmented polyurethane fibres are concerned, the suggested treatments to be carried out are the following:

- relaxation
- heat setting
- scouring
- bleaching/dyeing/printing
- finishing

Relaxation: Before carrying out any further treatment, it is recommended to relax woven or knitted goods to obtain a uniform shrinkage and avoid stitch distortion or fabric deformation, creases or wrinkles. The fabric relaxation is a crucial step to allow good shrinkage and give excellent elasticity since the fabric width on looms is always bigger than the finished one (tensioned yarns on the loom). Many techniques are used but here are some of the most frequently used ones: table
steaming, steaming carried out at the entry of the stenter, scouring carried out with hot solvents, relaxation in hot water with tensionless scouring; these techniques give poorer stabilisation results and do not provide permanent crease resistance to textiles and fabrics.

**Heat setting:** This process is crucial to give the fabric an optimum dimensional stability. It is recommended to carry out a heat setting treatment before any further wet treatment in order to avoid the formation of possible creases and folds. An optimum heat setting requires a temperature ranging between 180°-200°C, which must be maintained constant for at least 45 minutes. An optimum heat setting also requires the use of an indirect-air heating stenter, allowing more uniform temperatures and no-gas conditions, which could lead to fibre yellowing. The fabric is weighed at the entry of the stenter and then subjected to steaming. Since the fabric shrinks during the heat setting treatment, the fabric width on the stenter must exceed the desired width by 5-10%. An excessive heat setting could decolorise the fabric while an insufficient heat setting will result in poor fabric stability.

**Scouring:** It is necessary to carefully consider the characteristics of the fibre combined with the polyurethane elastomer.

**Bleaching:** This treatment is carried out using sodium hydrosulphite; a suitable optical bleaching agent can also be added.

**Washing**

Rinsing and washing are the operations carried out most frequently during a complete textile finishing cycle. They are almost always connected to key treatments and aimed at removing from the fabric insoluble matters, matters already in solution or an emulsion of other impurities. During the fabric preparation process, for example, washing is carried out after desizing, boiling and other bleaching and mercerising processes; in dyeing, the washing stage is necessary to complete the dyeing process itself or to eliminate the dyestuff which has not been fixed; during the printing stage, washing performs a finishing action. When using vat dyes or disperse dyes, the washing process aims at removing insoluble pigment substances from the fibre surface by means of wetting or dissolving agents.

This could therefore be considered a crucial treatment in the whole textile process, because of the frequent use and strong economic impact. Manufacturers increasingly focus their attention on reducing water consumption, which leads to subsequent energy and hot water saving as well as a reduction in wastewater. Together with traditional washing systems with vats equipped with "vertical cylinders" the market offers horizontal washing units, which reduce the liquor ratio and the energy and water consumption for each kilogram of washed material. Washing includes a chemical-physical process, which removes the dirt from the substrate, and a series of physical operations aiming at improving the "feedback action".

The sequence of the various washing steps is the following:

a. formation of the detergent liquor (transfer of matter + energy by mixing);
b. reaching of the process temperature and wetting (transfer of the liquor to the material);
c. separation of impurities and emulsification (transfer of matter from one step to the other);
d. removal of the liquor from the fibre (transfer of macroscopic matter);
e. drying (interstage transfer of heat and matter).

Often these steps occur simultaneously. The use of surfactants (detergents) during the washing stage is extremely important to speed up the wetting of the textile material, to facilitate the removal of dirt from the substrate, thus keeping the emulsion inside the liquor and preventing the particles laying down again on the fibre. Crucial factors are water (which must be quite soft to avoid precipitation of Ca and Mg salts which could give a rough and coarse hand to the textile) and chemical products to be used (emulsifying agents, softening agents and surfactants).

Contaminants to be eliminated

Obviously the use of detergents, as well as operating conditions, depends on the nature of the chemical substances to be eliminated, which need to be generally classified. A general classification is shown here below:

1) Spinning oils: We must distinguish between fabrics made with yarns spun from combed or carded fibres, which are extremely different in terms of quantity (5 and 1 % respectively) and the nature of the substances added: as far as nature is concerned, the substances most frequently used are in both cases synthetic or mineral oils. These oils are usually made selfemulsifiable by means of suitable additives (materials must always be accurately evaluated since a wide range or products and prices are now available on the market); olein can be used for woollens (oleic acid) while for worsteds a good alternative can be represented by vegetal oils;

2) Sizes: For treating wool (opposite to cotton, where it is possible to use finish, which requires a special treatment), the stuffs now used (carboxymethyl cellulose or polyvinyl alcohol) can be easily eliminated and do not give particular problems;

3) oily stains: It is very difficult to eliminate these types of stain due to their characteristics and to their deep degree of penetration in the fabric; oily stains usually require a pretreatment with solvents sprayed directly on the stain (by means of a special "spray gun"). They can also be removed using special expensive detergents containing solvents, or by means of dry washing;

4) solid residues of various nature (dust, non-fixed dyestuffs, etc.), usually fixed on the fabric by means of fatty substances. To eliminate these residues, general cleansing rules must be observed and applied and special attention must be given to the mechanical action of friction. It is worth specifying that the above mentioned discussion is not at all exhaustive; in particular, it is not a text relating to the treatment and elimination of severe stains (colors, metals, microbiological attacks, etc.), which cannot be treated with standard cleansing processes. Readers are recommended to consult the specific literature available on this subject.
Washing machines:

The scheme below shows all the categories of machines now in use; washing-milling machines are not included (combined washing and milling machines):

Washing can be performed on fabrics either in open-width or in rope form. Rope washing is more effective than open-width washing thanks to a stronger mechanic action, which favors the cleansing, and the relaxation of the fabric structure; for delicate fabrics an open-width washing must be preferred to avoid marks and creases. Open-width washing is also the best choice for processing huge lots.

Rope washing:

Substantially, batch piece washing machines are made up of a couple of squeezing cylinders, which make the fabric swell (the fabric is previously sewn on top and bottom and takes the shape of a continuous ring); these cylinders are assembled inside a vessel, whose lower part contains the detergent liquor. It is possible to wash a fabric inside this vessel, by feeding it into restricted area without laying it stretched out. The efficiency of this operation is enhanced by the mechanic action, which facilitates both detergency and tension relaxation. This operation is highly cost-efficient because open-width washing allows only one working position and therefore only limited loads can be processed (max. 180 kg) while a rope washing machine can include from one to eight ropes, with an overall weight exceeding 600 kg. Furthermore rope washing machines grant reduced operating times thanks to a more effective mechanic action.
**Open-width washing:**

An open-width washing machine is usually a system featuring a vertical path washing with driven cycle of multiple action baths, with a resulting 30/40% water and steam saving. This operating unit is manufactured in several versions (10-15-30 meters) and can be used for every kind of preparation and finishing treatment. Four different washing actions alternate inside this machine:

1) washing on rising paths;
2) washing on sloping-down paths, carried out by means of spray nozzles, which atomise on both face and back of fabrics, performing a strong penetration action;
3) "vibraplus" effect washing, which removes from the fabric the threadlike elements (fibrils) that do not dissolve in water;
4) extraction washing by means of vessel intermediate squeezing.

The longitudinal tension of the fabric remains perfectly unchanged on the whole path; it can be adjusted between 5 and 20 kg by means of upper cylinders equipped with self-adjusting control system which generates a sliding motion crease-and-fold proof also on extremely delicate fabrics. Plush fibrils are removed from the vessel with no need for brushes or liquor dilutions. Another type of machine divides the washing process into single steps, which are systematically repeated. In this way the whole process can be not only constantly monitored but also accurately calculated.

Inside every separated washing unit, an exchange takes place between the washing liquor and the chemicals-mixed-with-impurities on the fabric in a percentage ranging between 50 and 80%. The washing liquor absorbs both impurities and chemicals. Thanks to a squeezing step carried out by means of squeezing drums assembled at the exit of each unit, the dirty liquor does not leave the unit with the fabric. In the next unit the liquor exchange process repeats once more, but the washing liquor contains always-lower quantities of dirty particles. The repeatability of the process together with the addition of fresh water, are basic elements to estimate in advance the efficiency of the washing process. High-performance washing units, equipped with double-rope system and upper supporting cylinders made of rubber, recommended above all for medium and heavy fabrics, allow the maximum washing efficiency. Upper cylinders, individually driven and equipped with supporting squeezing cylinders, grant an accurate system control. In each washing unit the fabric is
soaked twice in the liquor, which washes the fabric by passing through it, and squeezed by the cylinders. The powerful liquor exchange in the fabric is also enhanced by the synergic crosswise flow of the bath.

Continuous washing systems:

From an output point of view, the continuous treatment of fabrics for open-width washing allows operating speeds of at least 25 m/minutes: these speeds are extraordinarily higher than the one obtained with batch open-width or batch rope washing. The output is also strictly related to the overall dimension of the system (quantity of washing and rinsing units) and can be substantially increased. From a technical point of view, the main problems to be solved in a continuous-system plant, are detergency and relaxation of internal tensions, essentially related to washing processes, above all when carried out with open-width systems. We sketch here below the example of an up-to-date plant, including:

1. A prewashing unit, where the fabric is sprayed with a detergent solution atomized by 7 nozzles: the treatment takes place outside the bath. The solution is collected into the cavity created by the slanting path of the fabric and is forcibly driven through it (Idropress system); the alternating direction of the solution passage allows the treatment on both sides and the particular design of the driving rollers (the roller inside part is driven by a motor and the outside by the fabric) allows a minimum tension on the fabric;

2. A soaping washing unit (working when the fabric is not immersed in the bath), whose capacity (25 and 50 meters respectively) determines the output speed of the plant, since the time needed for the operation cannot be changed (1 min);

3. Two or three rinsing units, by means of Idropress system.

An extremely innovative machine features a basic element made up by 8 vibrating fabric guides, which push the water under pressure against both fabric sides, beating them alternatively against the fabric guides; since the flow follows the fabric motion, the effect of the driving tension is also contrasted; this is crucial to allow fabric relaxation in the direction of the warp (obviously, also in all the other machine versions, manufacturers pay the maximum attention to keep tension as low as possible).
Some machines feature special water blade devices (replacing spray nozzles) which convey a huge quantity of water, homogeneously and at high speed, on the whole width of the fabric, thus performing a really efficient wash. The system includes a pipe with a special nozzle releasing water jets similar to blades; these water blades perform a powerful action on the fabric and remove filaments, thickening agents, non-fixed dyestuff, etc. Many of these machines have modular structures, and therefore can be adapted to specific operating requirements.

Among all the possible solutions, manufacturers offer also counterflow washing systems where the fabric flows from the dirtiest section of the washing bath to the cleanest. Through a series of recycling processes it is possible to use the washing liquor many times.

**Drying:**

The frequency of processes, requiring impregnation of the textile substrate (washing, impregnation in dyeing or finishing liquor, desizing and so on), consequently leads to the need of subsequent drying processes, with a high impact on processing costs. Depending on their nature and structure, textile fibres absorb greater or lower quantities of water; the water absorbed by the textile material is partly retained between the fibres and in the pores of the fabric and partly more deeply in the fabric by the swollen fibres. The water between the fibres or on the fabric surface can be eliminated mechanically while the water in the swollen fibres can be eliminated with a drying processes.

**General remarks on drying techniques:**

The drying process aims at eliminating exceeding water and achieving the natural moisture content of the fibre. Excessive drying can negatively affect the final appearance and the hand of the textile. It is possible to adjust automatically the drying process by means of modern electric gauges. When choosing a drying technique, the cost efficiency of the drying system must be carefully evaluated: the cost-efficiency of a drying process includes many factors such as the quantity of steam, water and energy required to evaporate one kilogram of water as well as the evaporation capacity of a machine, expressed in kilograms of water evaporated in one operating hour.
Adjustment of the moisture content in the drying process:

The drying speed is determined by the difference between the tension of water steam on the textile surface and the tension of the water steam in the drying unit: it increases proportionally to the decrease of the moisture content in the air of the unit. In order to keep this content on low levels it is necessary to blow in the drying units huge quantities of heated air at the same temperature of the drying unit, which leads to huge energy consumption. When setting the desired moisture degree of the air in the drying unit, it is worth considering that the best degree results from a correct proportion between efficient output speed and cost-effective energy consumption.

Adjustment of the drying speed:

The optimum time a fabric spends within a drying unit must correspond exactly to the time necessary to eliminate the moisture on the surface and between the free spaces of the fibres; the stay time must not exceed the optimum drying time (this would cause an extra drying) since the "natural" moisture of the textile must not be eliminated. The feeding speed of the fabric is adjusted by means of the special devices assembled at the exit of the drying unit, which vary proportionally to the moisture of the fabric leaving the unit.

Heating of the drying unit:

The drying units are usually heated by means of steam with an average thermal efficiency of about 64%. Better thermal efficiency is granted by dryers heated with thermal fluid (about 80%). Highly efficient heating is obtained by means of direct gas combustion, with an efficiency of almost 95%. The operating temperature can be reached in very short times and heating can be stopped simultaneously with the machine.

Hydroextraction:

This process removes the water (the water quantity varies according to the type of fibre) dispersed in the fibres by mechanical action; this process aims at reducing energy consumption and is carried out before the final fabric drying or between the various wet processing stages (washing, dyeing). It can be carried out in the following ways:

- **Squeezing**: The water dispersed on the surface and in the spaces of the fabric is removed by means of the pressure applied by two cylinders.

- **Centrifugation**: This process eliminates the greatest quantity of water dispersed on the surface of the textile by centrifugal force. It is applied above all to resistant yarns, knitted goods and fabrics.

- **Steam pressure**: A high-speed steam jet blown on the whole width of the stretched fabric passes through the cloth and eliminates the water in excess. Extracted water and steam are condensed and reused.

- **Vacuum**: This method applies vacuum technology and is used to dry very wet fabrics or delicate fabrics that do not stand up to the pressure of the cylinders of a squeezing unit, which could negatively affect the surface structure. The stretched fabric slides open-width above the opening of a cylinder-shaped structure connected to a suction system. The air drawn from outside removes the exceeding water when passing through the textile cloth.
Drying systems:

The water dispersed in a textile material by chemical-physical process is generally eliminated by the action of hot air, which makes the water evaporate; during the drying process, it is very important to carefully consider the way heat is directed on the fabric. The drying process can be carried out:

- by heat convection
- by contact with heated metal surfaces
- by infrared radiation
- by means of microwaves or high-frequency waves
- by combustion

Yarns and textile materials in bulk are generally dried inside hot air compartments. For the drying of piece fabrics, manufacturers have designed different drying units, which apply different principles, briefly described here below.

Drying by heat convection:

The heat diffusion onto the wet fabric is carried out by means of hot air circulating inside the drying unit. There are two different types of dryers applying this operating principle: compartment dryers and tunnel dryers.

1. Compartment dryers:

**Suspended fabric dryer:** it is made up of hot air compartments where the folded fabric with a maximum width of 3 meters is suspended on a series of rotating cylinders leading the fabric toward the exit. The circulating air is blown slowly downward. This system is suitable for light and medium-weight fabrics that can withstand the stress of mechanical feeding.

**Short-loop dryer:** this system eliminates almost completely the tension applied by the fabric weight; it also avoids the risk of possible downward migration of dyestuff or finish.
**Hot-flue dryer:** the vertically folded fabric is guided through a hot air compartment. The feeding motion is determined by means of different sets of rollers, while special cylinders separate the fabric folds. The drying temperature ranges between 80 and 100° C. This drying system is suitable for printed fabrics, above all for light and medium-weight fabrics, as well as the intermediate drying after printing, after impregnation in general, and after the application of background dyes and other similar operations.

![Diagram of hot-flue dryer](image)

A hot-flue dryer

The use of belt or perforated-drum dryers is often extremely effective to cut costs and increase output rates in continuous drying processes on fabrics and yarns in various forms. Thanks to suction effect of the hot air drawn into the cylinder through the holes, the fabric perfectly adheres to the external side of the rotating cylinders, moving forward inside the drying unit where it is dried gradually.

2. **Tunnel dryers:**

Supporting nozzles dryers: the fabric is suspended on an air cushion generated by blowing nozzles arranged in proper layout.

Stenter: it is made up of modular elements (arranged lengthwise and heated by means of forced hot air circulation) where the fabric passes horizontally, supported by a belt, by supporting nozzles or by air cushion. When the hot air comes into contact with the fabric, it cools down and removes the evaporated moisture. The air is partly drained and replaced by an equal quantity of fresh air. The remaining air is recycled, added to with fresh air and passed again through the heating element.

![Diagram of stenter](image)

Air flows inside a stenter featuring a hot air convection drying system
This machine is extensively used in the fabric drying sector, but is also used for the heat setting and polymerisation of finishing or bonding agents in pigment printing processes; it includes an "entry" area for the fabric provided with a pad-batch, where finishes and finishing products are applied or where the fabric is simply squeezed. The use of a drum coated with porous material, which dehydrates the fabric before the drying step, proves particularly efficient.

The unit is equipped with a stretching system to keep the fabric stretched and also with a special device that controls the perpendicularity of the weft to the warp. All the drying systems are assembled in the second section; they include a feeding system equipped with a fabric guiding system and the drying unit. The endless chains, with clips or pins for fastening the fabric, are positioned all along the front part, the drying compartment and the exit section; they guide the fabric by the selvedge. At the exit the fabric is released automatically from the fastening devices and wound up.
In the latest generation of stenters, manufacturers have tried to improve the quality of the fabrics with more rational fabric feeding systems and innovative solutions for heat treatment and reproducibility of the various processing stages. Together with an increased output in continuous operating conditions, manufacturers also aim at improving the machine utilization, reducing maintenance to a minimum and cutting energy consumption.

Multi-level stenter used for coating processes and incorporated on an existing operating line

Multi-level stenter:

Thanks to an excellent ratio between capacity and overall size, the multi-level stenter is also particularly cost effective for treatments requiring a certain standby time, such as for example the heat setting of synthetic fibres, chemical treatment setting and carbonising.

Advantages of the multi-level stenter:

- Compact structure: thanks to the multi-level design, the overall space required for the installation of the stenter is smaller than the one required for a standard flat stenter with the same output rates.

- High-performance drying process: for heavy textiles the efficiency of the machine does not depend on the evaporation on the surface but on the time required for the drying process. Powerful ventilation, generally applied to flat stenters, could cause an excessive drying of the textile surface and damage the material, while fibres inside the fabric could remain wet. The internal moisture migrates very slowly to the surface.

- Delicate drying: in a multi-level stenter, the drying process does not affect the material negatively and eliminates the moisture in the best possible way. In fact, we know that a delicate treatment, e.g. in a drying or heat setting process, can be ensured only with a slow ventilation of the material. Furthermore a longer treatment time, even at lower temperatures, gives a better appearance to the finished material, compared to tougher treatment conditions. The result is a bulky fabric with a softer hand, which gives the sensation of more weight.

- Lower operating costs: thanks to reduced number of operators, smaller space required, slight reduction of the yield for heavy textiles and reduced consumption of energy with the same output rate of a flat stenter.
Longitudinal section of a multi-level stenter with internal exhaust channels

Limits of multi-level stenters:
- only a few multi-level stenter models can be equipped with pin chains.
- in the path between one level and the next one, the fabric must be sustained to avoid the formation of wrinkles and therefore deformation. Telescopic drums are used to convey the piece of cloth by moving forward the whole fabric width thus sustaining it from one selvedge to the opposite one; unfortunately with delicate textiles, such as raised velvets and very lustrous viscose fabrics, this system causes evident and unpleasant stripes and marks on the surface.

Contact drying:
Drum dryer: with this system, the fabric moves forward arranged on several heated drums. The drying temperature ranges between 120-130° C and the cylinders are heated by means of steam at a pressure of 1-3 atm. This very efficient and low-cost drying system is particularly suitable for flat fabrics, with slightly evidenced structure, which cannot be easily affected by tension during feeding. Used for intermediate drying and for light finishes; this system is not suitable for durable thermosetting resin finishes.
Dyeing (Colouration):

The dyeing process is aimed at giving woven or knitted fabric its intended colour, crucial to its ultimate use. The dyeing process can be carried out at different stages of fibre processing, i.e. in different forms: staple, yarn, fabric (rope or open-width), and piece. When the dyeing process is carried out during the first processing stages, for example on staple fibres, a better colour fastness can be achieved; bulk dyeing refers to the system used to dye a staple fibre before it is spun, this process is carried out in perforated baskets and although there may be areas where the dye does not penetrate completely, in subsequent spinning operations these areas are mixed with the thoroughly dyed fibre, thus ensuring an overall even colour.

Yarn dyeing is carried out after the fibre has been spun into yarn. Yarn dyeing is preferred for manufacturing Jacquard or striped fabrics; this dyeing method grants a good colour fastness since the dye penetrates the fibres and reaches the yarn core. Skeins are dyed in hanks, spools are dyed in autoclaves and warp yarns are dyed in perforated beams loaded in autoclaves.

Piece dyeing is carried out on several types of machines and the material can be open-width or rope dyed. A good dyeing strictly depends on different parameters and conditions that can be evaluated immediately (such as good consistency of the dye and repeatability) or which require specific fastness evaluation (manufacturing, use, dry or wet processing) that can be controlled only by means of subsequent laboratory tests.

The machines used are chosen according to the material to be processed. The crucial requisites are the following:
- protection of the substrate
- repetitiveness of the results
- cheapness of the process (depending on process time, machine automation degree, liquor ratio, cost of the products used and wastewater purification).

Textile materials are dyed in aqueous solutions or dispersions of dyestuffs, together with dyebath additives such as salt, alkali, acids and other auxiliary chemicals. The dissolved or dispersed dyestuff must first be absorbed on to the fibre surface and then diffuse into its interior where finally it must be fixed.
To carry out a dyeing process it is necessary to:

- Dissolve or disperse the dye in a water bath (with manual, semiautomatic and automatic colour kitchens according to specific preset rules).
- Feed the dye solution in the machine after suitable filtering (automatic colour kitchen, supplementary vats, pumps and filters).
- Transfer the dye from the liquor to the fibre (process and machine).
- Distribute the dye homogeneously on the fibre (process and machine).
- Let the dye penetrate in the fibre structure and fix it (time and temperature).
- Wash or rinse the material to remove the dye on the surface or the unfixed dyeing liquor.

There are two different methods to transfer the dye from the liquor to the fibre:

**Exhaust dyeing (discontinuous systems):**

The dye is dissolved or dispersed in the dyeing liquor. The material is immersed in the dyeing liquor and is removed only when the dye has mostly transferred onto the textile to be dyed, distributed homogeneously, well penetrated into the fibre and fixed. At the end of the process the material is washed or rinsed to remove the unfixed dye.

**Pad dyeing (continuous or semi-continuous systems):**

This process is carried out using mechanical means (pad-batch wetting). The dyeing liquor is distributed homogeneously onto the fabric (i.e. also the dye is distributed homogeneously). In a second stage the dye penetrates into the fabric and is then fixed. At the end of the process the material is washed.

Some operations must be carried out for both exhaust or pad dyeing:

- dissolve or disperse the dye in water and filter.
- achieve an homogeneous contact between the dyeing liquor and the fibre.
- make the dye penetrate into the fibre.
- fix the dye in the core of the fibre.
- final washing.

**Preparation and Dyeing Machinery:**

The choice of dyeing equipment depends on the type of fabric (woven, knitted, nonwoven), and the fibres it contains. Polyester fibres often have to be dyed at temperatures over 100°C and so machines, which can operate under pressure, must be used. The dyeing process may be continuous, discontinuous (batch) such as Winch, Jigger and Jet dyeing machine or semi-continuous.

There is a wide variety of machines used for finishing processes (pre-dyeing, dyeing and finishing treatments). As far as dyeing machines are concerned, the most important aspect to be considered is the consistency of the dye distribution (or of other chemicals) that the machine must ensure in the shortest possible time. Generally, the systems allowing a homogeneous distribution of the dye
also allow a good removal of dirt, and a uniform contact of bleaching reactants with the material; therefore what we say about dyeing, in most cases can be also applied to pre-dyeing and finishing treatments that require the application of chemicals.

**Classification of machinery:**
The machines used for preparation and dyeing processes can be classified as follows:

- **Classification according to the textiles to be processed:**
  The machines to be used are chosen according to the type of material to be processed.
  - Machines for dyeing staple or yarn (in skeins, packages or beams)
  - Machines for dyeing woven-knitted fabrics or rope knits (the width is not spread)
  - Machines per dyeing open-width fabrics (the fabric is opened and flattened)
  - Machines for dyeing made-up garments.

- **Classification according to the processing method:**
  The processing method to be applied depends on the quantity of materials to be processed and on the type of finishing process.
  - Discontinuous (batch) systems.
  - Semicontinuous systems.
  - Continuous systems.

- **Classification according to the operating principle:**
  The system to be used depends on the elements that make up the material (fibre and eventual weave), as well as on the type of treatment to be carried out.
  - Circulating liquor systems.
  - Systems moving the material.
  - Systems moving both the dyebath and the material.

- **Classification according to the process conditions:**
  The system to be used depends on the type of material (fibre form) and on the process to be carried out.
  - Systems that can work under pressure at high temperatures (HT autoclaves)
  - Open systems, or, systems that run at a max. temperature of 100°C.

Here below the reader will find a brief description of the (A) category; each system is described in detail hereinafter.

**Machines to process staple, sliver and yarn (General remarks):**
These machines are used for dyeing staple fibres (and also for carrying out other treatments such as bleaching, scouring or finishing) and more frequently for dyeing yarn fibres in different forms (packages, cheeses, etc). With the use of modular and interchangeable carriers it is possible to carry out loading and dyeing processes using packages of different diameters. These machines are equipped with automated systems, such as automatic loading and unloading racks positioned above
the machine, centrifugation and drying systems, to best satisfy the growing demand for system optimisation.

**Open-width dyeing machines** (General remarks):
These systems are used for dyeing open-width and well-flattened fabrics. These systems can be used also for carrying out pre-dyeing treatments (for example upgrading, bleaching, mercerising), dyeing treatments and wetting operations for both types of treatment. Among the systems used for open-width treatments it is worth pointing out mercerizing machines, jiggers, pad dyeing machines, beam dyeing machines, continuous washing systems, stenters.

**Rope dyeing machines** (General remarks):
These machines process the fabric fed and driven lengthwise to form a rope. The hydrodynamic effect is obtained by means of the motion of the fabric rope, or by means of the simultaneous rope-and-dye-bath motion, which ensures a homogeneous contact of the material with the dyeing liquor and a quick exchange of the dyeing liquor dispersed in the material. Machines running according to these operating principle are suitable for treating almost all the fabrics made up of extremely different fibres, woven or knitted fabrics, during preparation and dyeing stages, with only some problems occurring with loose-weave fabrics. During the treatments the fabrics run freely weft-wise and therefore can freely shrink and set thus eliminating almost all tensions. Suitable operating conditions and technical adjustments also reduce to the minimum warp-wise tensions, and continuously move the wrinkles of the rope.

An unquestionable benefit obtained with these machines is the extremely soft and fluffy hand, particularly suitable for fabrics to be used for garments. Possible problems are connected to the formation of permanent wrinkles on the fabric, or to uneven dyeing shades, always connected to the problem of the rope wrinkles; for fabrics made up with very delicate or short staple fibres, mechanical stresses can cause losing or extraction of the hair on the surface.

**Piece dyeing machines** (General remarks):
These are discontinuous processing systems; the most modern machines are equipped with rotating systems, which apply low liquor ratios; the material is packed in a perforated basket, which rotates at variable speed. Once the dyeing process has been completed, the system removes the liquor in excess from the fabric by centrifugation before unloading. These machines are equipped with automated systems to optimise the process.

**Autoclaves:**
These machines are used for dyeing staple and yarns in different forms (package, cheese, beam etc.).
These systems are essentially made up of:
- Vertical or horizontal autoclaves, made of stainless steel, where interchangeable carriers are replaced for dyeing different textiles at any stage of their development (baskets for staple dyeing, package carriers, cheese carriers, fabric beams, etc.)
- Circulating liquor pump (with flow reversal system)
- Expansion vat to balance the increase in liquor volume, where the necessary dyes and auxiliaries can be added without stopping the operating cycle.
- Static pressure pump (which can be introduced whatever the operating temperature)
- Sample heater
- Control board for partially or completely automated dyeing cycle.

All manufacturers can now supply these machines equipped with microprocessor or PLC programming system for controlling and setting all the operating functions (filling / exhaust / heating / cooling / stage / dosing etc.) of the whole production cycle and, in specific cases, for adjusting the pump flow according to preset parameters. Some autoclaves are also equipped with Air Pad pressurizing system, which offers the opportunity to reduce the liquor ratio and the energy consumption; when the machine is running only the carrier, the heat exchanger and the circulation pump are completely immersed in the liquor, while the free space is filled with compressed air.

Systems equipped with volume or air reducers are actually used to satisfy the increasing demand for machines where batches with different weights can be loaded and treated (thus keeping a steady nominal liquor ratio). Thanks to these systems, the machine can process from '1' to an 'infinite' quantity of packages for each shaft entailing considerable energy saving, cutting plant and production costs, as well as a considerable reduction of delivery times. In the past, the reduction of the loading capacity thanks to the air cushion could only be ensured with vertical autoclaves; now it can also be obtained with horizontal units.

**Vertical autoclave**

An autoclave model used only for packages includes many small horizontal heaters (basically coils) instead of a single heated vat; each small heater can be loaded with a single package carrier shaft.
This autoclave allows working with an extremely low liquor ratio. The material to be dyed must always be accurately arranged to avoid possible disproportion in the liquor forced under pressure through it, in both directions alternately, from the core to the outer surface and vice versa, according to programmable times (for example from 2 to 4 cycles per minute).

In all these autoclaves, the dyeing liquor is kept circulating by means of centrifugal or helical pumps: these pumps must keep the liquor circulating through the mass of fibre, so that the fibre surface is saturated with the dye. To do that, the liquor must overcome all the resistive forces generated by pipes and by the textile mass (pressure drop) and reverse the direction of the liquor circulation at different times to obtain an overall even colour; in specific cases, the speed of the pump impeller can be set by means of inverters (frequency inverters) which adjust the flow of the liquor through the fibre mass.
These machines, built and tested according to the European PED standards, can operate at a maximum operating pressure of 5-6 bar, and are statically pressurized by means of a pump or of a compressed air cushion; they are suitable for treating synthetic fibres up to an operating temperature of 145°C, avoiding load-carrying drops due to cavitation of the liquor circulation pump. The average liquor ratio is approximately 1-10.

Automated dyeing cycles grant excellent quality and reproducibility of results. Some autoclaves also integrate dyeing, centrifugation and drying systems. These machines, used for dyeing various types of fabrics or blends can also be employed for scouring and bleaching tasks. We describe below several carriers made of two overlapping levels, which can be separated for easier loading and unloading. In fact these machines, besides packages, cheeses, tops, etc, which can be loaded in single-level machines or in machines equipped with horizontal heating vat, can be loaded with fabric beams; they also allows cutting the loading capacity in two (see drawings of the different carriers) thus increasing the operating flexibility.

With reference to the drawings above, we only need to add some detailed information about package yarn dyeing. This dyeing system is more popular than staple and hank dyeing (cheeses are no longer used) since it is more cost efficient and environment friendly. The diameter, and therefore the weight, of each single package greatly varies according to the type of fibre, to the count, to the final use and to the different classes of the dyestuffs used. Packages can be prepared by winding the yarn on perforated taper or cylindrical tubes of different height and diameter; the weight can range between 700 grams for very fine cotton yarns for shirts and knitted goods to 3.5-4 kilograms for large polyester packages.

![Different types of two-level overlapping carriers](image)

The dyeing sector has recently undergone a very incisive improvement in automation and robot control. Particularly, the handling of the packages is reduced to a minimum; simple and reliable robots load and unload the package carriers and carry out the subsequent dehydrating step by means of automatic hydroextractors and drying by means of fast dryers with forced air circulation or high-frequency heated tunnels (see chapter on drying).
Hanks:

Hanks are used for the dyeing of skeins; a hank is made up of a parallelepiped-shape vat divided into compartments by perpendicular partitions. The skeins are arranged on special carriers, which can be locked in special grooves inside the machine; the liquor circulates in both directions (up-and-down flow) and the yarn mass makes only a moderate resistance since it not very tightly packed. The machine operates with reduced liquor ratios and the liquor itself is kept circulating by means of major flow axial pumps (suitable for delicate yarns), assembled in the front part of the machine.

![Diagram of hank dyeing system](image)

1 central wall; 2 perforated separators; 3 perforated supports; 4 skeins; 5 circulation pump; 6 expansion vat; 7 auxiliary pump; 8 serpentine.

A hank dyeing system

The liquor flow inversion is obtained by reversing the rotation direction of the motor; the liquor is generally heated by means of serpentine assembles inside the machine or by means of heat exchangers. The hank can also run under pressure at a maximum temperature of 110° C and at pressures of 0.5 kg/cm2. If the pressurisation is obtained by means of an air cushion, it is possible to avoid the external circulation of the liquor in a lateral extension vat. As a result, the liquor can be maintained at a constant temperature, reducing energy, steam and cooling water consumption. The only negative aspect is the need to unload and load the machine each time it is used. Hanks can also be used for washing and bleaching treatments.

Winch Dyeing Machine:

This is a rather old dyeing machine for fabrics in rope form with stationary liquor and moving material. The machine operates at a maximum temperature of 95 – 98°C for open bath winch but for closed winch, the machine operates at a maximum temperature of 130° – 160° C. The liquor ratio is generally quite high (1:20 – 1:40) for open bath winch but for closed or high temperature winch the liquor ratio is 1:8 to 1:10.

The system includes a vat with a front slant side acting as chute for the folded rope, while the rear side is entirely vertical. A perforated separating compartment, positioned at a distance of 15 - 30 cm from its vertical side, creates an interspace for heating and for adding reagents. Heating can be
supplied by means of direct or indirect steam heating. The fabric motion is driven by a circular elliptic winch coated with a special blanket to avoid the fabric slipping during the dyeing operation with subsequent possible fabric scratches.

The rope to be dyed then passes through a rack on the vertical perforated divider, which ensures the separation of the various folds of the rope and avoids possible entangling; the rope is then transferred onto a cylinder, which guides the fabric during the lifting from the vat carrying out a partial squeezing with subsequent liquor exchange. The rope (carried by the winch) folds while passing through the liquor. Obviously when the fabric is loaded into the machine it is necessary to sew the tail with the head of the rope (the fabric must be sewn according to the grain line or direction).

The maximum motion speed of the fabric must be approximately 40 m/min., since higher speeds could cause peeling; an excessive stretch during the lifting stage could cause deformation while high circulation speed could cause excessive rope beating with subsequent entanglement. The fabric must not remain folded and kept stationary inside the vat for more than two minutes to avoid possible defects or wrinkles; therefore the rope must be relatively short.

The winch dyeing method is suitable for all fabrics (especially for knit and lightweight woven fabrics), except those which tend to originate permanent creases or which could easily distort under the winch stretching action (due to their fibre or structure composition).
This machine is used preferably for pre-dyeing treatments (scouring, washing, bleaching) since the high liquor ratio ensures excellent results; when used for dyeing treatments this system requires high energy consumption, extensive use of auxiliaries, dyes and water, which leads to high operating costs; furthermore, an inaccurate temperature control (the liquor does not move and the heating system is assembled only on one end) and the limited freedom of the rope folds could negatively affect the dyeing results.

This is one of the oldest systems used for finishing treatments, but it proves to be still extremely functional thanks to its flexibility, above all for scouring and bleaching treatments to be carried out on small production runs. This system can also be used for carrying out continuous washing processes; the fabric is loaded from one side, driven through the machine with a spiral motion (by means of the rack) and then unloaded from the opposite side.

**Jiggers:**

These machines have been used for a long time to treat medium-size lots of woven with an open-width exhaust dyeing process. The fabric moves while the liquor stands still, except for the very latest machines, which are also equipped with a circulation pump.

The fabric pieces are sewn together tail-to-head, forming a sort of ribbon.. At the head and at the tail of the ribbon two cloths are added (4.5 m long) to allow the regular dyeing of the whole pieces, also leaving the machine drawn-in once the dyeing process has come to an end. The assembled pieces are taken down from a roll, pass through the liquor (they are kept in the correct position by means of transport cylinders and a tension equaliser, which avoids the formation of wrinkles). The fabric is then wound on a takeup roll until the dyeing process has ended.

The piece through speed and tensions are adjusted by special devices to avoid any change in dimensional stability, above all when treating lightweight fabrics and/or delicate fibres. The maximum diameter of the roller can be 1,450 mm with a width of the piece of cloth ranging between 1,400 and 3,600 mm. The piece through speed is adjusted between 30 and 150 m/min. and kept constant during the whole operation. Also the tension must be constant and it can be adjusted between 0 and 60 kg. Since the passage time is very short, dyeing occurs above all on the fabric wound on the rolls.
The composition of the liquor absorbed must be as uniform as possible on the whole width and length of the fabric piece; for big lots, many additions may be necessary to avoid the so-called head-tail defects. Lightweight fabrics (viscose, nylon) that are stretched excessively during the takeup step can show shading defects. Jiggers work with a quite low liquor ratio (from 1:1 to 1:6). Together with standard atmospheric systems, builders also offer HT jiggers inside autoclaves working at high pressure. Jiggers are suitable for dyeing all type of fibres.

Dyestuffs:

The desire to colour textiles is an old as spinning and weaving. Natural colouring materials have been used for thousands of years; mineral pigments such as yellow and red ochre, cinnabar; vegetable dyes such as indigo, litmus, logwood, madder, saffron; animal dyes such as cochineal, Tyrian purple. Synthetic dyes were first produced in the 19th century and have now almost completely replaced the natural colours. Environmental and product safety aspects are currently very important.

With the exception of pigment/binder systems the type of dyestuff has to be chosen to suit the fibre substrate, because the formation of a physical or chemical bond between dye and fibre depends on the chemical and physical structures of both dye and fibre. A broad spectrum of colours is available in countless shades and a wide range of fastness for the different fibre types and blends.

Colour Fastness:

Colour fastness means the resistance of the colour to various insults which textiles may suffer during manufacture and use. Fastness depends on the type of dyestuff and the fibre substrate; there is no universal colour with the same fastness on all substrates. Moreover, different end uses have different fastness requirements; underwear has different requirements from furnishings. There are standardized methods (ISO 105) of evaluating the different types of fastness. The most important are:

Rubbing fastness: Resistance of the colour to rubbing, either wet or dry. Even the best dyeings, in a very deep shade, may lose some colour in wet rubbing.
Washing fastness: The fastness to washing determines the wash program, which must be used by the consumer. Nowadays, fastness to a strong wash at 60°C is expected.

Perspiration fastness: Resistance to the effects of perspiration is important for underwear, outerwear, and sportswear.

Colours may also be required to be fast to light, weather, sea water, solvents, ironing, etc.

Different types of Dyestuffs in relation to the fibre substrate:

- **Reactive Dye**: Applicable for cotton, linen, viscose, wool, silk. The dyestuff forms a chemical link with the fibre. It has very good fastness properties.
- **Disperse Dye**: Applicable for polyester, nylon, acetate. It is water insoluble; applied from dispersions; diffuse into the fibre at high temperature. It has also good fastness properties.
- **Vat Dye**: Applicable for cotton, linen, viscose. The insoluble dyestuff is made soluble in a reducing vat so that it can diffuse into the fibre. After diffusion is complete, it is then re-oxidised into its insoluble form. It has high fastness to washing, chlorine, boiling, light, weather, rubbing and perspiration.
- **Direct Dye**: Applicable for cotton, linen, viscose, silk. Simple diffusion into the fibre, from aqueous solution. It has relatively poor fastness properties to light, washing and perspiration. These fastness properties can be improved by aftertreatment.
- **Basic Dye**: It is suitable for acrylic fibres (other fibres by mordanting). It reacts with acidic groups, or mordants(a chemical which can react or complex with a chromophore to form an insoluble colour) in the fibre. It has good fastness properties on acrylic fibres.
- **Acid Dye**: Applicable for wool, silk, nylon. Applied from an acidic dyebath. The fastness properties of this dye-stuff depends on the fibre type.

There are also some other dyestuffs such as sulphur, azoic, metal complex, chrome dyes etc.

Printing:

Printing can be described as the controlled placing of defined areas of colour on to a substrate. The colourant must first be brought to the fibre surface usually in the form of a printing paste. If it is a soluble dyestuff, it must be diffused into the fibres. The colourant must then be fixed in place and finally, excess unfixed colour has to be washed out.

Printing could be referred to as a sort of selective dyeing that makes an important contribution to fabric decoration thanks to the combination of colours and dyeing methods. To obtain sharply defined, precise and reproducible patterns, the dyebaths traditionally used are not sufficient, because of the capillarity and/or hygroscopicity of fibres and migration of dyes that cannot grant sharp and well-defined colour patterns. It is therefore necessary to use special liquids, conventionally called "printing pastes", whose main characteristic is a high degree of viscosity
(improperly called density); in other words these printing pastes colours are fluids which oppose a
high resistance or friction to sliding or motion.

As a consequence, the dyestuff applied on the fabric in well-defined areas to reproduce the desired
pattern cannot migrate to other areas of the fabric. It is also worth considering that the high
viscosity of printing pastes will make the dye adhere to the surface of the fabric and the fibres, but
not penetrate into and fix on them. These operations (which may be referred to as diffusion and
fixation during the dyeing process) will be carried out afterward with a steaming process.

The application of the print dye on the fabric is carried out by forcing it through the gray fabric on
special printing blocks or perforated hollow rollers applied onto the fabric; the dye is then generally
fixed by means of a steaming process.

In other words, printing is a form of localized dyeing. Printing processes or techniques and printing
principles or styles can be distinguished. Printing processes include techniques such as roller
printing, screen printing. Printing principles include direct printing, discharge printing, resist
printing, flock printing, etc. Several of these processes and principles will be dealt with in the
followings.

**Printing Principles:**

Regardless of the printing process, there are several basic printing principles:

**Direct Printing or Overprinting:**

The printing paste is applied directly to the prepared fabric surface. Overprinting indicates that a
plain dyed fabric is printed with a pattern in a darker colour. This method involves the following
steps: printing, drying, steaming and washing.

This type of printing is generally used for white or dyed cloths (usually dyed in pastel shades), by
applying the sequence of all the colours, until the original pattern has been reproduced. This is the
most common printing method and can be used with all the main colour classes of dyes and on
fabrics produced with any kind of fibre (some problems may only arise with blends).

The technical limits of this printing method appear with endless design patterns (particularly those
obtained with screen printing methods, while no problems occur for roller printing). Some problems
may also arise when printing on backgrounds dyed with pastel shades: in fact, this could create
problems on several areas of the design to be printed in light shades, thus limiting the number of
reproducible pattern variants.

**Discharge printing:**

Basic steps are printing, drying, steaming and washing. This technique is used on dyed fabrics
{usually in dark shades). The fabric is dyed in the piece and then overprinted with a discharge paste
(chemical) that destroys or decolourises or changes the colour indesigned areas. A white discharge
is when the original white is restored to the printed area. A colour discharge is when a separate colour is applied at the same time as the discharge paste. Sometimes the base colour is removed and another colour is printed in its place; but usually a white area is desirable to brighten the overall design.

This printing method is generally used to obtain designs with tiny details, sharp and well-defined edges on coloured backgrounds, patterns with low coverage ratio on coloured backgrounds, and to avoid pattern matching problems on endless design patterns with coloured backgrounds. The results obtained with this printing method could be hardly reproducible with direct printing since it would be very difficult to obtain wide backgrounds, smooth and well penetrated, with sharp edges without seam defects.

A problem for this printing method is represented by the need to choose perfectly destroyable dyes for backgrounds, which cannot be affected by the discharging agent used as brightener. The selection restricts the number of applicable dyes and above all, for some colour classes, very few dyes grant a good fastness to light and moisture, but excellent colour effects. With this type of printing carried out on black or navy blue backgrounds it is also impossible to check if the various colours are correctly positioned; any mistake will be visible only after the steaming process and at that point it would be impossible to correct it. This problem could be limited by testing the printing result on a white cloth before beginning the printing process.

Resist Printing:

With the old method of physical resist printing, (hydrophobic) products or printing pastes were applied to the fabric to avoid contact and penetration when the fabric was subsequently immersed in the dyeing liquor (Batik). Now the most diffused printing system is the chemical resist printing carried out with different printing methods, using pastes containing chemicals, which avoid fixation of background dyes (particularly for reactive on reacts applied on fabrics made of cellulose fibres). Some of the printing methods are detailed in the following:

a) Resist printing on covered background: a pad dye is applied and dried; the printing is carried out with printing pastes containing products avoiding the fixing of background colour (but they do not avoid the fixing of any brightener used). The fabric is then dried, steamed and washed (this is the most diffused resist printing method).

b) Resist printing by over dyeing: the operations of the resist printing method previously detailed are carried out in inverse sequence; therefore the fabric is first printed and then covered.

c) Resist printing by over dyeing: this method is similar to the previous one, but the covering operation is replaced with the roller printing of the background.

d) Printing on polyester: polyester printing must be carried out applying the resist-discharge printing method. Printing pastes containing both the discharge and resist products applied on covered background must be used.
Transfer Printing:

The pattern is first printed onto a special type of paper with certain types of dyestuffs. These papers are prepared by specialist suppliers. The pattern is simply transferred to the fabric with the aid of a heated calender. The temperature is high enough to cause the dyestuffs to pass into the vapour phase (sublime). Since it is held in close proximity to the paper, under pressure, some of the dye vapour finds its way onto the fabric and diffuses into the fibres. The process represents about 6% of print production and finds its most direct and simple application on synthetic fibre textiles. Special techniques, papers, and fabric preparations have been developed for natural fibres and blends.

With this efficient method disperse dyes, previously printed on special continuous paper on the fabric, are transferred on the fabric by means of rollers with engraved frames. The design is transferred by contact between the paper and the fabric, which is then passed through heated rollers at a temperature of 190-210°C. With this method, disperse dyes sublime (i.e. change directly from the solid to the gaseous state without passing through the liquid phase) melt, penetrate the fibres and bind by heat and pressure onto the fabric surface in a few hundredths of a second.

Beside these basic principles, there are several types of printing technologies:

Flock Printing:

The fabric is printed with adhesive and cut fibre snippets are applied, which stick where the adhesive is present. A velvet-like appearance to the print can be obtained by electrostatic flocking, in which the fibre snippets are caused to stand upright in an electrostatic field as they are being applied.

Pigment printing:

Pigments are colours which do not dissolve and penetrate into the fibres. They have to be applied together with a film-forming binder. More than 50% of all printing colours are pigment types. Pigment printing represents an alternative to direct printing. With pigment printing there is no need to carry out a steaming process, as steaming is replaced by polymerisation (generally carried out simultaneously with drying).

This type of printing process is very simple, low-cost and can be carried out easily on all types of fabrics, particularly on blends, since pigments can adhere to all fibres; there is no need to use dyes of different colour classes. On the other hand, the adhesives, which bind the pigments to the fabric, can give serious problems when the fabric hand varies. For prints with a low coverage ratio, the hand variation can be acceptable but it is not acceptable when the coverage ratio is high, or at least for all uses. Furthermore, the pigment lies on the surface and has low fastness to friction (this depends mainly upon the type and quantity of binding agent and upon the polymerization degree). Some valid alternatives to this type of printing can give special effects such as printing with swelling agents (generally synthetic polyurethane-base pastes are used), with covering pigments and glitter (metal powders or particles of plastic materials) etc.
**Printing Processes:**

**Hand Printing or Block printing:**

This is the oldest method of printing but it is seldom used nowadays in the industry. The printing paste is applied by means of a wooden block which carries the design in relief, or by a stencil.

**Roller Printing:**

Roller printing is also referred to as intaglio or machine printing. The technique dates from the end of the 18th century (Scotland: James Bell) and has resulted in the disappearance of hand printing, which is a time-consuming printing technique. The technique of roller printing is especially used for very large batches but faces great competition from rotary screen printing.

The oldest mechanized method for continuous printing represents only about 16% of print production today, and is declining. Roller printing is capable of producing very sharp outlines to the printed pattern which is especially important for small figures. The maximum design repeat is the circumference of the engraved roller.

![Diagram of roller printing process](image)

The design is engraved onto copper rollers, a separate roller for each colour. The rollers are mounted against the large main cylinder, around which the fabric travels together with a resilient blanket and a protective back grey. The printing paste is located in a trough. A transfer roller runs partly immersed in the paste and in contact with the engraved roller. A doctor blade, scrapses away all of the paste except for that contained in the engraving. A cleaning blade on the other side scrapes away any lint picked up from the fabric. The pressure of the engraved roller against the fabric causes the design to be transferred. Any excess paste which is squeezed through the fabric, is taken up by the back grey. This protects the blanket and prevents the design from being smeared.

**Advantages and disadvantages of roller printing:**

Roller printing is especially suited for printing large batches. Speeds can amount to approximately 100 metres per minute. Moreover, roller printing can be used for very fine printing.
For small batches, however, the changing times between printing of the various batches are so considerable in the complete production process, that the efficiency (cost effectiveness) in machine utilization can drop to 50%. The changing time is necessary for adjusting and preparing the machines for a new series.

Another disadvantage is the crush effect. Applying several colours in one drawing is achieved by using several printing rollers. Each printing roller applies one colour. During the printing process, each colour will be “crushed” by the following rollers as many times as there are colours left to be applied. Consequently, the colour will be pushed more and more through the fabric to be printed. Deep colours are hard to obtain, which benefits screen printing. There may be a reduction in colour strength of up to 50%.

In roller printing, it is essential to apply the light colours before the darker ones because traces of the preceding colour can be carried forward into the following colour. Engraving the printing rollers is an expensive operation which raises the price of the roller printing technique considerably.

**Screen Printing:**

Screen printing is comparable to stenciling. A distinction is made between flat screen printing and rotary screen printing. In flat screen printing, rectangular frames (screens) are used with a thin gauze fixed to them. Rotary screen printing is done with cylindrical screens. The cylindrical screens contain the colour paste and rotate over the fabric to be printed. The dye is forced through the cylindrical screen which is perforated according to a particular design onto the fabric underneath.

Screen printing is becoming increasingly important. The designs are fairly simple to apply and the dimensions of the screens can easily be changed. The pressure which is exerted is also lower than with roller printing. Textured surfaces are not crushed and colour development is also better.

The screen properties are very important here. Stable screens are necessary. The frames used for flat screen printing are made of wood, or preferably of metal. The use of strong nylon or polyester gauze threads (hydrophobic materials) guarantees a tightly stretched mesh which will not bend under loading (with the colour paste). The paste is pushed through the screen by means of squeegees onto the fabric according to a certain design. The development of fully automatic printing machines for flat and rotary screen printing in the middle of the twentieth century has been an important step. It has contributed to rotary screen printing becoming the most important printing technique (> 60%).

**Flat Screen Printing:**

There are three types of flat screen printing, such as hand screen printing, semi-automatic flat screen printing and fully-automatic flat screen printing.

Hand screen printing is to be considered a craft rather than a productive working method. The fabric is fixed to a blanket or back grey on a printing table where the screens are put on. Normally,
another screen is needed for each colour of the eventual drawing. The print paste is spread across the screen by hand with a (rubber) squeegee blade forcing the paste through the screen. The manual method may cause irregularities.

In semi-automatic flat screen printing the squeegee is moved across the screen mechanically. It is impossible to reach a considerable speed of working with this method.

In both hand and semi-automatic screen printing, the various colours are applied one after another with intervals for drying (wet-on-dry method). Application with shorter intervals is known as the wet-on-wet method.

![Diagram of screen printing process](image)

Fully-automatic flat screen printing: Increasing the printing speed can be done by applying (printing) all colours on the fabric simultaneously which leads to a continuous process instead of a batchwise one. In that case the fabric to be printed moves over a distance equal to the width of the repeat (intermittent movement) between each printing operation. The repeat is that part of a design or pattern which is repeated on equal distances in length and width. The design or pattern is the whole set of figures which are printed on the material. The material to be printed is gummed to an (endless) printing blanket or conveyer. This blanket can be easily stuck to and removed from the textile to be printed. It is then washed and dried during one working period (so-called Buser system). Adhesives can be applied and removed in each cycle, or can remain on the blanket and be active permanently (thermoplastic layer). Some products in the paste, however, may (gradually) affect the adhesive layer.

The use of flat screens requires squeegees that can spread the paste, usually across the width of the screen. The two most popular squeegee systems are:

- The double-blade squeegee,
- Magnetic rod squeegee

A blade squeegee has two rubber or metal tongues and pivots around an axis. It is always the rear squeegee which is in contact with the screen. The rod squeegee is driven intermittently under the blanket by an electromagnet.
Rotary Screen Printing:

Fully-automatic flat screen printing is not continuous yet. Rotary screen printing on the other hand is continuous. Rotating cylindrical screens are used which are automatically fed (by means of pumps) with paste from inside. Driving the screens can be done at either side. During printing, the paste is pressed through the surface (nickel: ± 0.1 mm thick) via openings in order to obtain the desired design. The cylindrical screens allow more screens to be arranged per unit length than is the case with flat screen printing. Speed range from 30 to 50 metres/min. The standard internal circumference of cylindrical screens is 640 – 640.1 mm. However, other dimensions are also possible.

Functional Finishing:

The chemical structure of natural, artificial or synthetic fibres determines some of the properties that are naturally present also in finished products. Some fibres (such as linen, hemp, silk, nylon, polyester) are stronger than others (wool, viscose, acrylic) according to more or less controlled distribution of macromolecules in the polymer mass, structure stiffness and any possible inter and molecular interaction between the chains; other fibres tend to distort when stretched (cotton, viscose), and others recover their original shape after being distorted (wool); some others easily burn (cellulose), burn slowly and self-extinguish (wool, silk) or burn and melt (synthetic fibres). The above mentioned characteristics and many others make up positive and negative properties of a textile material, which must be accurately considered in view of their final application. The textile product final application will be considered from many points of view: wearability, hand, mechanical resistance, wettability, washability, deformability, fire-proof ability and many others.

The word "textile finishing" defines a series of processing operations applied to gray fabrics to enhance their appearance and hand, properties and possible applications. The term "finishing" includes all the treatments applied to gray fabrics such as scouring, bleaching, dyeing or printing while we will use the term ‘functional finishing’ with reference to all the mechanical orchemical finishing operations carried out on fabrics already bleached, dyed or printed to furtherenhance their properties and possibly add some new ones. The terms ‘finishing’ and ‘functional finishing’ are therefore similar and both play a fundamental role for the commercial excellency of the results of textiles, strictly depending on market requirements that are becoming increasingly stringent and
unpredictable and permit very short response times. Depending upon the type of textile substrate to be treated (staple, yarn or fabric) functional finishing processes are carried out using different means:

**Mechanical means**: involving the application of physical principles such as friction, temperature, pressure, tension and many others.

**Chemical substances** involving the application of synthesis or natural chemical products, which bind to the fibres more or less permanently.

**Combined mechanical and chemical means** involving the application of both chemical and mechanical processes.

The main purposes of functional finishing processes are the following:
- Develop the "product finishing" in all its fundamental elements such as hand and appearance;
- Give the finished fabric some properties that grant an optimum behaviour during the makingup and all through the life of the textile.

The parameters influencing the choice of the most suitable finishing process are the following:
- Fibre nature or fabric to be subjected to functional finishing treatments
- Final application of the fabric to be subjected to functional finishing treatments

**Mechanical Finishing Treatments:**

Mechanical finishing processes can be referred to as those processes generally carried out on open-width dry fabrics, with or without heat application, which give the fabric good dimensional stability (shrink proof and shape retention) and modify the "hand" of the textile product by altering its structure (at least its surface structure).

**Dry finishing:**

**Calendering:** a lustrous, dense and compact appearance can be obtained by means of friction, pressure and heat.

**Ciréing:** this calendering operation is carried out using special calenders and exploiting the combined actions of heat, friction and polishing agents.

**Embossing:** this particular type of calendering process allows engraving a simple pattern on the fabric.

**Sueding:** thanks to this process, the fabric has a much softer hand and an improved insulating effect thanks to the fibre end pulled out of the fabric surface. This process is carried out by means of a roller coated with abrasive material.
Raising: the fibre end pulled out to the fabric surface imparts an insulating effect. This process is carried out by means of hook-needles running in different directions on the fabric.

Shearing: the fibre ends on the fabric surface are cut by using special cutting tools.

Singeing: the fibre ends pulled out to the fabric surface are burnt by means of a flame (see preliminary treatments).

Wet finishing:

Wet calendering: this process is quite similar to the dry one. The only difference is the use of steam.

Fulling: the structure, bulk and shrinkage of wool are modified by applying heat combined with friction and compression.

Sanforising: the fabric is given an optimum dimensional stability by applying mechanic forces and water vapour.

Decating: the lustrous appearance of the textile material is eliminated, the surface is smoothed and the fabric is given an optimum dimensional stability thanks to the action of dry or overheated saturated vapour.

Calendering:

This non-permanent mechanical finishing treatment is applied to fabrics made of cellulose, protein and synthetic fibres, by means of a calender. This machine generally includes one or a series of couples of rollers pressed one against the other with adjustable pressure and identical or similar tip speeds. The cloth passes through one or more couples of rollers, which exert a smoothing and a pressing action. Some rollers are stiff while some others are made of softer material. Stiff rollers are generally made of steel or hardened cast iron and the surface can be chrome-plated, nickel-plated or made of stainless steel and can be subjected to treatments that give:

- a matt appearance similar to the abrasive blasting;
- a cross-stripe engraving to improve the fabric resistance to sliding;
- a very thin diagonal stripe patterning with silk-sheen appearance;
- a patterned engraving with embossed effects.

The fabric passing through the rollers of the calender is subjected to a very uniform pressure all along its width; if the rollers rotate at a different speed, a vigorous friction effect is generated. Steel rollers may be equipped in such a way to be heated from the inside by means of steam, circulating fluids or electrical power. They are supported by a vertical central frame made of steel, having the same size of rigid rollers, while the surface is coated with softer material like cotton (to stand high temperatures), wool paper (to enhance the glaze finish), or jute, wool or plastic material such as...
polyamide. The rollers coated with paper/wool, containing 45-50% of wool, feature good elasticity and excellent resistance to wear and are suitable for a wide variety of applications; they can also be used in embossing calendering units. Rollers made of paper/cotton, are used almost in friction calendars and for treating hard fibres, thanks to their high resistance capacity. Cotton rollers, featuring higher elasticity than the paper ones, are mainly used for cotton and blends finishing and for a final full hand effect.

Calendering Machine

The life of cotton-polyester or polyamide rollers is considerably longer; in fact they are very resistant and cannot be easily etched by the passage of creases, knots or sewing. Thanks to their improved hardness, they produce on the fabric a particularly lustrous appearance and allow higher operating speeds. The effects on the cloth can be set permanently by using thermoplastic fibres or by applying suitable (thermosetting resin or reactive-based substances) finishing products.

The use of different types of calenders gives different effects such as:

Sheen appearance: it can be obtained by smoothing the cloth surface, which ensures a better reflection of light.
Better coverage: it is due to the compression of the cloth, which generates a flattening of each single yarn.
Softer hand: it is obtained thanks to a slight ironing effect, which produces a smoother, and softer cloth surface.
Surface patterns: they can be obtained by means of special effects ("embossing" for example) for decorative purposes or to modify the surface smoothness.
Yarn swelling and rounding effect: they give a modest glaze finishing to the fabric, a surface smoothness and above all a full and soft hand.
**Embossing:**

Embossing is a particular calendering process through which a simple pattern can be engraved on the cloth. The embossing machine is made up of a heated and embossed roller made of steel, which is pressed against another roller coated with paper or cotton, its circumference being exactly a whole multiple of the metal roller. A gear system drives the harmonised motion of the rollers, preventing them from sliding and granting a sharp engraving of the patterned design. After being engraved, the pattern can be stabilised by means of an appropriate high-temperature treatment or by applying suitable starchy substances.

The process can be applied of fabrics made of all types of fibres with the exception of wool. This finish is permanent when applied to fabrics made of thermoplastic fibres. It is not permanent when applied to untreated fabrics made of natural fibres or manmade fibres that are not thermoplastic; however, if these fabrics are treated with certain chemical resins, the embossing is considered to be permanent. To preserve the embossed finish of such fabrics, they should be washed in lukewarm water with a mild soap, never be bleached, and be ironed on the wrong side while damp.

**Sueding:**

This operation is often carried out before the raising process to reduce the friction between the fibres making up the cloth and consequently to facilitate the extraction of the fibre end. The sueding process is carried out on both sides of the fabric and modifies the appearance and the final hand of the cloth; when touched it gives a soft and smooth sensation similar to the one given by a peach-grain surface.

The sueding machine is made up of some rotating rollers coated with abrasive paper, which emerise the cloth and produce a more or less marked effect depending upon the pressure exerted on the fabric by the abrasive rollers. The abrasive paper used can vary according to the desired sueding degree and must be replaced after a given number of operating hours, or when it does not properly carry out suitably the sueding function. In some cases, it is possible to use also metal rollers with the surface coated with uneven and rough grains or pumice rollers performing an excellent sueding action on both dry or wet fabrics. For a very superficial sueding, the natural abrasive power of pumice can be applied with successful results.

Gray fabrics as well as dyed ones can be subjected to the sueding process; the cloth to be emerised must be completely free from any finishing resin or adhesive substance remaining on the fabric surface after desizing. The sueding process reduces mechanic and dynamometric resistance of the fabric, thus making it more subject to tearing and seaming.

The fabric can run at different speeds inside the sueding unit; a smooth pressure is kept thanks to two balancing arms assembled at the entry and at the exit of the unit. The pieces of cloth must be sewn with abrasion-resistant material such as polyester or nylon. The gears must be suitably cleaned with compressed air jets since the presence of pile residues could clog the ball bearings or drop again on the fabric surface thus creating some problems with dyeing machines filters. The
sueding process, which can affect the fabric with a very wide range of effects, can give some problem when applied to knitted tubular goods but it’s widely used on woven fabrics with different weights and weaves (its application ranges from coarse jeans cloth to light and delicate silk or microfibre, coated fabrics and imitation leather).

The sueding unit is equipped with 6 rollers performing the sueding action on the face of the fabric and 1 roller performing its action of the back of the fabric; an advantage of this system is the possibility to use sueding cloths with different grains on each single roller. Thanks to three dandy rollers, the sueding action can be automatically adjusted during the fabric processing thus allowing the sueding process to be carried out also on knitted goods.

The 24-roller sueding unit assembled on 2 rotating drums features some advantages if compared to traditional machines equipped with 4-6-8 rollers: the combined action of several rotating rollers and the beating effect grant a smooth sueding, and a much softer hand than any other machine; no differences are generated between the centre and the selvedge; no stripes are formed on the fabric; the wide contact surface allows very high operating rates. The great number of moving rollers performs a gentle action on each single sueding roller thus granting the maximum sueding smoothness. Furthermore the life of the abrasive cloth is much longer than the one assembled on conventional machines. In fact, 100,000-150,000 meters of synthetic fabric and up to 200,000-250,000 meters of 100% cotton fabric can be processed in standard processing conditions before replacing the abrasive; sueding units can also be transformed into raising (napping) units by assembling a special conversion kit. All sueding machines are equipped with a brushing unit assembled at the exit to reduce the powder resulting from the sueding process.

**Raising or Brushing:**

The raising process is a very old technique known also to Romans (as pictured in some paintings found in Pompeii). This operation is particularly suitable for wool and cotton fabrics; it gives a fuzzy surface by abrading the cloth and pulling the fibre end to the surface. During those last years this process has also been applied on polyester/viscose blends and acrylic fabrics.
By means of this process a hairy surface can be given to both face and back of the cloth providing several modifications of the fabric appearance, softer and fuller hand and bulk increase. This enhances the resistance of the textile material to atmospheric agents, by improving thermal insulation and warmth provided by the insulating air cells in the nap. The fuzzy surface is created by pulling the fibre end out of the yarns by means of metal needles provided with hooks shelled into the rollers that scrape the fabric surface. The ends of the needles protruding from the rollers are 45°-hooks; their thickness and length can vary and they are fitted in a special rubber belt spiral-wound on the raising rollers. These rollers are generally alternated with a roller with hooks directed toward the fabric feed direction (pile roller), and a roller with the hooks fitted in the opposite direction (counterpile roller).

The machine also includes some rotating brushes, which suction-clean the nibs in pile and counterpile directions. Actually the trend goes towards a ratio of raising rollers/pile rollers equal to or 1/3. The two series of rollers have independent motion and can rotate with different speed and direction thus carrying out different effects.

The action of these systems is almost powerful and the results depend upon the effects and the type of fabric desired. The raising effect can be obtained by adjusting the fabric tension (5) or by adjusting the speed and the roller rotation direction (2). Once a certain limit has been exceeded, the excessive mechanical stress could damage the fabric: it is therefore better, when carrying out a powerful raising, to pass the wet fabric through the raising machine many times (dry when processing cotton fabrics) and treat the fabrics in advance with softening-lubricating agents. The pile extraction is easier when carried out on single fibres: it is therefore suitable to reduce the
friction between the fibres by wetting the material or, in case of cellulose fibres, by previously steaming the fabric. For the same reasons, it is better to use slightly twisted yarns. The same machine allows different options of independent motions:

- fabric moving between entry and exit
- motion of large drum
- motion of raising rollers

The raising intensity can be adjusted by suitably combining the above mentioned independent motions, the tension of the textile material, the number of ‘pilewise’ or ‘counterpile’ raising rollers and their relative speed. It is possible to obtain ‘combed pile’ raising effect, "semi-felting" effect with fibres pulled out and re-entered in the fabric, and ‘complete felting’ effect.

Stabilisation:

This process produces greater density and stability (e.g. the Sanforset process) and gives the fabric a controlled compression shrinkage, which eliminates distortions originated during previous processes. The fabric finished with this treatment keeps its shape also after repeated washing thus providing an excellent dimensional stability of the textile substrate. The fabric is fed into an opener/tension-adjusting device, and subsequently passes through a wetting unit where the quantity of water necessary for bulking the material is sprayed on the fabric. A steaming treatment can be carried out by passing the fabric onto a heated cylinder, which allows the water spreading in the fibre bulk and completes its swelling. The textile material passes to a stenter which gives the fabric the desired width and is then fed into the rubber-belt squeezing unit.

The fabric shrinkage is carried out with several simple operations: the rubber belt pressed between the squeezing cylinder and the drum is stretched and, once out of this squeezing unit, it again takes
its original shape. The fabric is made to adhere to the rubber belt in the squeezing area and, since it can slide more easily on the heated and mirror-polished surface of the drum than on the rubber one, it is forced to follow it during the subsequent shrinkage. The resulting effect is a continuous and steady sliding between the drum and the rubber belt and consequently between the drum and the fabric. Since the stretching of the rubber belt depends upon the intensity of the pressure exerted by the squeezing cylinder, each pressure variation corresponds to a shrinkage variation. Therefore the higher the pressure the greater the shrinking effect.

![Compacting Process](image)

After leaving the squeezing unit the fabric is sent out to the drying unit (180°-190°) with the slightest possible tension. The fabric is fed into a felt calender, which sets the shrinkage. The fabric immediately after the squeezing compression must be subjected to the slightest tensions and the moisture must not exceed optimum values.

![Shrink area](image)
Tubular knitted goods can be treated on stenters (to impart dimensional stability), only after the cutting operation and eventual bonding. Drying and dimensional stabilisation of tubular knitted goods can be obtained by passing the relaxed fabric into belt drying units and by steaming them in the final path.

![Diagram of compacting process for tubular knitted fabrics](image)

The fabric (T), wet or dampened with a solution containing softening agents in a vat (V), is laid down, overfed by a little calender (C), on metal-mesh vibrating conveyor belts (N) into a drying unit. On the first two conveyor belts, the fabric is dried with hot air (1) while vibrations make the fabric shrink freely; the steaming treatment (2), which sets the dimensional stability, increases the fabric bulk and gives a soft hand to the fabric, is carried out on a third conveyor belt. The fabric is then folded in a special folding unit (A). In case of further cutting and bonding units, a shrinking machine can be added to the system.

### Decating:

This process is mainly carried out on wool by exploiting its elastic properties in hot and wet conditions by the direct action of the steam on the fabric. This treatment gives the processed fabric the following characteristics:

- dimensional stability;
- setting of pile after raising;
- reduction of possible glazing effect after calendering, thank to the swelling caused by steam blown on fibres;
- modification of the hand, which is much more consistent after the treatment;
- pre-stabilisation to autoclave dyeing

This category of treatments does not include the stabilisation of wool fabrics such as potting, where the dimensional stabilisation is obtained thanks to the "plasticisation" phenomenon occurring when the wool fabric is immersed in hot water. On fabrics made with other fibres, the same treatment can be carried out as "steam ironing" alternatively to the calendering treatment, when an excessive 'glazing effect' could result from the treatment.
The steam decating, which is also referred to as dry decating, is carried out on decating machines in one continuous treatment or two discontinuous ones, according to the following operating techniques:

- drum decating (alternated at atmospheric pressure);
- autoclave vacuum decating (KD);
- continuous decating.

**Chemical Finishing Treatments:**

By applying chemicals of different origins, a fabric can receive properties otherwise impossible to obtain with mechanical means. Chemical finishing treatments:

- allow the stabilisation of fabrics already subjected to mechanical finishing processes, such as calendering;
- give fabrics some properties (e.g. flame retardancy and water repellency), which would be otherwise absent

The products used can be classified as follows:

- **Natural** (adhesives, fats, oils, starches)
- **Artificial** (modified starches, modified cellulose)
- **Synthetic** (synthesis products) including: N-methylol derivatives (thermosetting, reactants), linear reactants (carbamates, epoxy resins), thermoplastic polymers (vinyl, acrylic, polyethylene), polyurethanes and silicones.

This classification, helpful for students, does not coincide with the products actually sold on the market since these products are blends containing also catalysts and auxiliaries which interact and produce complementary effects. It is therefore necessary to underline how chemical finishing can affect the textile product by altering its mechanical properties, sometimes changing the colour shade or its original colour fastness. Different techniques are available for applying the above mentioned finishing substances: by solution, dispersion, and emulsion, pad wetting, exhaustion, coating, spraying, etc. The most appropriate technique must be carefully studied for each fibre type, and the most suitable chemical finishing process applied to obtain optimum results and grant a reasonable safety margin for any possible error.

**Application of the finish:**

The operations to be carried out when applying the finish to a textile substrate are mostly conditioned by the structural and hygroscopic properties of the material to be processed, by the desired effects, by the physical and chemical nature of the elements that make up the finishing substance and by the machine's output rate. In textile finishing, we can distinguish between five main application techniques:
a) padding;

b) spraying by means of atomisers;

c) exhaust process in treatment liquor;

d) coating carried out by means of doctor knives;

e) controlled application of low liquor quantities.

Padding is by far the most common among the various finishing techniques.

Padding:

This is certainly the most popular process for both the most conventional and innovative finishing treatments. The machine used for this process can be referred to with various definitions such as padding unit, squeezing unit, etc. After ensuring that the textile substrate can be padded by evaluating its mechanical and structural properties, this technique can be applied to carry out all wet finishing operations, except for some cases.

Spraying:

The application of finishing substances by spraying is used for carrying out gentle finishing processes which leave on the textile material a small concentration of products, and is particularly indicated for applying softening, anti-static and anti-mildew agents. For a good and homogeneous penetration and diffusion of the finish in the textile material, it is better to let the sprayed and wound fabric rest for some hours before drying. In the last few years, a very important field has been developed in the textile sector, i.e. the production of webs made of synthetic fibres. For this particular type of product, the resincoating process is carried out only by spraying the finish directly on the fibrous substrate and by generally applying synthetic resins in aqueous emulsion.

Exhaustion:

The treatment of yarns or fabrics in exhaustion liquor is recommended above all when stable chemical products are applied on the textile substrate. The manufacturing process undergone by the material is useful to precisely evaluate the best method for applying the finish, for example on hosiery or tubular knitted goods. From a chemical point of view, the most suitable products for the exhaust process are those with cationactive properties. In particular cation-active softening agents are often applied with this process, as well as paraffin- and wax-based emulsions, and more recently, cation-active polymer emulsions.

Coating:

At present, after the launch and diffusion of synthetic resins, the so called “coating and bonding” applications have been experiencing an extraordinary growth, above all in Italy. Coated and bonded fabrics are now simply classified, according to their end use, i.e. for garments, upholstery, draperies and tapestries, footwear, leather goods and technical articles. Generally the process starts from a fabric or from a non-woven fabric as a ‘backingAll fibres can be used, from light silk to linen and hemp, from synthetic fibres to glass fibres. As regards the resins used for the coating layer,
manufacturers once employed only natural substances, but are now using almost exclusively synthetic polymers of high molecular weight.

Today manufacturers are constantly in the search for coating substances that are more and more elastic, able to withstand different mechanical stress and washing conditions, and above all resistant to wearing and weather agents. These coating polymers are bonded to the fabric backing by means of calenders, in the form of thin sheets or are mainly spread in the form of aqueous dispersions or solutions in solvents.

The characteristics and the properties of coated fabrics depend on the chemical structure of the coating resins applied and the type of backing fabric used. The coating layer undoubtedly plays the most important role for appearance, hand and resistance properties: its elasticity, its behaviour at high and low temperatures, its resistance to abrasion, to solvents and to the effect of ageing and weather agents, depend on its chemical composition as a substance with a high molecular weight and more or less thermoplastic qualities.

Softening:

As a general rule, each fibre has its specific softness value, which depends on its chemical composition and physical structure (less crystallinity = greater softness). The fineness of the fibre or of the filament directly affects the softness of the yarn (woollens, worsteds, microfibers etc.). The yarn twist ratio is inversely proportional to its softness. The weave also contributes to reducing (closer weave = plain) or increasing (looser weave = satin) the fabric softness. Furthermore, a greater number of yarns per centimetre increase the stiffness of the fabric, thus reducing its softness. Softening is carried out when the softness characteristics of a certain fabric must be improved, always carefully considering the composition and properties of the substrate. It is also worth underlining that no standard methods have been developed and established to determine exactly what the softness of a fabric is. This evaluation is therefore almost personal and carried out on the basis of operator's experience. It is anyway possible to distinguish between many types of softness:

a) surface softness,

b) surface smoothness,

c) elasticity (to compression and stretching).

To change the hand properties of a fabric, we can apply mechanical, physical, chemical or combined techniques; some of these methods (sueding, raising) have already been explained in detail in previous sections of this handbook, while some others refers to machines that give different degrees of softness, by means of high-speed rope processing in wet or dry conditions, with the drying stage carried out during the treatment (with or without softeners or enzymes.) The functional core of these machines are the two tunnels where the fabric is fed through two Venturi tubes. The energy applied for drawing the material is produced only by air and pressure. The fabric flowing through the Venturi tubes is pushed at high speed against a grid on the machine rear side; the fabric then slides on Teflon-coated chutes and reaches the machine frontside to start the cycle.
again; the fabric can reach a speed of 1000 m/min., depending on the type and weight of the different textiles to be processed and according to the desired results.

The following picture details an industrial softening system.

Anti-static Treatments:

Wool and such manmade fibres as nylon, acrylic, and polyester develop static electricity from the friction caused by wearing and general use. As a result, the fabrics attract dirt particles, cling and climb, crackle, even spark, and cause very minor but discomforting shock to the user. Some companies do apply antistatic treatments, sometimes in combination with other finishes which may have antistatic components in them. One form of Zepel is such a finish. These vary in effectiveness and durability. Some manmade fibre producers are making types of fibres which have built-in antistatic properties. There are several household products used in laundering that provide nondurable antistatic properties.
Being characteristically hydrophobic, synthetic fibres present a low electrical conductivity, so low that, after rubbing against other bodies, they can retain an electrical charge for a long time. Indeed, when two bodies, characterised by a neutral electrical charge and each having a different chemical composition, are rubbed together, the electrons of each of them will attract those of the other in such a way that both bodies acquire an electrical charge. Generally speaking, the body with the higher dielectric constant takes a positive charge, while the substance with the lower dielectric constant takes a negative one. A potential difference, of as much as several hundred millivolts, is created between the two contact surfaces. If these two bodies, both charged with electrical energy, are separated, the potential is increased, even as high as many tens of thousands of volts. As far as fabrics are concerned, this discharge of energy occurs mainly between the innumerable fibrils. It is responsible for creating the familiar crackling sound and for the formation of the tiny sparks and the genuine electrical discharges that can cause perceptible discomfort. To reduce this phenomenon, one can operate in a controlled environment that has high relative humidity, use conductors that can discharge the material, ionise the atmosphere, or apply hydrophilic chemical substances. Chemical products that confer an anti-static effect on synthetic fibres form, on the fibre surface, a thin film whose electrical conductivity is higher than that of the fibre. These substances are anionic, cationic, amphoteric, or even non ionogenic. The conductivity of a synthetic fibre is thus increased when it is covered with a surface-active substance in which the hydrophobic groups are oriented towards the fibre and the hydrophilic groups are oriented away from it.

The presence of mobile electrical ions is, however, important. Depending on the substantivity of the chemical products used, it is possible to choose between different application processes: immersion, exhaust or padding. Anti-static finishing treatments are rarely applied through spraying. Chemical products that have the capacity to confer a permanent anti-static effect condense at high temperatures; they can even condense when stored at ambient temperature in hermetically sealed rooms or containers (as can epoxy resin-based products). All the anti-static products available on the market can be applied by padding, while only a few can be applied using the exhaust process. The material is immersed in liquor containing the anti-static chemical product, squeezed (to 40-60% absorption) and finally dried in a stenter at 80-100°C. If the stenter is equipped with additional chambers that can be used to carry out heat setting processes, then it is also possible to condense, at the same time, anti-static products able to confer permanent effects.

Anti-mildew Treatments:

In certain ambient (humidity and heat) conditions, cellulose can be permanently damaged. This damage can be due to depolymerisation of the cellulose or to the fact that certain microorganisms (mildews) feed off it. The situation is worsened, during long storage periods, by the presence of starch finishing agents. This damage can be prevented by the use of antiseptics, bacteria controlling products containing quaternary ammonium salts, and phenol derivatives. Dyestuffs containing heavy metals can also act as antiseptics. Permanent modification of the fibre (cyanoethylation) is another possibility.

Cellulose fibres are particularly susceptible to mildew; silk and wool are also susceptible, but to a lesser extent. Such untreated fabrics will become stained, malodorous, and eventually deteriorated
by the fungus if allowed to remain in a moist condition for a period of time. Shower curtains or other cotton fabrics may be mildewproofed at home by soaking the material in very soapy water, then, without rinsing, dipping it into a solution of copper sulfate. Antiseptics, such as boric acid and carbolic acid, also prevent rapid growth of the mildew fungus. One compound that is not easily washed out is a 0.05% solution of phenyl mercuric acetate in water. This is one of the most effective mildewproofing agents. Certain organometallic compounds, such as of tin and copper, are powerful mildew retardants. Copper imparts a greenish colour to fabrics. Certain resins based on melamine formaldehyde are also valuable for mildewproofing. Rotproofing, an extension of mildewproofing, is very important in agricultural applications.

**Dimensional stability:**

Cotton knitted fabrics in tubular form often show excessive lengthways shrinkage on washing unless given a pre-shrinking treatment based on compressing the fabric lengthways. A new technique is to pre-shrink the fabric by transferring it from one suction drum to another, the second operating at a lower surface speed than the first.

The Koratron durable-press finish has been applied to polyester-cotton weft-knitted fabrics with a resulting improvement in dimensional stability on washing. A combined mechanical-chemical finish, namely, “Perset”, has been applied to cotton and polyester-cotton fabrics and washing shrinkage has been restricted to about 5% in each direction by this treatment.

The Micrex Process is also a combined chemical-mechanical treatment when applied to open-width knitted fabrics containing a substantial proportion of cellulosic fibre. The sequence is (a) pad with resin, (b) dry, (c) compressively shrink lengthways, and (d) cure, treatment usually by means of infra-red radiation. For fabrics containing a large proportion of polyester or polyamide fibre, the padding and drying stages are omitted, the fabric being compressed and then heat-set in a relaxed state. Fabrics treated by this process are claimed to have a lengthways shrinkage on washing of less than 1%, and improved shape retention, lengthways stretch, and handle.