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update to July 2000

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The Italian textile machinery sector, today

The textile machinery industry requires conspicuous research investments, in-depth know-how, long experience in textiles, mechanics and electronics, so that there are not many countries capable of ensuring a textile production of technological high level. Italy is one of the 3 leading producer countries in the world and the technological level of its production is considered, even by its competitor countries, as up to the highest standards. The value of the Italian production of textile machines in 1998 amounted to 3.7 billion dollars, 65% of which exported to more than 100 countries. The Italian export of textile machines can be divided as follows:

- 25% spinning machines
- 20% weaving machines
- 25% knitting and hosiery machines
- 21% finishing machines
- 8% dry cleaning and laundry machines
- 1% other machines

Europe (48%) is the main export area, followed by Asia (22%), North America (17%), South America (8%) and Africa (5%).
A complete production line

The Italian offer of textile machinery is characterised by an extremely wide and complete range, which includes:

- spinning preparatory and spinning machines
- twisting, winding and reeling machines
- weaving preparatory and weaving machines
- hosiery machines
- dyeing, printing and finishing machines
- machines for the making-up industry
- machines for textile maintenance

The Italian textile machines can process any kind of fibre, both natural (cotton, wool, silk, etc.) and man-made fibres, thus meeting adequately any requirement by the textile industry.

The reasons of a success

The Italian companies manufacturing textile machines and accessories are over 350 and employ 26,000 people. They are generally situated in areas of age-old textile tradition, where a synergetic exchange of experiences with the end-users offers a big stimulus to the improvement of the machinery.

These areas are situated in the North and Centre of Italy: at Biella, Como, north of Milan, Prato and Vicenza. Thanks to the high number of manufacturers, almost any type of machine can be supplied by more than one manufacturer, so that the customer can easily find the type of machine which is better suited to his own requirements.

As however a process of industrial integration is under way also in our sector, the number of companies active in this field seems to be doomed to a slow but progressive reduction.

The main characteristics of the Italian textile machines which ensured their success worldwide are:

- extremely advanced technological level
- versatility and flexibility
- excellent quality/price ratio
- reliability.

Moreover the Italian manufacturers are continuously intensifying their research on the issues of industrial safety and environment in order to propose solutions which are more and more abreast of the times.

ACIMIT’s fields of activity

What is ACIMIT

ACIMIT, the Italian Association of Textile Machinery Producers, groups together at present 251 Italian producers of textile machines and accessories, whose production accounts for 85% of the whole production of Italian textile machines, and 19 associated members (consortia, technical institutes, technical magazines, engineering and trading companies, research centres).
The purposes of the Association
The main purpose of the Association (which is a non-profit-making body) is the promotion of the Italian textile machinery industry and the support of its activities, especially abroad, through the most innovative means.
In order to promote in particular the knowledge of the Italian textile machinery worldwide (that is to inform about “who is making what”), ACIMIT can offer any kind of information on the activity of their member companies, thus ensuring to the image of the Italian textile machinery sector the widest diffusion (through exhibitions, publications, technological seminars).
Another important activity of ACIMIT is to inform their member companies about the commercial, financial and technical problems which can be met with on the various markets, thus making their access easier.

The ACIMIT Foundation

Beside these activities, ACIMIT felt the necessity of promoting an additional range of initiatives regarding economical and professional training issues, which however can be better dealt with by a Foundation: this was the reason of constituting the ACIMIT Foundation in 1997.
Among the most significant activities started by the Foundation during the first three years of activity, worth mentioning are the publication of 4 economic researches on the textile machinery sector and a significant activity of professional training in favour of Italian and foreign students (which involved the implementation of technology courses in Italy, the publication of school text-books and the awarding of scholarships).

The ACIMIT service company

With a view to build up an organisation which could be better up to the new requirements of the enterprises and to the provisions newly established for the associations, ACIMIT constituted on January 1st, 1999 the service company ACIMIT Servizi srl.
The subject-matter of the new company is to provide services for the promotion, organisation and advertising of exhibitions and shows in Italy and abroad, as well as administrative outsourcing services for the companies intending to displace abroad their tasks and activities.
2.1 The textile fibres

As known, the range of the textile fibres available on the market is at present rather extended. It includes in fact both natural and man-made fibres, which last were created about 100 years ago to the end of making up for the increased demand deriving both from the progressive improvement in the living standard and from the considerable growth of world population.

The natural fibres are divided, according to their origin, into animal (silk, wool, etc.) and vegetable (cotton, flax jute, etc.) fibres. Man-made fibres are divided into artificial (mostly originating from cellulose) and synthetic (from synthesis products) fibres.

Classification of fibres

<table>
<thead>
<tr>
<th>Natural fibres</th>
<th>Man-made fibres</th>
</tr>
</thead>
<tbody>
<tr>
<td>Animal</td>
<td>Artificial</td>
</tr>
<tr>
<td>from sericteries</td>
<td>cupro</td>
</tr>
<tr>
<td>silk</td>
<td>- viscose (rayon)</td>
</tr>
<tr>
<td>from hair bulb</td>
<td>- modal</td>
</tr>
<tr>
<td>- wool</td>
<td>- polynosic</td>
</tr>
<tr>
<td>- animal hair</td>
<td>- deacetylated acetate</td>
</tr>
<tr>
<td>- horsehair</td>
<td>- acetate</td>
</tr>
<tr>
<td>Vegetable</td>
<td>- triacetate</td>
</tr>
<tr>
<td>from seeds</td>
<td>- alginic</td>
</tr>
<tr>
<td>cotton</td>
<td>- protein</td>
</tr>
<tr>
<td>from the inner bark</td>
<td>- elastodiene</td>
</tr>
<tr>
<td>- flax</td>
<td>- tencel</td>
</tr>
<tr>
<td>- hemp</td>
<td></td>
</tr>
<tr>
<td>- jute</td>
<td></td>
</tr>
<tr>
<td>- kenaf</td>
<td></td>
</tr>
<tr>
<td>- ramie</td>
<td></td>
</tr>
<tr>
<td>from leaf</td>
<td></td>
</tr>
<tr>
<td>- abaca (manilla)</td>
<td></td>
</tr>
<tr>
<td>- sisal</td>
<td></td>
</tr>
<tr>
<td>from fruit</td>
<td></td>
</tr>
<tr>
<td>coir</td>
<td></td>
</tr>
</tbody>
</table>

Artificial

- cupro
- viscose (rayon)
- modal
- polynosic
- deacetylated acetate
- acetate
- triacetate
- alginic
- protein
- elastodiene
- tencel

Synthetic

- acrylic
- chlorofibre
- elastane
- fluorofibre
- modacrylic
- polyamide (nylon)
- polyester
- polyethylene
- polypropylene
- polyurethane
- trivinyl

Organic

- from metals
- from boron
- from others

- textile glass
- carbon
- others
In 1998 the world production of textile fibres amounted to over 47 million tons, which means a (potential) per capita consumption of about 8 kilos per year.
After the severe downturn of the world economy in the years 1992-93, in 1994 there was a recovery in textile production and consumption which went on, even if not at such a bright pace, also in the subsequent two years.
While cotton production depends substantially on the climatic conditions of the major producer countries and is therefore subject to heavy fluctuations (even up to 10%), the wool production is by now more or less stable since several years.
On the contrary the production of synthetic fibres, which in 1993 exceeded for the first time that of cotton, continued to grow, even if at a lower rate, in the following years to the extent that the synthetic fibre production exceeds nowadays that of the other fibres altogether.
Finally, as far as the production of artificial fibres is concerned, this is since some years slowly but steadily decreasing and accounts at present for only 4,6% of the global world fibre production.

**Textile fibre world consumption in 1998 (%)**

![Graph](image-url)
### Textile fibre world production (thousand tons)

<table>
<thead>
<tr>
<th>Year</th>
<th>Cotton</th>
<th>Wool (1)</th>
<th>Synthetic fibres</th>
<th>Artificial fibres</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1985</td>
<td>17.383</td>
<td>1.744</td>
<td>13.146</td>
<td>3.223</td>
<td>35.496</td>
</tr>
<tr>
<td>1987</td>
<td>17.670</td>
<td>1.832</td>
<td>14.475</td>
<td>3.231</td>
<td>37.208</td>
</tr>
<tr>
<td>1988</td>
<td>19.366</td>
<td>1.886</td>
<td>15.244</td>
<td>3.286</td>
<td>38.782</td>
</tr>
<tr>
<td>1989</td>
<td>17.431</td>
<td>1.955</td>
<td>15.718</td>
<td>3.284</td>
<td>38.388</td>
</tr>
<tr>
<td>1990</td>
<td>18.997</td>
<td>1.927</td>
<td>16.006</td>
<td>3.145</td>
<td>40.075</td>
</tr>
<tr>
<td>1991</td>
<td>20.793</td>
<td>1.735</td>
<td>16.381</td>
<td>2.897</td>
<td>41.806</td>
</tr>
<tr>
<td>1992</td>
<td>18.101</td>
<td>1.674</td>
<td>17.046</td>
<td>2.737</td>
<td>39.558</td>
</tr>
<tr>
<td>1993</td>
<td>16.673</td>
<td>1.633</td>
<td>17.249</td>
<td>2.752</td>
<td>38.352</td>
</tr>
<tr>
<td>1994</td>
<td>18.982</td>
<td>1.544</td>
<td>19.125</td>
<td>2.863</td>
<td>42.514</td>
</tr>
<tr>
<td>1997</td>
<td>20.018</td>
<td>1.440</td>
<td>24.884</td>
<td>2.314</td>
<td>48.766</td>
</tr>
<tr>
<td>1998</td>
<td>19.308</td>
<td>1.405</td>
<td>25.635</td>
<td>2.185</td>
<td>47.533</td>
</tr>
</tbody>
</table>

Source: CIRFS, AKZO, Fiber Organon, ICAC, Acordis

(1) Scoured wool basis

### 2.2 Cotton

#### 2.2.1 A millenary history

All varieties of cotton (botanical name "Gossypium") grew originally in the desert zones of both the old and the new world. The cotton fibre was used probably at the end of the stone age in both hemispheres, to manufacture strings and maybe also fishing nets. The time at which the real cotton growing started is not known, but from the remnants found at Cuzco (Peru) it was deduced that cotton spinning and dyeing date back to at least 2500 years ago; the excavations carried out in the village of Mohen Daro (Pakistan) gave evidence that cotton spinning and weaving were known already in 3000 B.C. Other archaeological finds prove that the Aztecs in Mexico and the Olmecs in central America, beside the Incas and their ancestors in the Andes produced cotton fabrics with very nice and complex designs which date back to over 2000 years ago.

The word “cotton” comes from the Arabic “Katun” which means plant of the conquered lands, with reference to the invasion of India by Alexander the Great in 327 BC. Several cotton fabrics still today bear the names of Asiatic and European towns, as well as of sea harbours situated along the cotton sea routes to Europe. Thus e.g. the term “satin” originates from the Arab name of the Chinese town Tsutung (Canton, today), the very popular “denim” from the French town Nimes, the name “poplin” from the papal city of Avignon and the name “lisle” from the French town Lille.

The cotton plant, as it originates from the desert, needs much sunlight and a warm climate; consequently it cannot be grown in Western Europe, except for Greece and Spain.

#### 2.2.2 Production and consumption

The major cotton producing countries are at present China, the United States (the renowned “cotton belt” where the celebrated “U.S. Upland” cotton is being produced embracing several States: Texas, California, Mississippi, Louisiana, Alabama, Arizona and New Mexico), followed by CIS, India and Pakistan. According to a recent report of I.C.A.C. (International Cotton Advisory Committee), the world production of raw cotton in the harvest 1998-99 is estimated at around 18,3 million tons, recording a drop against previous years, while world consumption is predicted to remain at about 19,3 million tons (a rather stabile value).
The main exporting countries of raw cotton are the USA and the CIS (in the first place the state of Uzbekistan, followed by Turkmenistan and Tajikistan).

Cotton is mostly imported by those countries which, although having no possibility to grow it, have within their borders a more or less well developed textile industry. Typical countries are Italy, which in the biennium 1998-99 imported 355.000 tons of cotton, Germany (135.000 tons) and Portugal (174.000 tons). Russia too is a big cotton importer.

The major raw cotton producer countries (1997-1998 harvest)

<table>
<thead>
<tr>
<th>Country</th>
<th>Thousand tons</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>USA</td>
<td>1.067</td>
<td>19</td>
</tr>
<tr>
<td>China</td>
<td>520</td>
<td>9</td>
</tr>
<tr>
<td>Argentina</td>
<td>256</td>
<td>5</td>
</tr>
<tr>
<td>Mali</td>
<td>217</td>
<td>4</td>
</tr>
<tr>
<td>Greece</td>
<td>145</td>
<td>2</td>
</tr>
<tr>
<td>Syria</td>
<td>142</td>
<td>2</td>
</tr>
<tr>
<td>other countries</td>
<td>2.025</td>
<td>36</td>
</tr>
<tr>
<td>Total</td>
<td>5.680</td>
<td>100</td>
</tr>
</tbody>
</table>

Source: I.C.A.C.

In the Far East, the major raw cotton importer countries are Japan (278,000 tons, again in the year 1998-99), South Korea (275,000 tons), Thailand (315,000 tons) and Indonesia (386,000 tons). Even China imported about 400.000 tons of cotton. These figures correspond in most cases to the consumption volumes.

The major raw cotton consuming countries (cotton harvest 1998-99)

<table>
<thead>
<tr>
<th>Country</th>
<th>Thousand tons</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>4.877</td>
<td>25</td>
</tr>
<tr>
<td>India</td>
<td>2.776</td>
<td>14</td>
</tr>
<tr>
<td>USA</td>
<td>2.400</td>
<td>12</td>
</tr>
<tr>
<td>Pakistan</td>
<td>1.550</td>
<td>8</td>
</tr>
<tr>
<td>Turkey</td>
<td>1.115</td>
<td>6</td>
</tr>
<tr>
<td>Brazil</td>
<td>765</td>
<td>4</td>
</tr>
<tr>
<td>CIS</td>
<td>487</td>
<td>3</td>
</tr>
<tr>
<td>Mexico</td>
<td>469</td>
<td>2</td>
</tr>
<tr>
<td>Indonesia</td>
<td>386</td>
<td>2</td>
</tr>
<tr>
<td>Italy</td>
<td>355</td>
<td>2</td>
</tr>
<tr>
<td>other countries</td>
<td>3.837</td>
<td>20</td>
</tr>
<tr>
<td>Total</td>
<td>19.332</td>
<td>100</td>
</tr>
</tbody>
</table>

Source: I.C.A.C.
2.2.3 The cotton plant
In ancient times the cotton plant was a perennial big shrub which bore fruits at all seasons; in time and after careful selections, almost in every country it has become a more or less branched out plant which is sown every year, grows and crops in 5 to 6 months. The blooming takes place eight weeks after sowing, after few days the white and yellow flowers fall, leaving the boll which contains the seeds, around which the fibre fluff develops. In the subsequent weeks the capsule boll grows up to the size of a hen egg and bursts, releasing the white and bright cotton fibre which will continue to ripen until the harvesting time.
The cotton fluffs are picked either mechanically or manually and brought to the ginning room, where special machines called “gins” complete the separation of the fibres from the seed. The fibre mass is tightly compressed into bales, hence the term “raw cotton” used for this fibre. At this point the seeds are separated from the shorter cotton fibrils named “linters”, which are used for the production of valuable artificial fibres, as we shall see later on. From the botanical point of view, there are four basic species of cotton: Gossypium arboreum, herbaceum, hirsutum and barbadense. The first two species yield short staple, the third medium staple and the fourth long and extralong staple cottons (the term “staple” identifies the fibre length). In this connection we have to remind the prestigious varieties called ELS (extra-long staple), which are grown in relatively small quantities in Egypt, Sudan, Israel, USA and Peru. The staple length is one of the most decisive characteristics of the cotton fibre because the longer the staple length, the finer the spinnable yarn count. According to the official American standards, the staple lengths are divided into four ranges:

- below 0.99": short staple
- 0.99" to 1.10": medium staple
- 1.11" to 1.26": long staple
- over 1.26": extra-long staple.

2.2.4 Fibre characteristics
The cotton fibre is characterised by the presence of a cavity in its interior, named “lumen”. The quality assessment of the cotton fibres is based on following characteristics:

- staple length
- cross-section size, usually called fineness
- linear mass

The spinnability of a fibre, i.e. the finest yarn count attainable in spinning, depends on the length and on the fineness, while the yarn tenacity is related to the strength of the individual fibres as well as to the number of fibres in the yarn cross-section, which has to range between 90 and 120.
The fibre fineness is defined by the American standard ASTM D 123-85 and D 1448-84 as the weighted average linear mass expressed in micrograms per inch, but also in millitex µg/cm. For many years these values were assessed with a gravimetric test method, by weighing measured fibre lengths. For commercial purposes, the linear mass is assessed today more rapidly through special micronaire testing (or similar) instruments.
Besides fineness, a very important fibre property is the maturity degree, which is the ratio between the lumen length and the thickness of the fibre wall.
In fact there is a correlation between fibre maturity, linear mass and micronaire test readings, which is expressed by following values:
- micronaire lower than 3.0 = very fine; maturity degree 0.70-0.80 = immature
- micronaire from 3.0 to 3.9 = fine; maturity degree 0.80-0.85 = maturity below average
- micronaire from 4.0 to 4.9 = medium fineness; maturity degree 0.85-0.95 = ripe
- micronaire from 5.0 to 5.9 = coarse fineness; maturity degree 0.95-1.00 = maturity above average
- micronaire 6.0 and higher = very coarse fineness; maturity degree 1.00 and higher = very ripe

The fibre strength is, like fineness, the property which most affects the yarn characteristics: in fact the two properties are closely connected one another. Owing to the enormous difference in the values of these characteristics among the various fibres, cotton strength is measured with a so-called Pressley tester a flat fibre bundle composed by 500 to 1500 fibres.

For the assessment of fibre quality, also following factors are significant:
- colour: white, slightly spotted, spotted, slightly coloured, yellow stained, slightly grey, grey. The spinner requires anyway colour evenness.
- purity: contents of foreign matters. In fact another requirement of the spinner is the presence of a limited quantity of trash (coarse dusts).
- fibre preparatory process: this corresponds to the ginning process, which is a decisive factor for fibre softness, for uniform and open condition of the tufts and for the persistence of fibre entanglements, called “neps.

Maturity degree of the cotton fibre– Relationship between lumen width and fibre wall thickness

The typical cotton characteristics all together as colour, foreign matter contents, kind of preparation as well as length and strength contribute to determine the “grade” and consequently the commercial value of the fibre, which in the trade is usually referred to as “good middling”, “strict middling”, “middling”, “low middling”, “strict good ordinary” or “good ordinary”.

2.2.5 The quality tests
In cotton spinning the cost of the raw material is equal to 50% of the total processing cost.
It is therefore essential that the cotton type selection is based on a wide knowledge of the fibre properties and on the end-item to be produced.
In the last decade the so-called testing lines, which were initially used only by cotton producers and exporters, have been steadily developed and improved, so that they have now been adopted also by the spinning mills; these are driven in this direction by the need to control the quality of the various fibre sources and the reliability of the suppliers, moreover they are attracted by the effective advantages offered by these integrated testing systems, which ensure a closed loop control of fibre characteristics, yarn quality and production process and are focused on the spinning mill’s profit. The initials HVI (High Volume Instruments), now well known to all cotton dealers, stand for the kind of instruments which compose the cotton testing lines. These lines offer several advantages:

- measurement of the main characteristics on a cotton fibre bundle: span length as measure of the fibre length, length uniformity, strength, elongation, micronaire as a fineness measure, colour and reflectance, foreign matter (trash) contents. The spinners have asked to add also the SFC (Short Fibre Contents) value which, as already mentioned, has a great impact on the quality of carded yarns. In fact short fibres increase yarn breakages while reducing the yarn tenacity and regularity. The combing process removes the short fibres and originates a quality yarn, but at the expense of a larger quantity of wastes. At least one manufacturer of HVI systems has already the software suited to provide the SFC value from the fibrogram produced by the HVI system. Although the standard error is still about 2%, this procedure allows to identify cotton batches which went through an excessive beating or drying or were too intensively cleaned in the ginning machine.
- possibility of testing up to 180 specimen/h and of checking each single bale.
- attainment of reliable test results.

The American cotton growers, under the guidance of USDA (U.S. Department of Agriculture), are making considerable efforts to improve the quality and to reduce the damages caused to the fibre by mechanical picking and ginning. Therefore they were first to equip themselves with these HVI instruments, so that they are in a position to deliver controlled cotton bales with every information which can help the spinner to plan in the best way his production through:

- cotton bale management
- raw material optimisation
- process optimisation with consequent cost reduction.

By bale management we mean the ideal selection of the cotton bales to obtain acceptable technical and economic performance during their processing as well as consistent yarn quality.
By raw material optimisation we mean the result of following operations:

- consistent blending with the support of bales management;
- selection of fibre characteristics according to the requirements of the end-product and based on yarn structure;
- purchase of the most convenient raw material suited to meet the requirements of the end-product.

The process optimisation, on the other hand, depends on following factors:

- selection of the best setting for the drafting rolls;
- optimisation of the processing speeds through comparative trials.
2.2.6 Cotton stickiness
The thorn in the side of the cotton producers and particularly of the spinners, is the notorious honeydew. This term defines the dreadful stickiness of cotton fibres due to the contamination by two terrible insects: the cotton aphid and the white fly, which last is widely spread in case of long dry spells. The researchers have intensified their efforts to control the reproduction of these insects in the last years, during which this infestation increasingly expanded. This spreading of the phenomenon is demonstrated by the result of a survey carried out by ITMF (International Textile Manufacturers’ Federation) with 201 spinning mills in 22 countries all over the world about raw cotton contamination: a good 27% of the answers reported as serious the problem of cotton stickiness originated by honeydew, and Sudan was leading the high-risk countries.

Trials are under way to identify the honeydew-affected cotton batches through:

- the analysis of the sugary substances in the honeydew, which cause the cotton stickiness;
- the development of tests on the spot in order to detect the presence of sticky cotton types.

Specific treatments to neutralise cotton stickiness due to honeydew were also studied. Already in 1988 J. Gutnecht explained the results of stickiness tests carried out by “Minicard” method to show the influence of the relative humidity in the spinning room on the potential stickiness of a wide range of sticky cotton types and on various blends of sticky and non-sticky materials. At the same time he presented a new thermal method, simpler and less expensive than the Mini-card test, which results correlate pretty well with the Minicard System.

To remove stickiness from cotton fibres, various systems have been used:

- spraying of chemical substances on the fibres, which however causes some problems in subsequent processing
- passage of cotton bales or of a web of opened fibres through high frequency ovens.

In the past years a project was presented by R. Demuth to eliminate the cotton stickiness caused by honeydew. The project consisted in two phases: washing of the fibre with water and detergent with subsequent mild drying followed by thorough drying of cotton in a microwave tunnel, so that the adhesive substances become brittle and are reduced to powder. These systems however are not sufficiently cost-effective, so that there is a trend to dispose of the sticky cotton by mixing it in small percentages with the regular cotton.

2.2.7 The cotton stock exchange
The major stock exchanges for cotton trading are situated in New York, Bremen and Tokyo. The cotton price is subject to broad fluctuations, which quite often are due to the seasonal and climatic trend.

Obviously the positive operating results of a spinning mill depend also on a careful and “lucky” purchase of the raw material. In this regard we would remind the practice of the purchase option of a “future”, according to which during the validity of the option the buyer has right, but not the obligation, to turn the option into a “cotton future”. In practice futures are contracts for the purchase or sale of goods to be delivered at long-term, but at a price established at the time of entering into the contract. There are two possible types of option:
- CALL, in this case the buyer has the right to convert the option into a long-term “future”.
- PUT: in this case the buyer has the right to turn the option into a short-term “future”.

In New York since 1870 the NYCE® (New York Cotton Exchange) take place, which is the world’s leading market for the sale and purchase of cotton futures and options. It is a non-profit-making organisation which assists all segments of the cotton industry by providing the financial means needed for risk management.

### 2.3 Wool

Wool, as all animal hair both coarse and fine, falls under the class of natural fibres and more precisely under the class of animal fibres from hair bulbs. Although the term “wool” is commonly associated also with the name of the animals which supply the relevant pile as for instance Angora wool, this term wool stands only for the hair of the domestic sheep (Ovis aries L.) of various breeds. Archaeologists affirm that sheep existed already when the man appeared on the earth, and it is almost beyond any doubt that wool was one of the first textile fibres available for spinning and weaving. Archaeological finds on the Zagros mountains, at the border between Iran and Iraq, prove that sheep were tamed already 9000 years BC. For a long time, sheep and their products were the main source of wealth and the best medium of exchange. In this connection we remind that the Latin word “pecunia” (money) derives from the word “pecus” (sheep) and that the first coins portrayed this animal.

Wool characteristics depend on following factors:

- method used to obtain the fleece:
  - virgin wool = wool obtained by shearing the living animal;
  - plucked wool = wool obtained by chemical treatment of skins of slaughtered sheep
- sheep age or sex:
  - lamb’s wool = first wool sheared from a lamb less than one year old;
  - ewe’s wool = wool obtained by subsequent shearing;
  - ram’s wool
- breed:
  - merino = wool with fineness \( \leq 24.5 \mu \);  
  - cross-bred wool = wool with fineness between 24.5 and 32.5 \( \mu \);
  - coarse wool = wool with fineness > 32.5 \( \mu \).
- wool state:
  - greasy wool, containing the original substances of just shorn wool, i.e. yolk and suint;  
  - fleece washed wool, obtained by making the living sheep pass through water;  
  - machine scoured wool, in which the grease is to a great extent removed;  
  - carbonized wool, that is wool treated with acids and heated to eliminate the contents of vegetable substances;  
  - wool tops, that is regular combed silvers composed of parallel long fibres from which all original impurities have been removed, intended for worsted spinning and for high quality products.

#### 2.3.1 Production and consumption

It is estimated that sheep living on earth are today about 1 billion, of which 14% in China, 13% in Australia, 5% in the CIS and 5% in New Zealand. In the last years the production has progressively decreased. For the 1998-99 season a production of 2.4 million tons of raw wool (equal to 1.4 million tons of scoured wool) is expected. According to IWS estimates, the major producing countries of greasy wool in same season 1998-99 are: Australia (681,000 tons), the People’s Republic of China (302,000 t), New Zealand (256,000 tons), CIS (139,000 tons), Uruguay (63,000 t), Argentina (70,000 tons), Turkey (73,000 t), Great Britain (55,000 tons), South Africa (60,000 tons).
Production percentages for the different breeds are: merino 41%, crossbred 25%, others 34%; 80% of the merino wool is supplied by Australia ad South Africa.

<table>
<thead>
<tr>
<th>The main exporting countries of virgin wool (1998 estimates-1000 tons)</th>
<th>The main importing countries of virgin wool (1998 estimates-1000 tons)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia 470</td>
<td>China 154</td>
</tr>
<tr>
<td>New Zealand 198</td>
<td>Italy 115</td>
</tr>
<tr>
<td>CIS 39</td>
<td>United Kingdom 76</td>
</tr>
<tr>
<td>United Kingdom 30</td>
<td>France 73</td>
</tr>
<tr>
<td>China 29</td>
<td>Germany 68</td>
</tr>
<tr>
<td>South Africa 26</td>
<td>India 45</td>
</tr>
<tr>
<td>France 14</td>
<td>Taiwan 38</td>
</tr>
<tr>
<td>Spain 9</td>
<td>Japan 38</td>
</tr>
<tr>
<td>USA 32</td>
<td>South Korea 12</td>
</tr>
</tbody>
</table>

Source: IWTO

The main producing countries of greasy wool (1997-98)

2.3.2 Other animal fibres
The so-called luxury fibres are produced by several different animals: rabbit, mohair goat, cashmere goat, camel, llama (alpaca, vicuna, guanaco) and cattle (yak and musk ox). In recent years a crossbreed, called Cashgora, was obtained by mating the angora he-goat with a wild she-goat. This name was acknowledged by the International Wool Textile organisation (IWTO) only in 1988, but the new wool variety aroused immediately the interest of many Italian spinning mills.

Luxury fibres gad their golden age at the beginning of the 80’s; from the middle of the decade, various political and economic factors caused a general recession and a market stagnation. Italian spinners proved however to be real masters in the use of these fibres and especially in constantly creating new blends, making the most of the peculiarities of the woollen preparation and spinning machines “made in Italy”.
Hereunder we give some information about the various types of luxury fibres:

- **Angora rabbit**: the yearly production of about 6,000-7,000 tons takes place mostly in China. The rabbits are clipped up to 4 times a year, thus producing about 250 grams of fibre each. The main market outlets are Japan and Italy. One of the latest developments is a process to produce unfelting angora yarn for handknitting.

- **Mohair goat**: These animals are bred in South Africa, Texas and Turkey, and it is precisely to the Turkish town of Angora, Ankara today, that they owe their name. The word “mohair” which identifies in trade their wool stems from the ancient Arabic word “Mukhayar”, which means “glossy goat hair cloth”. In fact the fibre has a rich silken aspect, but has a considerable strength. It is available in relatively large quantities - world production is about 13,000 tons - and is used in both apparel and furnishing. Each goat yields about 4 kg of hair per year. The finest hair coming from goatlings - 24-25 µ - is called kid-mohair. The main consuming countries of this fibre are Japan (25%), Europe and North America. The promotion of this fibre is co-ordinated by the International Mohair Association, which also created a quality trademark.

- **Cashmere goat**: these animals live in the plains of Central Asia, where climate is ice-cold in winter and hot in summer; just to protect them from cold, their skin gets covered by a thick and soft down (under-fleece down), which is plucked before summer. Each goat yields only 200 g of fibre per year, consequently the total production does not exceed 7,500 tons/year.

- **Camel**: camel hair is obtained mostly from the camel living in East and central Asia. The main outlet market for this fine, soft and golden fibre is America, where it is used for both woven and knitted fabrics, whereas in Europe it is used mostly for knitwear, especially in men’s garments. Each animal yields about 5 kg of fibre per year. Particularly valuable is the “baby-hair” type. The world production is about 3,000 tons/year.

- **Alpaca**: these are humpless animals of the camel family living in the Andean regions at heights up to 5,000 m. They are sheared only once every two years and each animal yields from 2 to 4 kg of fleece. This breed produces hair in 14 different natural colours, which is used in knitting and hand knitting yarns in the classic blends alpaca/wool, alpaca/wool/acrylic, alpaca/mohair/wool/acrylic. The alpaca production is about 6,000 tons/year.

- **Yak**: it is a long-haired ruminant living in Tibet at an altitude of 5,000 m. Its hair is considered as an acceptable alternative to cashmere. It is not produced in commercial quantities and, until 1980, the whole yak hair was exported to Europe and to the United States. At present the Chinese have developed a technology of their own and use directly most of this raw material.

- **Musk ox**: the underfleece of the musk ox is called “the Arctic’s Golden Fleece” and is probably the rarest and most expensive animal fibre in the world. Declared a protected species in the 30s, the musk ox has been saved from extinction and is today living in herds in North Quebec and in Alaska. Every spring, the animal looses its extremely valuable underfleece, known as “quiviut”.

### 2.4 Silk

Silk is one of the most precious textile fibres of animal origin, obtained from the flossy filament ejected by the silk worm of the butterfly Bombyx mori. According to tradition, silk was discovered by a young Chinese empress, Hai Ling Shi, in 2640 BC. She noticed in her garden, on the branch of a mulberry tree, a small white cocoon, and brought it into the imperial palace to examine it more closely. Casually she dropped it into hot water and noted that a thin filament began to unwind. The court weaver was asked to do experiments with the new filmy fibre which kept unwinding as the empress pulled it; his trials resulted then in the weaving of the first silk dress.
Silk processing aims at obtaining from cocoons a yarn as uniform as possible. It should be pointed out that it is the only continuous filament existing in nature. Raw silk consists by 60-70% of fibroin (a white coloured protein), by 20-22% of sericin and, for the rest, of gummy substances, minerals and dyestuffs.

Before the pupa changes into a butterfly, cocoons are submitted to a first selection to eliminate the faulty ones and remove their outer layer (floss silk); then they are kept 16-18 hours in drying ovens to cause the pupa’s death and to eliminate moisture which would jeopardize their preservation.

The next operation is the cocoon sieving aimed at removing the residual floss silk, which may however be used together with other types of waste: imperfect cocoons, flock silk, filoselle, broken silk in schappe spinning.

A second sorting is then carried out to divide the cocoons into three size categories, which will be reeled separately because the smaller the filament diameter, the smaller the corresponding cocoon. After softening by immersion in warm water to facilitate the filament extraction, the cocoons are brushed to find the tail end of the filament and to remove from them the top layer of hair (flock silk). Once the tail ends are found, the cocoons are unwound until reeling begins to take place without difficulty. Degumming is followed by filament reeling, which produces a yarn composed of several filaments depending on the required yarn diameter. Once the yarn is twisted, it is wound with helical angle on reels, which are generally contained in special boxes which are closed and heated to enable yarn drying. The dried yarn is packed into skeins and put on the market under the denomination of raw or ecru silk.

2.4.1 Production and consumption

During the past 30 years, the world production of raw silk has steadily grown; this was however associated with a deep change of the production structure in terms of producing countries. In fact in 1970, with a silk world production amounting to abt. 40,000 tons, Japan accounted for the highest share with more than 50% (20,500 tons), followed by China (10,200), Soviet Union (3,000), South Korea (2,850), India (2,250). At that time, Italy still ranked among the producing countries with 310 tons.

On the contrary, today, the estimates of the International Silk Association show a global production of abt. 100,000 tons, where China is the leading producer with 70,000 tons (70%), whereas in Japan the production declined sharply to abt. 4,000 tons (4%). India, with 13,000 t, has therefore overtaken Japan and is now in second position, followed by CIS, Brazil and North Korea.

Among the “other” countries, let us mention Thailand, Turkey, South Korea, Vietnam, Indonesia and Paraguay.

Italy continues to rank among the leading importing countries of raw silk, which is converted, thanks to the skill of its domestic silk industry and to the high-tech Italian machines, into ply and schappe yarns, also blended with other fibres, into silk and bourette fabrics, scarfs, foulards and ties, which have made the Italian design renowned all over the world.
2.5 Bast fibres

The main bast or stem fibres, which are fibres containing fibrous bundles in their inner bark, are: flax, jute, hemp, ramie and kenaf. We shall here limit us to some short hints at flax, ramie and jute, which are currently the three most widely used bast fibres.

2.5.1 Flax

*Flax* is a herbaceous plant (*Linum usitatissimum*) of the Linaceae family, which is grown to obtain the most valuable vegetable fibre. It is part of the so-called bast fibres, as from their inner bark, called liber, fibrous bundles are extracted which, properly treated, are converted into fibres. As to the processing of flax, we refer to the chapter 4 “Bast fibre spinning technologies”, which illustrates two different spinning systems: wet and dry spinning.

The linen fabric is characterised by a considerable moisture absorption, therefore linen items are particularly comfortable. Linen is employed for the manufacture of high-class fabrics for top quality household linen, apparel and also decoration fabrics.

In these last years the linen world production has gradually declined. In 1996, in Western Europe about 21,000 tons of flax yarns and 16,000 tons of linen fabrics were produced. Italy ranks first in terms of production of both flax yarns (6,800 tons) and of linen fabrics (9,100 tons), followed by Ireland, Belgium and France.

2.5.2 Ramie

Ramie is a bark or stem fibre, which use in fabric production dates back to ancient times; in the ancient Egypt, it was used as early as in 500 BC. At present it is mostly grown in China in form of white ramie; its production totals about 100,000 tons/year.

The ramie plant is a species of the Urticaceae family and resembles the flax plant; in fact it grows up to 2 metres height and to a diameter of 1-2 cm; the fibres are distributed on a cortical layer situated just underneath the outer bark and are glued together by gummy and gelatinous substances.

Unlike other bast fibres (flax and hemp), ramie is not retted, because of the low corruptibility to micro-organisms of the organic substances gluing the fibres together, and because of the risk of fibre fermentation during retting, with ensuing tenacity loss.
Owing to its whiteness and silky lustre, ramie is the most beautiful cellulosic fibre. Its tenacity and the possibility of converting it into single fibres enable to produce fine counts, while its resistance to wear and to excess of moisture (rot) makes ramie fabrics extremely weather resistant. Unlike flax, ramie does not show any tenacity loss in wet state. Its length can vary from 60 to 250 mm and its diameter from 10 to 100 μ: as such, it is the longest and broadest vegetable fibre. Its chemical resistance is better than that of other bast fibres; it reacts properly to bleach, which yields light, extremely pure colours and pearly shades.

2.5.3 Jute
Jute is obtained from the bark of some trees of the Tiliaceae family which live in Asia and in Africa and is grown mainly in Bangladesh. It is mostly used for weaving primary and secondary carpet backings and packaging materials.

2.6 Artificial fibres
As already mentioned in the introduction, the increase in world population (from 3 billions in 1960 to over 6 billions in the year 2000) and its growing needs made it necessary to integrate the production of natural fibres with those of man-made fibres; these last expanded altogether at higher rates than natural fibres. Moreover this fact permitted to countries lacking in natural raw materials to develop an important textile industry and to extend their application field (just think of the countless blending possibilities of natural with man-made fibres).

The exact product definition of artificial fibres (quite often referred to as “cellulosics”) originates from the fact that they originate from a raw material which, though fibrous in nature, cannot be used directly by the textile industry and is therefore properly “reclaimed” through technical processes or “expedients”.

Silk is the queen fibre that served as a model for the development of artificial silk, which took place at the turn of the 19th century thanks to the invention of Count Hilaire de Chardonnet who applied for the first patent covering a “textile material similar to silk”. Silk was also the model for the chemist Max Fremery who, in co-operation with the engineer Johannes Urban, succeeded in 1891 in dissolving cotton’s natural cellulose in cuprammonium and thus obtained a filament for electric bulbs with better performances and much longer life than the filament used until then. Later on, having realized that by stretching the filament they could obtain a much finer yarn suitable for the textile sector, they started the production of viscose.

The artificial silk by the cuprammonium process was successively produced and bore the trademark Bemberg. The raw material of the Bemberg yarn are the linters, which are filaments of pure cellulose covering the cotton seeds and which are used in the production of some rayon types.

At the same time a process was developed, by which cellulose was converted to the liquid state through a solution of diluted caustic soda. This principle was successively named “viscose process”.

Viscose too has a natural origin as it is derived from the cellulose of trees, which are specially grown for this purpose. It takes 22 years to a tree (generally pine tree) to reach the inner structure and the maturity which are decisive for the future quality of viscose. 100 years after the discovery of viscose, its production, in particular filament yarn production, remains still rather complex and time-consuming; in fact 30 days are necessary to obtain viscose from the cellulose sheet.

With the advent and development of synthetic fibres, the production curve of the artificial fibres have gradually levelled out, so that already in 1970 they were surpassed by synthetics. In fact in 1970 3.6 million tons of artificial fibres were produced, compared to 4.8 of synthetics. In 1998 the output of artificial fibres amounted to 2.8 million tons against 25 million tons of synthetics; therefore artificial fibres account today for less than
10% of the total production of man-made fibres. The Italian production of artificial fibres in 1998 amounted to about 30,000 tons; our country does not produce viscose staple. As a matter of fact, in the last few years there has been a certain revival of the interest in viscose, especially as a filament yarn, which application fields extended from the traditional and highly appreciated linings to apparel and furnishings. However the viscose producers proceeded cautiously in new investments to cope with the increased demand, since these plants often use old technologies and have to tackle serious environmental problems. On the other hand, as regards staple fibre, new processes have been developed. They are solvent processes: one for Tencel viscose fibre produced in the U.S.A. by an English company, and the other for Lyocell fibres produced in Austria by a process in which cellulose is dissolved in N-methyl-morpholine oxide (NMMO) and water.

Well established is the high wet module viscose fibre, known as modal fibre, which is often used in blend with other fibres. A 1.0 dtex micro-version of this type of staple has been recently introduced. On the market there are also types of flame resistant viscose staple, which can be used in blend with other fibres to provide textile items with fireproof properties. We also wish to mention the extra-bright silky acetate and triacetate yarns derived from cellulose acetate. After spinning, also acetate can be subjected to the regular textile operations, as twisting, texturing, warping and sizing.

2.7 Synthetic fibres

Synthetic fibres originate from non-fibrous products which become textile raw materials thanks to “synthesis” operations, hence their name. In chemistry, by the term synthesis is meant an operation by which, starting from simple substances, more complex substances are obtained. Thus synthetic fibres are the result of the combination of a great many chemical units, which are assembled to form long chains, the polymers, which are then converted into fibres by the spinning operation. The polymer is transformed by orientating the macromolecules in the formation process of the filament, which is the basic element of the following phases: drawing, production of continuous filament yarn or of staple fibre and, if necessary, texturing. By this last process, the filaments composing the continuous yarn are crimped to make the yarn bulkier. Polymerisation is the basic requisite for fibre chemistry, as shown by the fact that the prefix of several product names is “poly”: polyamide, polyester, polyacrylonitrile, etc. The world production of synthetic fibres has by now surpassed that of cotton; in 1998 it amounted to more than 25 million tons, compared to a little more than 18 million tons of cotton. Growth has been considerable over the last 30 years: suffice it to say that the output was 4.8 million tons in 1970, 10.6 million tons in 1980 and 16.0 million tons in 1990.

It is noteworthy that the synthetic fibre production, which until some years ago was concentrated especially in the United States, Western Europe and Japan, has progressively extended to other countries. Suffice it to say that, whereas in 1990 45% of the production still came from those three areas, in 1998 their market share shrunk to 31%, and this trend is likely to go on.

As regards Italy, the total synthetic fibre production reached in 1998 abt. 600,000 tons, which is equivalent to about 20% of total EU production and to 2.4% of world production.
2.7.1 Polyamide fibres

Polyamide fibres were the first synthetic fibres to appear on the market. They were produced for the first time in USA in 1938, as a result of the research which Wallace H. Carothers had started already a decade before with the objective of preparing through synthesis polymers with a structure similar to that of cellulose and silk. The way followed by Carothers was directed at achieving, as an intermediate material for fibre production, a polymer of hexamethylene diamine adipate (salt N) resulting from the reaction between hexamethylene diamine and adipic acid. This end-product was called nylon 6.6, because its two components have 6 carbon atoms each. However, in the same year 1938, Paul Schlack, taking advantage of the error of judgement of Carothers who claimed that caprolactam could not polymerise to form polyamides, succeeded in obtaining all the same a nylon - this time named nylon 6, being made up only of one product with 8 carbon atoms — without infringing the American patents. In the following years, his discovery was extensively exploited in Germany, where the product was called Perlon. Nylon 6.6 and 6 were later produced, under licence or through patent acquisition, also in other European countries, Italy included.

The polyamide fibre was rightly regarded as the “wonder” fibre by virtue of its countless end-uses: stockings and pantyhoses, swimwear, ladies’ underwear, corsetry, linings, umbrellas, outerwear, raincoats and floorcoverings. Nylon is also used for several technical applications: tyre cords, conveyor belts, filters, fishing nets, cordage, parachutes, safety belts, inflatable boats and other sport articles.

More recently, this fibre has been further developed to originate continuous filament yarns composed of very fine filaments (abt. 1 dtex) as flat yarns, false-twist textured and air-jet textured yarns, which are used in the production of a new generation of high performance fabrics which meet not only quality and fashion requirements, but also take into account the physiological properties needed by clothing (snowsuits).

This yarn has good dimensional stability to washing, impermeability to water and to air, permeability to steam, good heat transfer, silky and soft handle, good dye yield; all these factors contribute to make this material particularly suited to sport and leisure wear.

The polyamide family includes also other types of nylon: nylon 4 and 11.

More and more important is becoming the category of polyamide-imides, known also as aramid fibres. Of relatively recent development, these high-tech fibres, which resist
highest temperatures and even flame and have excellent resistance to chemicals, are suited to technical and industrial uses.

A specialty fibre with optimal comfort properties belongs to the new category of the polyoxyamide fibres. This fibre, which is produced in Italy, is particularly suitable for 20-50% blends with wool, angora, cashmere, alpaca, cotton, viscose staple and synthetics, thus resulting ideal for knitwear.

For dyeing nylon 6.6, usually acid and disperse dyes are preferred, although many other dyestuff classes can be used. Dyestuffs suitable for nylon 6 are disperse and microdisperse, acid, mordant acid, premetallized, synthetic (on the fibre) dyes. The overall world output of polyamide fibres in 1998 was about 4.0 million tons (about 16% of the total production of synthetic fibres altogether).

2.7.2 Polyester fibres

While pursuing the studies and the research works begun but left unfinished by Carothers, the British chemist John Rex Whinfelden with the co-operation of his young assistant James J. Dickson invented a method to produce polyester fibres from terephthalic acid and ethylene glycol, and applied for a patent on July 29, 1941. This new polymer was suited to produce extremely fine, soft and strong filament yarns, but it was only in 1949, after the second world war, that a pilot plant for the production of polyester fibres was put on stream in England. The commercial production started both in USA and in England in 1953.

Polyester is the most common synthetic fibre and is marked by a high growth rate. At present polyester production (filament yarn + staple) accounts for 60% of the total production of synthetic fibres.

In 1998 polyester world production amounted in fact to 16 million tons (9 million tons filament yarn and 7 million tons staple).

Up to 1975, polyester was produced on ethylene glycol (EG) and dimethyl terephthalate (DMT) basis; later also a second method based on terephthalic acid (TPA) was used. Also the discovery of polyester marked a new milestone in the industrial revolution, because this fibre has deeply changed the textile industry, imposing itself for its great versatility. Either pure or in blend with cotton and wool, it gave rise to new types of clothing and furnishing fabrics with interesting easy-care properties.

A further advantage was provided by the development of inherently flame-resistant polyester types, which allowed its wide application in products where fire resistance is a must: furnishing and in particular curtainings, industrial textiles and protective clothing. These special fibres, which resist or slow down flame propagation, retain an agreeable textile handle.

Polyester has excellent properties: dimensional stability, high tenacity, good resistance to light and weathering. Beside having increasing success in woollen, worsted and cotton-type apparel fabrics, polyester fabrics find wide application in household textiles and in nonwovens.

2.7.3 Microfibres

Concerning filament yarns, two were the most recent and striking developments: their application in textiles for automotives and the microfibres, that is yarns composed by filaments with a count finer than 1 dtex, hence fine than silk, for use in clothing. Microfilament yarns are offered in following versions: flat, untwisted, twisted, false-twist textured, false-twist textured and hard twisted, crêpe and air-textured. Microfibres have obtained with polyester amazing results in terms of filament fineness: 0,4 dtex. These yarns established themselves on the market of the silk-like products and in part replaced previous types which too had been designed to imitate silk. These are polyester yarns woven into fabrics which were treated batchwise or continuously with a decorticating finishing process also on Italian machinery, to impart a soft feel and a silky look to the fabric.
It is also worth to mention, that microfibres and in particular polyester microfibres, accomplish the task of satisfying “fashion + function” requirements. In fact from the aesthetic point of view the outstanding filament fineness translates into fabrics with absolutely innovative drape and handle, which are very often obtained through an emery grinding process carried out once again on Italian machines. As regards comfort, microfibres allow to manufacture fabrics with a density of up to 30,000 filaments/sq.cm., which are absolutely waterproof and yet breathable thanks to their permeability to body moisture.

Microfibres are offered also in staple form in 0.85 dtex by several producers both for short staple spinning on ring or open-end machines, and for long staple spinning. A special version for nonwovens is also available. Developments in the fibre sector continue unceasingly all over the world. Nylon and polyester producers bring out fibres with special cross-sections which differ from the basic sections, i.e. round, multilobal and triangular sections. A separate sector is that of the hollow fibres: recently a polyester hollow fibre with round cross-section has been produced for underwear of tracksuits. This is the finest polyester hollow fibre so far produced, which has outstanding heat insulation properties. The researchers of the U.S. laboratory where it was developed claim that undershirts made of this thermal fibre are 23% warmer than currently available products. Moreover these fibres can be dyed at lower temperature and can also include a percentage of elastomeric fibre (see below) to impart stretch properties, a result which was almost impossible to obtain before.

2.7.4 Acrylic fibres

Acrylic fibres were officially developed in 1948 by the same American producer who launched nylon. It was marketed two years later, but in the 50s this fibre was produced also in Europe by several companies and was characterised by a rapid boom which in 1975, barely 25 years after its invention, got it to equal wool world consumption. This success is closely related to the development of flat and circular knitting machines, which can produce considerable quantities of knitted fabrics.

In 1998 the world production of acrylics was 2.5 million tons (10% of the world total of synthetic fibres).

The name acrylics identifies the fibres made of pure polyacrylonitrile or of its co-polymers containing at least 85% in weight of acrylic nitrile. On the contrary the name modacrylics identifies the fibres produced from polymers containing at least 35% (but less than 85%) in weight of acrylic nitrile. The latter fibres have excellent flame-retardant properties and, through this characteristic, they integrate the polyester fibre range.

Acrylic fibres are offered as tow, staple and top. Quite economical are the spun- or producer-dyed types, which now account for a substantial share of the total production. The use of dyed fibres allows a lower processing cost (from fibre to dyed yarn) compared to the conventional cycle composed of raw yarn spinning and of hank, cone or piece dyeing, moreover it enables to obtain a superior quality in terms of appearance and properties of the yarn. Also dyeing evenness and shade uniformity among different lots are better. By mixing 2 to 4 basic colours with the raw fibre, a wide range of melange colours can be also obtained.

The end-uses which emphasize the characteristics of the acrylic fibre are:

- all knitted items: outerwear and underwear, hosiery, hand knitting yarns (advantages: high bulkiness, stitch clarity, unshrinkability, easy washability without any felting, quick drying, high comfort);
- fabrics, furnishing velvets, carpets (advantages: item’s long duration, low soiling, easy cleaning, good resilience of the pile which therefore does not get crushed);
- awnings (advantages: excellent resistance to sunlight, weathering and mildew);
- imitation furs (so-called ecological furs) and pile fabrics for clothing linings (advantages: lightweight, softness and easy-care properties).
In 1991 microfibres were developed also in the acrylics sector with the launch in Italy and almost at the same time in Germany of staple fibres 0.8 dtex which were immediately well accepted by the spinning mills. The yarns produced have a very soft, but firm handle, a silky lustre as demanded by the knitwear market, optimal bulkiness and roundness and, therefore, a high covering power and high thermal insulation even with lightweight fabrics.

2.7.5 Polypropylene fibres
Polypropylene fibres belong to the polyolefin fibre group. They were the result of the research work and of the discovery of isotactic polypropylene by Giulio Natta who, in 1963, together with K.Ziegler, was awarded the Nobel prize for chemistry. The term “isotactic”, which summarizes a concept of molecular structure is best explained by the stamp issued in Sweden in 1988, which symbolizes the close link between the order given for the molecule aggregation - the spider, admirable architect of nature - and a spinneret which - like the spider - extrudes thin filaments from a melt of ordered macromolecules.

The world production of polypropylene fibres amounted in 1998 to over 2 million tons. Polypropylene fibres have following peculiar properties:

- very low specific weight
- high tenacity
- high resistance to acids and caustic soda
- high rubbing resistance
- minimal thermal conductivity, low soiling thanks to low electrostatic charges and to water-repellency.

On the other hand, just because of this last property, polypropylene fibres are difficult to dye and therefore are supplied already dyed by the producer (dope dyed fibre) in very nice colours. Research works and studies aim in fact at developing dyeable types and finer filaments, according to the general trend.

Polypropylene is the most used fibre in baby diapers and adult pads, because the so-called coverstock does not absorb liquids, but spreads them to the underlying fluff, thus ensuring that the skin remains dry.

2.7.6 Elastomeric fibres
These fibres are derived from an elastomer containing at least 85% of segmented polyurethane. The fibre, when stretched under tensile force until three times its initial length, recovers rapidly this length as soon as tension is removed.

This fibre was launched in 1959 by an American producer, who is still their major producer in the world. Its use became however widespread only some years ago when the stretch comfort became a must, so that, at a certain moment, available capacities were no longer sufficient to cover the market demand, and expansions and new plants had to be provided. Some new producers were also attracted by this promising market outlet.

Concerning this leading fibre, it has to be taken in mind that the yarn, although looking like a single continuous filament yarn, is actually composed of a bundle of thin filaments joined together. Main end-uses are: stockings and panty-hoses, tubular knit fabrics for ladies’ underwear and sportswear, warp knit fabrics for ladies’ lingerie and swimwear, warp knit fabrics for corsetry and sundry applications.

The elastomeric yarn is used in different percentages, depending on type of fabric and on its end-use; even only 2% is sufficient to improve the quality of the product by imparting liveliness, drape and better recovery properties. The yarn has the same dyeability and processing characteristics as a synthetic fibre and can be integrated, in the nude state, into many textile structures. It can however be covered with another yarn
or with another fibre. The covering can be either single or double; alternatively it is possible to produce stretch core yarns which, during weaving or knitting, are doubled with non-elastic yarns, thus obtaining fabrics of greater value, more comfortable and with better wear properties.

A third alternative is interlacing: an anelastic multifilament yarn is caused to pass through an air jet together with the strained elastomeric yarn. As a result of an air jet, the yarns get interlaced and the elastomeric yarn gets partially covered.

### 2.8 Textiles for technical uses

Technical textiles have some characteristics in common with traditional fabrics, but also other specific and different characteristics. The elements which should be taken into consideration to identify this sector are:

- the raw materials
- the technologies
- the products and the end-uses.

#### 2.8.1 Raw materials

Raw materials for the production of technical textiles are virtually all fibres, with preponderance of man-made fibres. Technical textiles are still nowadays composed largely by traditional fibres, entirely similar to the raw materials of traditional textiles. Innovative fibres are going however to be created even more in the future; these fibres have new and special features unobtainable in nature, aimed also at attaining performances which often conflict with each other (e.g. tenacity and softness, durability and degradability after use) which cannot be obtained with traditional fibres. These high performance fibres (HP fibres) have however a cost considerably higher than traditional fibres. Their cost is in fact closely related to the exceptional performances imparted by them, consequently their use has to be weighed depending on the real requirements of the single end-use.

<table>
<thead>
<tr>
<th>Cost ratio between high performance (HP) fibres and traditional fibres</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fibre</td>
</tr>
<tr>
<td>-----------------------------</td>
</tr>
<tr>
<td>Traditional fibres</td>
</tr>
<tr>
<td>Glass</td>
</tr>
<tr>
<td>Para-aramids</td>
</tr>
<tr>
<td>Carbon fibres</td>
</tr>
<tr>
<td>Polyethylene (high module)</td>
</tr>
<tr>
<td>Ceramic fibres</td>
</tr>
<tr>
<td>Boron fibres</td>
</tr>
</tbody>
</table>

*Source: Tessili per Impieghi Tecnici, December 1996*

#### 2.8.2 Production technologies

Many of the technologies used for technical textiles are the same as for traditional textiles, from spinning to weaving until making-up, with some adjustments and modifications. In some cases, however, specific technologies are used, which find exclusively application in technical textiles: f.i. nonwoven production, three-dimensional weaving, braiding, composite formation.
In this regard we point out that nonwovens overlap to a wide extent technical textiles: in fact nonwovens are largely applied in technical textiles, of which they have an important share.

### 2.8.3 Products and applications

Textiles for technical uses are products which are assessed on the basis of a series of factors which are the same used for assessing traditional textiles, but refer to a different hierarchy of values in terms of importance and of priority.

#### Hierarchy of the factors applying to traditional textiles

<table>
<thead>
<tr>
<th>Factor</th>
<th>Ranking</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aspect</td>
<td>1</td>
</tr>
<tr>
<td>Colour</td>
<td>2</td>
</tr>
<tr>
<td>Handle</td>
<td>3</td>
</tr>
<tr>
<td>Delivery time</td>
<td>4</td>
</tr>
<tr>
<td>Cost</td>
<td>5</td>
</tr>
<tr>
<td>Workability</td>
<td>6</td>
</tr>
<tr>
<td>Resistance to maintenance</td>
<td>7</td>
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<tr>
<td>Minimum lot size</td>
<td>8</td>
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<tr>
<td>Comfort</td>
<td>9</td>
</tr>
<tr>
<td>Quality guarantee</td>
<td>10</td>
</tr>
<tr>
<td>Tuning with seasonal deadlines</td>
<td>11</td>
</tr>
<tr>
<td>Environmental regulations</td>
<td>12</td>
</tr>
<tr>
<td>Safety regulations</td>
<td>13</td>
</tr>
<tr>
<td>Mechanical performances</td>
<td>14</td>
</tr>
<tr>
<td>Technical specifications</td>
<td>15</td>
</tr>
<tr>
<td>Behaviour forecast</td>
<td>16</td>
</tr>
<tr>
<td>Physical-chemical performances</td>
<td>17</td>
</tr>
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</tr>
<tr>
<td>Resistance to maintenance</td>
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<tr>
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<td>12</td>
</tr>
<tr>
<td>Comfort</td>
<td>13</td>
</tr>
<tr>
<td>Handle</td>
<td>14</td>
</tr>
<tr>
<td>Colour</td>
<td>15</td>
</tr>
<tr>
<td>Appearance</td>
<td>16</td>
</tr>
<tr>
<td>Tuning with seasonal deadlines</td>
<td>17</td>
</tr>
</tbody>
</table>

*Source: Tessili per Impieghi tecnici, December 1996*

In reality we are facing two different worlds which however have some overlapping areas and some zones of common interest:

- they use the same kind of raw materials
- they use the same processes, and often the same machines
- they involve the same kind of operators
- in many cases the producers of technical textiles come, more or less directly, from traditional textile enterprises
- many enterprises have in their production both technical and traditional items technical products too have to comply with high aesthetical requirements, while traditional products must have well defined technical performances.

As for traditional textiles, also in the case of technical textiles there is a close link between the economical situation and the consumption volumes, but it differs according to the sector.

For instance, the trend of the transport sector conditions considerably the consumption of textiles for automotive applications (air bags, safety belts, panels and seat covers), just as the trend of avionics conditions the consumption of composites.
In other cases, on the contrary, technical textiles are anyway expanding, e.g. in the sectors related to ecology, health and wellbeing. Here trends remain even under difficult economic situations: in fact some values have become for certain reasons irremissible. The following tables show the fibre consumption for technical textiles in the major countries, the percentages of used fibers, the processes employed, the products and the market shares of each type of technical textile.

<table>
<thead>
<tr>
<th>Country</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Japan</td>
<td>39</td>
</tr>
<tr>
<td>USA</td>
<td>29</td>
</tr>
<tr>
<td>Germany</td>
<td>25</td>
</tr>
<tr>
<td>France</td>
<td>22</td>
</tr>
<tr>
<td>Spain</td>
<td>19</td>
</tr>
<tr>
<td>EU average</td>
<td>15</td>
</tr>
<tr>
<td>Italy</td>
<td>14</td>
</tr>
<tr>
<td>U.K.</td>
<td>12</td>
</tr>
</tbody>
</table>

Source: Tessili per Impieghi tecnici, December 1996

<table>
<thead>
<tr>
<th>Fibre</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polyester</td>
<td>32,7</td>
</tr>
<tr>
<td>Polypropylene</td>
<td>30,8</td>
</tr>
<tr>
<td>Polyamide</td>
<td>12,1</td>
</tr>
<tr>
<td>Acrylics</td>
<td>2,8</td>
</tr>
<tr>
<td>Cellulosics</td>
<td>21,5</td>
</tr>
</tbody>
</table>

Source: CIRFS, from Technische Textilien, March 1997

<table>
<thead>
<tr>
<th>Processes</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nonwovens from staple fibre</td>
<td>43,6</td>
</tr>
<tr>
<td>Spunbonded</td>
<td>22,7</td>
</tr>
<tr>
<td>Continuous filament yarns</td>
<td>27,3</td>
</tr>
<tr>
<td>Staple fibre yarns</td>
<td>6,4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Types</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nonwovens for technical uses</td>
<td>59</td>
</tr>
<tr>
<td>Tyres</td>
<td>8</td>
</tr>
<tr>
<td>Fabrics</td>
<td>13</td>
</tr>
<tr>
<td>MRG</td>
<td>5</td>
</tr>
<tr>
<td>Knits</td>
<td>3</td>
</tr>
<tr>
<td>Waddings</td>
<td>3</td>
</tr>
<tr>
<td>Ropes</td>
<td>3</td>
</tr>
<tr>
<td>Others</td>
<td>6</td>
</tr>
</tbody>
</table>
3.1 Technologies for cotton spinning

3.1.1 The spinning systems
The Italian textile machinery industry can offer a complete range of machines for the spinning of cotton and of man-made fibre in cotton staple length. Chart 1 shows the spinning systems which are used for converting the fibre into yarn.

Chart 1 - Spinning systems using Italian machinery

<table>
<thead>
<tr>
<th>Short staple spinning</th>
<th>Long staple spinning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rotor spinning</td>
<td>Worsted spinning</td>
</tr>
<tr>
<td>Ring spinning carded</td>
<td>Semi-worsted spinning</td>
</tr>
<tr>
<td>Ring spinning combed</td>
<td>Wollen spinning</td>
</tr>
<tr>
<td></td>
<td>Dry and wet spinning of flax and hemp</td>
</tr>
</tbody>
</table>

The insertion of electronic systems for controlling the various movements, as well as the use of pneumatic and hydraulic devices and of data processing systems permitted not only to enhance performances, but also to obtain flexibility in spinning and the on-line control of product quality consistency.

The installation of automation systems on board the machine and the linkages among the various machines enable to reduce the attendance by the operator. Besides we point out that the personnel in charge has taken up mainly a function of supervision and of control, while dropping progressively the heaviest and most exacting tasks.

3.1.2 Spinning preparation
The laying out of a spinning preparatory line shall take following targets into account:

- minimization of the residual impurities in the fibres
- most intensive mixing of the fibres
- lowest discard of good fibres
- maximum flexibility

This is in fact a continuous process, from the fibre bale up to the card sliver contained in the cans, which later on are carried to the drawing frames.

The factor which became of the utmost importance is the flexibility of the process, which permits blends of up to 4 different types of fibre in percentages ranging from 2% to 98%.
3.1.2.1 Opening and cleaning
Spinning preparation begins with the bale plucker (Fig. 1). This machine has been fundamental in improving quality, as it enables to remove from the feeding bales, which number can be up to 100, very small tufts of material. This fact is the ideal prerequisite for a good blending in the subsequent passages. The plucking carriage can handle cotton and man-made fibres with up to 60 mm staple length.

Figure 1 - Bale plucker

The subsequent opening and blending line must be studied and adjusted according to the kind of cotton, to its degree of impurity and to the quality to be obtained. The search after blends of different qualities of cotton is of utmost importance to optimize the quality/cost ratio.
The mixer (Fig. 2) plays therefore a fundamental role to produce a homogeneous fibre mixture which can lead to an optimal regularity in terms of tenacity and of count of the end-product and consequently to reduce yarn breakages on the following machines.

The automatic mixer can have up to eight cells, with standard delivery or with joint cleaning unit.

The material, reduced to small tufts, is delivered to the horizontal opener and to the dust separator.

In case of blending of two different fibres, two weighing hopper feeders can enter into the line, in order to achieve an intimate blend of the two fibres (Fig. 3).

**Figure 3 - Weighing hopper feeder**
The fibres are conveyed by a *power-driven fan* into the feeding channel of the *feed chute* positioned above the cards. Each card is equipped with its own feed chute. In some cases a *horizontal opener* is used, equipped with dust suction hood before the feed chutes. A regular feeding of the material to the upper rooms of the feed chutes and a constant weight of the delivery material guarantee the excellent count regularity of the card sliver. In the opening line, machines have been included which detect foreign substances among the cotton fibres, as heavy matters, synthetic material, etc. and eliminate them through local suction systems. The spinning preparation phases are summarized in Chart 2.

**Chart 2 - The phases of the preparation to short staple spinning for a two-components blend**

(*) Number and type of opening and picking machines depend greatly on the quality degree and on the impurity contents of cotton

**3.1.2.2 Flat card**

This machine is intended to clean and parallelise the fibres and to produce a card sliver in which fibres are regularly distributed (Fig. 4). The card carries out also a cleaning action. The careful study of the clothings and of the air passages permitted to increase further the productivity of these machines.
An industrial production of 50-60 kg/h has become to-day a quite usual reference. This result has been attained by further developing following features:

- the feeding of a batting of constant count, well opened and sufficiently cleaned
- a more intensive opening and cleaning action, by the licker-in, with an effective waste removal
- the improvement of the suction system
- the automatic control of the sliver regularity and quality, in terms of neps.

### 3.1.2.3 The cotton drawing frames

The purpose of this machine is to parallelise the fibres by doubling and drawing several slivers.

In order to produce a sliver with maximum regularity, automatic adjustment systems are used for reducing short-, medium- and long-term variations in the sliver weight. In fact sensors are used to measure the variations in sliver weight, and the consequent necessary corrections are applied by varying the draft, that is the speed of the delivery rollers as compared to the feed rollers.

Depending on the envisaged end-product, one or two drawing frame passages can be made. This processing stage is extremely important for the regularity of the end-product, as the following machines (the roving frame and the spinning frame, both ring and rotor frame) cannot correct any more the weight irregularities of the roving and of the yarn.
3.1.3 The spinning
The spinning technologies are three (Chart 3):

- carded ring spinning
- combed ring spinning
- open-end rotor spinning

Chart 3 – Short staple spinning systems

3.1.3.1 Carded ring spinning
Carded ring spinning is employed for coarser yarns (up to Ne 40) and makes use of less valuable cotton types in terms of fibre length, diameter and cleaning degree.
After one or two drawing frame passages, the sliver coming from the cards is laid into cans which feed the **roving frame** (Fig. 5). This machine has the purpose of reducing through draft the weight of the sliver, forming a roving which receives a certain twist by a flyer system. This roving is wound onto bobbins suited to feed the ring frame.
Figure 6 – Ring spinning frame
The roving frame can be equipped with a manual doffing, in which case the bobbins are positioned on trolleys and carried to the spinning room. Alternatively the roving frames offer, now quite frequently, automatic linkage systems between the roving frame and the spinning frames. The bobbins are laid by this system on a storage line in front of the spinning frame. The machine is equipped with automatic cleaning and suction systems of the broken rovings. The next machine is the ring spinning frame (Fig. 6). The roving coming from the bobbin of the roving frame is drawn up to 50 times. Fibres up to 60 mm length can be processed. The drawn and parallel fibres coming out of the draft unit are imparted a twist through the ring-traveller system. Special systems have been worked out, which at the delivery of the draft unit improve the control on the fibres and prevent the edge fibres from moving with their ends outwards, which would cause a certain hairiness to the yarn as well as a loss of tenacity. These developments offer following advantages:

- improve yarn quality and reduce hairiness, with ensuing advantages in the subsequent singeing and sizing operations
- increase yarn tenacity while leaving twist unvaried, or increase production, as it is possible to confer a lower twist while leaving tenacity unchanged.

The yarn thus obtained has the final dimensions and, through the fibre twist, attains the desired tenacity according also to the fibres used. The yarn is wound on bobbins weighing about 50 to 100 grams. Bobbin removal from the ringframe is at present generally carried out by automatic doffing devices, as also the loading of the empty tubes, ready to be wound. The bobbins can be discharged into containers which feed the following machines: the winders. The spinning frame can be also linked through automatic conveyor systems to the winders, a machine which we shall examine more in detail in the chapter concerning yarn finishing.

The spinning frame can produce a wide range of counts and handle both up to 60 mm long cotton and man-made fibres, with a wide range of ring diameters, depending on the count being processed. Spindle speed can attain up to 25,000 rpm. The spindle can be operated either by tangential drive through a single belt for each side of the machine, or by tangential drive divided into sections of 48 spindles each and a single shaft along the machine. At the moment the single motor systems are too expensive, even if they have inferior energy consumption and are less noisy.

### 3.1.3.2 Combed ring spinning

To obtain finer yarns, besides using longer fibres (30-38 mm) of smaller diameter, the sliver is submitted to a combing operation, which has a dual purpose:

- to eliminate the shorter fibres
- to further parallelise and clean the longer fibres.

Before combing, the sliver must be prepared with a passage of pre-combing drawing frame, followed by a lap winder, which has the task of assembling a certain number of slivers (24 or 36) in form of a roll (lap) suitable for feeding regularly the combing machine. The lap winder is equipped with automatic systems for lap weighing and with differential pressure systems during lap formation, so as to reduce felting even at high production speeds.
The **combing machine** (Fig. 7) in which, through an intermittent movement, some fibre tufts are picked up, made to pass through two combs (a circular comb for combing the top ends of the tufts and a straight comb for the back ends), separates the short fibres according to the fibre diagram to be obtained. This operation causes also a reduction in the neps, the fibre entanglements which cause later on broken ends in the spinning machine and irregularities in the yarn.

**Figure 7 – Cotton combing machine**

The new models of combing machines are equipped with automatic lap feeding devices. Besides, systems have been developed for the automatic lap transport from the lap winder to the combing machines. After combing, the cycle continues with a drawing frame passage, the roving frame, the spinning frame, the winder and, if necessary, yarn doubling, twisting and finishing (see chapter 3.3).

**3.1.3.3 Open-end spinning**
This is a spinning system in which the spinning frame is fed by the drawing frame sliver and builds up directly the cones, omitting the roving frame passage and in many cases the cone winding.
The fibres composing the sliver are drawn and individually separated by an opening roller and are conveyed into a rotor which regroups them and imparts the twist to the yarn.

The rotor speed has now reached 130,000 rpm, which enables to the machines a considerable production.

The system has however a technical limit: in fact as not all fibres are positioned parallel to the yarn axis, the yarn has a lower tenacity. Moreover a certain number of fibres per cross-section is necessary, therefore it is not possible to spin counts finer than Ne 32-36.

The produced yarn is of optimal quality and is used also to produce knitwear and plush fabrics, besides household textiles and denim.

The open-end spinning frame, thanks to its particular configuration (feeding through slivers, take-up on cones) has enabled a complete production automation through following units:

- automatic can-changing
- piecing of the fed sliver
- piecing of the broken yarns and automatic rotor cleaning
- change of the full cones and feed of the tubes
- production of metered cones
- control of yarn regularity
- centralized control of all machine functions.

The production data of the spinning machine can be displayed on a video terminal or printed for each spinning position or for each section or each shift. The possibility of producing low twist yarns and of spinning successfully polyester, acrylic and viscose fibres, both pure and blended, make this machines highly flexible.

3.1.4 Automated systems for material handling

The automated systems have been installed in the spinning mill whenever the price/performance ratio was profitable. Automatic can changing devices on cards and drawing frames have become standard, as well as the automated doffing systems on roving frames and on spinning frames.

As to the linkages between the various machines and to the material handling, following systems gained ground:

- linkage between lap winder and combing machine, for lap transport
- transport system for the roving bobbin with bobbin change by six or three units. An overhead trolley removes the bobbins produced by the roving frame, in a number corresponding to a sixth of the machine spindles and conveys them to an overhead store-room situated in front of the spinning frame. With same system the empty tubes are removed from the spinning frame and brought to the roving frame.
- robotized systems for unloading the bobbins from the open-end spinning machines and from the winders and their loading on pin trolleys or on pallets. These last, as soon as full of cones, are wrapped with a polyethylene sheet, weighed and labelled. These equipments can be placed at the end of the machine or in fixed positions fed by a bobbin transport system.

3.1.5 Environment technology

Air conditioning, waste recovery, dusty air control, noise abatement, are all essential conditions to optimize product quality and working environment.

The air-conditioning plants for textile mills are based on cooling through evaporation and have as their target to keep temperature and relative humidity constant in the various
production departments. These two parameters are essential for a successful running of the machines in all departments.
The air in the various departments is changed 20-30 times per hour, using suitable fans. The air is filtered, cooled and humidified and conveyed back to the working rooms. The plants have generally modular structure and are adjusted to the requirements of the single department.
Cotton processing causes the emission of large quantities of dust.
The machines are maintained clean through suction systems integrated in the machines, as in the case of cards and drawing frames.
On roving frames and spinning machines cleaning systems running on trolleys along the machines (travelling cleaners) are used which, through appropriate air blowing and suction phases keep machines and floor clean.
A particularly important role is played by the filtering systems, which are suited to the kind of dust originating in the different departments.
The spinning mills are also provided with waste recovery systems, which separate the single types of waste depending on the machines originating them, as they can be reused in different forms.

3.2 Technologies for wool spinning

Wool and man-made fibres with wool staple length can be processed according to three systems:

- Worsted system
- Semi-worsted system
- Carded system

3.2.1 Worsted system - Wool top preparation
Wool is received in bales and has to be scoured to eliminate all foreign substances. Prior to scouring, wool is prepared in a plant including a bale-breaker and an opener (Fig. 8).
The bale-breaker has an opening and evening cylinder running at variable speed as well as a stripping roll. The opener has a step structure without watertight elements, so that wool can reach the scouring bowls thanks to the simple action of the beating cylinders.
To prepare blends of various types of wool ensuring an optimal price/performance ratio, prior to scouring a blending system is used.
The line is composed of a heavy-duty bale-breaker, of a drum beater which cleans and opens up the greasy wool (raw wool). A system of conveyor belts transfers the wool to a set of storage bins with a capacity of 10 tons each. In this way it is possible to form layers of different types of wool.

From these bins the wool is automatically conveyed to the feeder of the scouring line. After passing through a step cleaner, the scoured and dried wool is pneumatically conveyed to into storage bins having a capacity of 7 tons. Wool is taken out from these bins and transported to the feeding hoppers of the cards by means of mechanical systems. The technological cycle from the wool bale to top is described in Chart 4.
3.2.1.1 Opening - blending - oiling
For the processing of small lots (100 to 1000 kg of fine and delicate fibres), a monobloc line is used; this carries out all following working stages:

- bale-breaking
- mixing of different components
- fibre opening and intimate blending
- dust exhaustion
- batching oil spraying (fibre is oiled to facilitate subsequent processing stages)
- proper baling for the semi-finished product.

3.2.1.2 Carding
For wool worsted spinning, cards with rotating drums covered with needled clothing are used. The card has the task of cleaning, parallelizing and laying the fibres in form of a web (Fig. 9). The fibre feeding is at present completely automated. The cards are equipped with computerized control systems which monitor each processing phase. The result of the process is entrusted to precise micrometric adjustments of the various machine members and this is the more important, the more valuable are the fibres to processed. In these cases cards with up to 12 carding points are used, which ensure a mild and progressive opening and parallelizing action.

At the delivery from the machines, the web is taken-up in form of sliver which is made thinner by passing through a draft unit with pinned discs for a guided control of the fibres.
To increase production at same speed, the working width have been increased up to 3500 mm.
In this draft unit also autolevelling systems are installed.

3.2.2 Combing

This operation characterizes the processing of longer and finer wool for the production of valuable yarns.
Combing produces wool slivers (tops) of 20-30 g/m, which are made up in bobbins or cans, which contents is successively pressed into bumps.
The aim of this operation is to eliminate the shorter fibres and at the same time to parallelize and to clean the fibre bundle.
The combing line envisages several passages.

3.2.2.1 Pre-combing

Pre-combing lines generally consist of three intersecting passages which enable to parallelize the fibres, so as to comb the fibres with minimum discarding of long fibres. When processing wool and long-stapled man-made fibres, pin drafters are used which have combs placed between the feed and delivery rollers to control the fibres during the drawing operation.
The combs are driven by chains or by rotating cams and the drawing frames can be fed by cans or by bobbins. The delivery units are automated both for can and bobbin delivery.
The drive systems use motors with frequency controlled speed (inverter), which permit to change the working speed according to the kind of processed fibres.
The drawing frame has at its delivery automatic devices for sliver threading, so as to facilitate sliver piecing in case of sliver breaking.
The geometry of the comb system is of primary importance, especially the distance between the points at which the comb quits the sliver and the nipping point of the delivery rollers, in particular when processing wool types containing high percentage of short fibres.
In the latest machines, the axis of the feed and delivery sides are driven by separate motors with electronic control of the speed and consequently of the change of draft ratios. These drawing frames can be equipped also with on-line control systems to ensure sliver regularity. The drawing frames with electrically driven axis enable to apply new self-adjustment systems, since the speed of the feed and delivery rollers are controlled and can modify the draft ratio depending on the electronic impulses coming from mechanical feelers which measure the mass of the input sliver.
The system includes also a memory which considers the time needed by the sliver coming from the feeler to reach the draft zone. These electronic systems have replaced complex mechanical systems.

3.2.2.2 Rectilinear combing machine

The purpose of this machine is:

- To eliminate shorter fibres
- To obtain a sliver with a fibrous diagram showing fibres with a higher average length
- To clean the sliver
- To further parallelize the fibres.

This process is carried out with the single-headed, intermittent working, rectilinear combing machine (Fig. 10).
A fibre tuft is torn out of the feed sliver by a gripper system. The heads of the fibres are cleaned by a rotating comb and the fibre tuft is then gripped by a pair of detaching rollers. At this stage the rectilinear comb lowers itself and combs the back ends of the fibres. The tufts are then overlapped and taken up in form of sliver. A crimping device imparts consistency to the sliver, before its laying into a can. The working speed reaches 260 strokes/min, the feeding charge is up to 500 g/m and the delivered slivers weigh 23-35 g/m.

The machine is provided with a suction system which removes impurities and collects the discarded short fibres, which are used within further processes.

3.2.2.3 Post-combing
The combing machine is followed by three passages of intersecting gill-box which, through the usual doubling and drawing actions, impart regularity to the sliver. A contribution in this direction is also given by the autolevelling system applied on one of the three intersecting passages. This operation is extremely important, as this is the last passage in which a change can be brought about to obtain a regular yarn. In fact the following passages - the finisher drawing frame or the roving frame or the spinning machine - have only the function of thinning the count. The pre-combing and post-combing stages can rely, in case of big production lots, on automated systems, although not neglecting the technological requirements which are essential for a good yarn quality:

- Doubling of the slivers
- Alternate combing of the top end and of the bottom end to eliminate fiber hooks.

Considerable are the economies in material handling (-30%) and in the occupied floor space (60%).

3.2.3 Blending and preparation to spinning
This operation is the first stage of preparation to spinning and has the task of mixing the fibres before spinning (Chart 5).
The fibre slivers are dyed and dried and then conveyed to a drawing frame. Successively the slivers, delivered into cans or in form of bobbins, reach the feeding unit of the drawing frame blenders. The blender can double up to 24 slivers and draw them up 18 to 24 times, which results into a thorough mixing of the fibres.

### 3.2.3.1 Preparatory drawing frames to spinning

The slivers coming from the blender need, in case they have been dyed, a re-combing to separate the fibres which felted and thickened during dyeing. Re-combing includes two drawing passages, combing and re-combing through one passage of finisher drawing frame.
Further operations are 3 drawing passages, the first of which single-headed the second double-headed and the third 4-headed. The aim of these passages is always the same: to parallelize the fibres and to level the sliver weight. The heads of these machines can envisage the use of combs driven by chains or by revolving cams, or the use of rotating and toothed discs in the place of the combs.
The machines can be provided with autolevellers, generally placed on the first single-head passage.
Suction systems and sound-proofing casings are mounted on the drawing heads in order to limit the noise, while safety systems block the access to the drawing heads if these have not come to a standstill. During the preparation to spinning, while proceeding from the first to the third passage, the yarn count becomes finer; consequently, to maintain balanced the production, the number of drawing heads has to be increased.
The third passage has 4 heads and runs at up to 200 m/min speed.

3.2.3.2 Vertical rubbing finisher
This final passage of the preparation to spinning has a vertical lay-out. The drafting zone is followed by two rubbing zones which, thanks to their vertical lay-out, are easily accessible by the operator.
Rubbing provides the sliver with consistency and firmness. At the delivery, two slivers are doubled and wound together on the take-up bobbin. The machine is provided with an automatic device for the unloading of the full bobbins and the loading of the empty tubes. The machine permits a rubbing speed as high as 2200 strokes/min and productions over 200 m/min.

3.2.3.3 Roving frame
This machine is essentially equivalent to the cotton roving frame, but has draft unit suited to process wool or long staple fibres, in a count range from Nm 0.66 up to Nm 5. The machine can be used for fibres with low cohesion, as the roving gets anyway a certain twist. Besides, as every roving forms a bobbin, the machine can be easily connected through automatic linkage with the spinning machine.
The machine can be equipped with an automatic doffing system which, through an adequate transport system, conveys the bobbins to the spinning frames.

3.2.4 Worsted ring spinning frame
This is the last machine of the spinning cycle. It is fed by roving bobbins or finisher bobbins, has a three or four cylinder draft unit with double apron to ensure fibre control, grooved intermediate cylinder under the top apron to enable a controlled flowing of the fibres.
The machine uses the ring/traveller system to impart twist to the yarn and to obtain in this way the final strength properties.
The spinning frame has integrated automatic doffing for the unloading of the full bobbins and the loading of the empty tubes. The machine can be linked to the automatic winder. The bobbins are conveyed through a tray system. The latest models of spinning frames are driven by electronically controlled individual motors, which enable to quickly change twist, speeds and displacements of the ring rail according to the yarn count in process. Also in this machine the mechanical systems have been replaced with electronic control systems.
In the case of worsted spinning frame, the spindles are provided with a so-called “spinning head” system positioned over the turning element of the spindle, which produces a yarn geometry such as to reduce the tension and enables to attain speeds up to 16.000 rpm and to spin counts from Nm 10 to Nm 100. The spindles drive can be of tangential type or through bands and automatic tensioners.
3.2.5 Semi-worsted spinning system
This system (Chart 6) is used for the production of medium to coarse counts and eliminates the combing, rubbing frame or roving frame passages. It uses wool of medium fineness and blends with man-made fibres of medium deniers. The spinning frame is driven directly by individual motors.

Chart 6 – Semi-worsted spinning

![Diagram of Semi-worsted spinning process]

3.2.5.1 Preparation to spinning
Also this system includes opening, blending, oiling and carding on compact cards with one or two drums. The material can be delivered into cans or by a lap winder, which takes up the production of several cards.
The working width ranges from 2000 to 3500 mm.
The line includes successively three passages of intersecting gill, one of which with autoleveller, and the final drawing frame equipped with four vertical heads delivering 4 slivers into 4 cans.

3.2.5.2 Spinning
The semi-worsted spinning frame is fed directly by drawing frames cans with slivers weighing up to 15 g/m, and produces counts from Nm 1 to Nm 32.
The spinning frame can be linked to the automatic cone winders.
Drafts, spindles and ring rail drives are equivalent to those of the worsted spinning frame.

3.2.6 Woollen spinning
Opening and blending plants are designed according to the characteristics of the end-product and include different models of bale breakers and feeding hoppers, cleaning and blending machines, opening willows and fine openers, automatic boxes for fibre blending and stocking, vibrating chute-feed units, oil spraying systems, as well as pneumatic and belt conveyor systems.
All these machines are equipped with automatic systems for plant control and operation.
Short and coarse wool is used and sometimes even reclaimed fibres, resulting from rag tearing (Fig. 11).

3.2.6.1 Preparation to woollen spinning
The preliminary fibre opening is carried out by an opener and by a step cleaner with 6 beaters at progressive speed, which has also the task of removing dust. The following willow card, which performs the opening and blending of the fibres, has two feeding cylinders and three or four sets of workers/strippers.
The machine ensures a production of 1000 to 2500 kg/h, and yet leaves the fibres undamaged. The main cylinder of the willow card has a large diameter and is covered by hardened steel pins of special shape. The doffing cylinder rotates at high speed and is covered with special clothings.

3.2.6.2 Woollen cards
The carding set is composed of a breaker card, two carding units with elastic clothings and a condenser card. A double belt conveyor system crosses the web and feeds thereafter the condenser cards. The web of the last card is cut into stripes by a series of rubber tapes in a machine called web divider. The fibre stripes pass on to the rubbing apron, which forms a sliver of felted fibres. The slivers are then wound on bobbins which are placed side by side on cardboard tubes, called condenser spools. The modern machines have a device for the automatic unloading of the full condenser spools and their replacement with empty ones. The carding set is equipped with drive and monitoring systems for the speed of the various elements, as well as with data storage systems.

Figure 11 – Feeder and 2 drums rag grinder

3.2.6.3 Selfacting mule
This machine is particularly suited for the production of fine woollen yarns. It is fed by the condenser spools delivered by the carding set, which are positioned on a fixed part of the machine. The yarn is unwound by the condenser spools and drawn while it is twisted by the spindles placed on a travelling carriage. During the return of the carriage to its starting point, the yarn is wound on the spindles. All these motions are co-ordinated by a centralised electronic system which controls 8 axis. The latest machines have a moving out length of 4 meters and ensure 20 to 30% increases in production and an improvement in the yarn quality. The mules are equipped with automatisms for the change of the condenser spools, for the doffing of the bobbins from the spindles and for the piecing of the rovings.

3.2.6.4 Woollen ring spinning frame
This spinning machine is virtually the same as for semi-worsted spinning, with the exception that the feeding material consists of condenser spools coming from the carding room, instead of sliver. This machine produces a limited draft, owing to the nature of the fibres composing the yarn. Also this machine has integrated automatic doffing device and automatic condenser spool change. The diameter of the rings used ranges from 65 mm to 250 mm, while the height of the tubes ranges from 320 mm to 600 mm depending on the yarn count. The mule can be linked with the winders.
3.2.7 Spinning frames for fancy yarns
This machine enables to produce slub and knob yarns. The present trend is to design standard machines, on which various types of feeding systems can be installed so as to cope with market requirements. The use of hollow spindles in combination with ring spindles, permitted to design spinning/twisting machines which can be fed with flyer roving or with drafting frame sliver. It is also possible to build machines without draft unit, to perform only the twisting.

3.3 Technologies for yarn finishing
This sector includes all operations, through which the yarn is prepared into packages meeting the requirements of subsequent weaving, knitting and dyeing stages.

3.3.1 Bobbin-to-cone winding
The automatic winders have the task of unwinding the yarn from the bobbins and of winding it into cones having a form suited to the subsequent working stages (Fig. 12). Also the dimensions of the yarn is kept under control, as the yarn is made to pass through electronic supervision elements (yarn cleaners). Should the yarn dimensions exceed certain parameters, the yarn is cut and spliced. At the same time also the waxing of the yarn can be carried out, in case of yarn intended for knitwear production.

Figure 12 – Automatic winder
Yarn geometry is conceived so as to permit to perform all these processing stages at speeds which today can reach even 1500 m/min. All the various organs of the latest winders are driven by independent motors and are electronically controlled. It is thus possible to accomplish following targets:

- flexibility, productivity and reliability to ensure yarn and cone quality;
- total covering of all application fields of fibres with cotton and woollen staple length, as well as of flax and silk.

The machine can be supplied in following versions, with:

- manual loading and automatic cone doffing;
- automatic loading and cops preparation room;
- automatic linkage to the spinning frame;
- integrated continuous steaming system of the cops coming from the spinning frame (in case of worsted yarns);
- pre-set metering system;
- waxing system;
- manual or automatic feeding from cone;
- in a special version for wet spun flax;
- retroactive heater and continuous bulking of acrylic yarns in pure and blended with wool.

The conveyor belt which takes up the cones can be linked to an automatic palettization system.

### 3.3.2 Cone-to-cone winding

The cone-to-cone winding is used to produce cones having weight and form suited to the subsequent operations. In these machines the chucks of the creeling devices, the yarn carriers and the flute rolls are driven by electronically controlled independent motors. This permits to optimize cone formation by eliminating ribbons and hard edges and to make a more flexible use of the winding heads which can produce, depending on the mounted chuck, variously tapered conic bobbins or cylindrical bobbins. The winders are equipped with all accessories presently needed:

- preset metered length
- thread reserve device for head/tail piecing;
- waxing;
- cone doffing and automatic loading of the empty tubes;
- pneumatic and adjustable control weighing.

The electronic control of the motors driving the various members permits to have a computer assisted production.

### 3.3.3 Singeing

This operation is carried out on a cone-to-cone winding machine. The yarn passes through a gas flame at a speed of 400-1000 m/min. This process eliminates the hairiness of the yarn, which is so prepared for the subsequent reeling and mercerization processes. The machine is equipped with dust extraction system, flame temperature control system, and with all safety systems required by this kind of operation.
3.3.4 Reeling
Reeling has the aim of preparing the hanks to be used in the successive mercerization and dyeing of the yarn. Yarn is fed from cones. Yarn is wound with differentiated crossing, moreover both hank length and crossing type can be varied. Also these machines permit, thanks to the electronic control of the motors driving the reel and the yarn carriers, to obtain a perfectly uniform yarn lay. The hanks have standard diameter of 54", equal to about 1375 mm, and can reach a weight of 1,2 kg. A special device permits also to produce jumbo hanks weighing up to 5-6 kilos. The reel can be provided with automatic knetter.

3.3.5 Reeling off
This machine is fed by the hanks which were submitted to mercerization and dyeing and produces cones suitable for the subsequent operations, as: weaving preparation, feeding of the weft in weaving, feeding of the knitting and hosiery machines. The winding heads are virtually equivalent to those of a winder from cones, with hanks feeding. A compensation system prevents the breakage of the yarn in case of entanglements in the hank, at the same time stopping the winding head. The feeding system used up to now, i.e. with idling reel, was the cause of the speed limits of this machine (300-350 m/min). However at present reeling systems driven by independent, electronically controlled motors, are used; these, thanks to integrated brakes, ensure a quick stop of the head without end breakages, even at reeling off speeds of 600-650 m/min.

3.3.6 Doubling
The doubling of two or more yarns on same winding head is obtained through a winder fed by two or more cones per head. These cones feed the two-for-one twister. For this use, precision winding heads with driven chucks are preferred to heads with dragged chuck with parallel winding coils, in order to reduce tension variations when the yarn is unwound on the spindle of the two-for-one twister. In this case flanged bobbins are used.

3.3.7 Twisting
Yarn twisting has the aim to impart twist to two or more doubled yarns in order to obtain a stronger yarn which moreover lends a particular aspect to the woven or knitted fabric. This rather expensive process is used for the most valuable yarns. The machines used at present for this operation are the two-for-one twisters (Fig. 13). With this system, at each spindle rotation two twists are imparted to the yarn. The feeding material can be a cone of doubled yarns, or two cones laid one on top of the other, in which case the doubling takes place directly on the spindle. The feeding cone is idle and the wound off yarn is inserted into the stalk of the spindle, comes out of it from the bottom, places itself on a disk which rotates together with the spindle and then re-ascends on the outside of the feeding cone forming a balloon and finally, by passing through the loop, feeds the cone under formation. An overfeeding system controls the tension and therefore the cone density.
The yarn geometry, the yarn carrier position, the finishing of the container and the thorough design of the form of the ceramic elements have made this machine extremely functional.

An optical system integrated in the spindle ensures spindle stop in case of feeding defects, such as thick and thin places, singles, entanglements.
4.1 Introduction
Flax, the only natural fibre produced in Europe, after periods of reduced use, is resuming an important position in the field of pure or blended flax yarns with other natural and/or man-made fibres.
Flax processing is not easy, owing to the difficulty of producing fibres of sufficient fineness. This result can be obtained through a series of properly studied passages. From the conceptual standpoint, the processing stages are similar to those of wool, but the machinery, the settings and the number of passages have to be adapted to the type of fibre (Table 7).

4.1.1 Spinning preparation and spinning of flax
Before spinning, flax is subjected to some preliminary operations: retting, drying and scutching to remove gummy and woody substances composing the plant and to release the fibres.
The fibres resulting from the scutching process can be divided into:

- long staple fibres, which are the fibres extracted from the plant: they are about 1 meter long, are grouped into big bundles (sheafs) weighing 400-1000 g and joined into 80-100 kg bales.
- scutched tows, that is short fibres (100-300 mm) removed from the long staple bundle, which present a scattered fibre diagram and several foreign impurities.

4.1.2 Processing of long staple flax
Flax hackling transforms raw flax into hackled (combed) flax which is used for the production of high quality yarns. The process opens the fibre bundles into single fibres, parallelizes the fibres, eliminates the residual woody fragments and the short fibres, which are then removed by the combined action of rotating brushes, cylinders with rigid clothings and stripping hackles (combs).
The complete hackling line (also suitable for hemp processing) is composed of: a vertical hackling machine with 24 hackles, equipped with doffing device, automatic feeding of the spreadboard and an autospreader with hackle drafting system, designed in particular to take up automatically the sheafs coming from the vertical hackling machine and to form a sliver prepared for the subsequent preliminary spinning and spinning operations, or properly pressed for storage or sale.
The slivers resulting from hackling are progressively thinned on drawing frames, which reduce their weight from 30-40 g/m to 3-4 g/m. It is recommended to carry out 5 drawing passages using drawing frames with screw driven combs. At the delivery from the last passage, the sliver can be processed according to two methods:

- dry spinning directly from the sliver, for the production of a certain count range, according to criteria similar to those followed for flax tows.
wet spinning, used for finer counts, through the process traditionally employed for bast fibres, which entails before wet spinning a roving frame for further sliver thinning and, if needed, the bleaching of the sliver.

Table 7 - Spinning of long staple flax and of its by-products

The roving wound on flanged bobbins can be bleached and boiled off in order to remove every dirt particle, pectine, lignine and to separate further the single fibres, so as to improve fibre spinnability.

The spinning frame is available in two versions, one of which equipped with auto-doffing, fixed spindle rail (variable balloon) and max. 480 spindles placed on two independent machine sides.

The spinning frame has a draft unit composed of three rows of fluted rollers.
Each machine is equipped with an electronic roving stop-motion. Spindles are driven by an AC motor, with speed variation through inverter. Wet spun yarns are dried in drying rooms composed of:

- pre-heating zone
- drying zone (from 2 to 5 zones)
- cooling zone
- conditioning zone, to ensure uniform distribution in the yarn of the residual humidity.

### 4.1.3 Flax tow processing

As already mentioned, there are two types of tows: tows discarded from the hackling of long staple flax and tows obtained as by-products from scutching of stalks. Whereas the first can be directly processed in the preparatory cycle to spinning, the second need a preliminary process, the so-called “breaking”, on a machine composed of a couple of licker-in rollers which feed the material to the main cylinder, on which circumference couples of cylinders with different speeds are fitted, each couple being an opening point. At the end of this operation, a coarse but relatively clean fibre web is obtained, which will be submitted to carding.

The **card** has the task of starting or completing, in case of material delivered by the breaker, the opening and cleaning of tows of various origin, delivering them in form of slivers weighing from 20 to 25 g/m.

The **finisher card** is equipped with a mobile feed table, a tearing feeder to open the fibres, special steel cylinders and stiff saw-tooth clothings. There are models with different main cylinder diameters, 6 or 8 workers and strippers and 2 doffing cylinders. The flax tops which are produced in the pre-spinning cycle can be conveyed to the spinning room for processing in blend with other natural fibres or man-made fibres.

The card is followed by the pre-hackling drawing frames, which can be the same as used for wool and long fibre processing. The lines for tow processing include, as first and second draft passage, intersecting gill-boxes with screw driven hackling heads. The rectilinear hackling machine is similar to the one used for the traditional worsted wool combing process, but was adjusted to the particular requirements of flax tow processing; it has the task of parallelizing in the best way the fibres and of completing the cleaning operation started by the card. A high production hackling machine with single can delivery and speeds ranging from 170 to 220 strokes/min is available.

### 4.1.4 Tow spinning

The final tow spinning can follow two different processes:

- wet spinning
- dry spinning.

The first process employs the same machines and similar processes as described already for long staple yarns.

The dry spinning includes following operations:

- post-hackling and spinning preparation with intersecting gill-boxes - three passages plus a fourth passage carried out on finisher drawing frame with needle comb drawing system. The following stage can be direct spinning, as in the case of long staple flax;
- roving frame (same as described for wet spinning) or rubbing finisher, as used also in wool spinning lines.
For sliver dry spinning from sliver, the market offers a high draft ring spinning frame with one or two drafting fields, which can process fibres 40 to 350 mm long. The roller setting can be adjusted according to the type of processed fibre through a quick setting device.

4.1.5 Flax yarn winding
The winding of flax yarns requires as ever the use of specially designed machines. The processing difficulties of flax are due to fibre stiffness, to the use of water during spinning, to the consequent soiling of the machinery which creates maintenance problems, to the low yarn contents of the bobbins and to the high fault rate.
The automatic winder with independent winding heads has been modified for flax wet processing and has been equipped with automatic bobbin loader. The bobbin quality is guaranteed by the total and precise control of the wound yarn, through electronic clearer with optical measurement cell. The yarn clearer is self-regulating according to the actual yarn speed, of which it assesses exactly the defects even during the acceleration and deceleration phases of the machine. The clearer controls also the yarn piecings. Another quality factor is the water-air splicer, which is fitted on the winder to ensure the optimal piecing of yarns having count Nm 10 and finer. The winding takes place at a speed of up to 1600 m/min with maximum precision, consistency and efficiency.

4.2 Hemp preparation and spinning
As for flax, also in the case of hemp the processing of long staple yarns differs from the processing of tow (Chart 8). Hemp reaches the mill in form of 400 to 1000 g sheafs, which feed the hackling machine. The short fibres are collected in boxes and delivered to the packing department as hackling tows.
The preparation process of long staple fibres allows to transform the sliver produced by the hackling machine into a 2 - 4 g/m roving through a series of drawing passages and a high number of doublings, which ensure the high blending rate necessary for heterogeneous fibres like hemp. The flow chart is similar to that used for flax processing and the machines employed are practically the same. At the delivery from last drawing passage, the sliver can be subjected to one of two alternative processes:

- wet spinning, the typical process used for bast fibres, with bobbin drying and winding. As for flax, the roving can be degummed and bleached before spinning.
- dry spinning directly from sliver through the same spinning frames used for flax tow spinning.

*Tow spinning*, as also dry spinning of long staple yarns, follows the same criteria as wool spinning on machines characterised by wider pitches and by more rigid and firm opening points, which can stand the high stresses caused by extremely hard and stiff fibres.

We point out that the card sliver has not the cleanliness degree which is necessary to produce a regular yarn, therefore it requires a hackling operation on machines very similar to wool combers.
*Tows can be dry or wet spun. For dry spinning, two kinds of spinning frames are used:

- with drafting cylinder systems which operate according to the typical criteria of the semi-worsted system, with settings suited to the high length of these fibres
- with gill-bars, i.e. with needle bars placed in the drafting fields assigned to the guide of the fibres, which are similar to those used for long fibre dry spinning.*
As already for flax, the prospects for a widening of hemp use are conditioned by the finishing operations. In fact the fibre can undergo some important changes, if the order and the crystalline lay-out of the fibrous cells are adequately varied; moreover, if full advantage is taken of the inner channels (lumens) for fluid diffusion by preparing them for a more efficient migration of fluids capable of modifying the fiber’s physical properties, completely new handle and appearance effects, even adjustable by the finisher, can be obtained.
5.1 Introduction

The woven fabric is the result of the interlacing of two components: the warp and the weft. These elements must be prepared at a precedent stage in a form suited to feed the weaving machine (Chart 9).

Chart 9 - Weaving technologies

The present requirements of the weavers can be summed up as follows: increasing further the production, shortening of the weaving machine setting-up time considering that, at least in Europe, the number of warp changes is steadily increasing because the average fabric lengths per article are progressively decreasing. Another factor which today is considered as important is the unceasing quality control through systems integrated in the weaving machine and the possibility of transmitting the operational data to control the productivity of the weaving machine in real time for each fabric style to be produced.
5.2 Weaving preparation

The warp quality is one of the crucial factors affecting not only the performance of the weaving machine and on the whole the efficiency of the weaving plant, but also the quality of the end-product. A slight difference in tension in the yarns composing the warp can entail irregularities in the fabric and consequently dyeing unevenness, which faults down-grade the finished fabric.

5.2.1 Creels

The creels are the frames on which the cones which feed the warper are pinned. The number of cones depends on the type of fabric to be produced. The yarns are wound side by side and parallel one another on the beam, if possible with the same tension. The tensioning devices fitted on the creels are designed to obtain this uniform tension. The cone position and their accessibility are two important factors for the operator. The latest creels have yarn tension devices with automatic control and centralised tension variation. These devices allow also to process a wide range of yarns on the same creeling plant.

Warping is a low yield operation owing to the time needed for creeling. Various solutions have been conceived to minimize this time, by trying to perform the creeling of the full cones while the warper is running.

The trolley creels have a yarn cutting and knotting device which can cut 720 ends in 50 seconds and knot them in 10 minutes. This system is suitable for staple fibre yarns in counts ranging from Nm 10 to Nm 140. Trolley creels have generally two series of trolleys: one in operation and one waiting for being creeled.

For staple fibre yarns also mobile creels are used. These can be equipped with a series of trolleys for the transport of the reserve cones; as an alternative, two creels with stationary cone carrier frame are used together with the warper. In both cases the bobbins are creeled during warping.

Another solution employs swivel frames. While yarns are unwound from the bobbins placed in the inside of the creel, it is possible to creel at the outside of the creel the new lot of cones.

For luxury yarns, the so-called magazine creels are used, which enable to creel two cones per creeling position and to piece head-tail end of two cones.

For the creeling of dyed yarns, a programmable electronic system has been studied. A warning light indicates the position where the yarn of a certain colour must be creeled. This allows a time saving of 60% in creeling and avoids patterning faults and double ends.

The creels are equipped with yarn break detectors which warn the operator through display at the start of the creeling operation. When the yarn breaks, the sensor stops the warper and indicates through signal lights the position of the yarn breakage.

All types of creels can be equipped with air-blowing trolleys to maintain tensioners clean.

5.2.2 Sectional warper

The yarns are wound on a warping cylinder, which initial part has conical shape (Fig. 14). The yarns are laid on this conical element. The term section identifies a yarn bundle which is generally a sub-multiple of the total ends to be laid on the weaver’s beam which successively feeds the weaving machine. A comb situated near the cylinder sets the section width and shifts the yarn winding position at each turn of the cylinder. The conical element of the cylinder can be fixed or with variable inclination, depending on the type of yarn to be wound. As soon as the planned section number is completed, the yarn is transferred from the warping cylinder onto a beam which can be conveyed to sizing or directly to the weaving machine.
This type of warper is used for short warps, both in the short staple and in the long staple sector. The beam can be produced with a limited number of cones. The latest sectional warpers make use of control systems operated by optical fibres, which ensure a perfect warp formation. The machine is equipped with automatic beam loading and unloading system, which facilitates its operation and shortens the setting-up time. The warping speed is about 800 m/min, the beaming speed about 300 m/min.

5.2.3 Fractional or direct warper
Fractional warping is used for larger lots of staple fibre yarns or of continuous filament yarns (Fig. 15). The number of wound yarn ends is, also in this case, a sub-multiple of the total yarn number required for the warp.

The yarns are laid over the whole beam width. The final diameter of a fully wound beam can reach 1400 mm, maximum running speed is 1200 mm. The yarns are guided by a zigzag expanding reed, which permits to set the pitch between threads. The distances between the reed of the guide cylinder and the winding point are the shortest possible, to ensure a more precise yarn guide. Extremely important is the beam braking system at yarn breakage. In fact the end of the broken yarn wound on the beam must be easily traceable, to proceed quickly to its knotting with the yarn end coming from the cone and restart the warper. Modern warpers are provided with devices for the suction of dusts, which are emitted in large quantities, especially during the yarn passage through the reed. Special warper models for narrow fabrics and elastic threads are available.
5.2.4 Sizing
This operation consists of applying on the yarn glueing products, based on starch and on other chemical substances, to increase yarn strength and to create a sheath on the fibre surface, thus reducing hairiness (Fig. 16).

Figure 16 - Sizing machine

The machine is fed by several beams coming from the warper; the threads are then impregnated by immersion into the size and squeezed by a couple of cylinders. This operation can be repeated two times in succession.

The yarn is then dried on steam heated drums, in some cases it is stored in a radio-frequency heated or hot-air heated pre-drying chamber. The yarn is finally rewound on a weaver’s beam (3000-8000 ends).

The feeding beams, which can be from 4 to 12 in number, are equipped with electronically controlled braking devices.

Centralised systems control also all other parameters, as: concentration, viscosity and temperature of the sizing liquor, drying drums temperature, as well as the humidity contents of the yarn at the delivery from the drying section.

In case of continuous beam dyeing, the sizing machine operates on-line (the sizing machines are linked to a size preparation system and to size filtering and recycling systems). In the processing of woollen yarns, the size is applied by tangential drum contact instead of by immersion into size boxes.

5.2.5 Draw-warping + sizing
For continuous filament yarns and in particular for microfilament yarns, processing lines are used in which the yarns are drawn during their passage through a steam oven and are then sized and dried in hot-air or radio-frequency ovens. Also intermingling units with individual air nozzles for each yarn end read can be fitted to improve yarn tenacity.

5.2.6 Drawing-in
The drawing-in machine performs in a semiautomatic or automatic way the threading of the warp ends through the drop wires, the eyelets of the heddles and the dents of the reed.

An automatic drawing-in system, unlike the traditional systems, carries out the drawing-in operation in absence of the warp. In fact it does not use the warp ends, but the ends coming from an auxiliary cone. The warp stop motion, the heddles and the reed are then set up on the weaving machine and prepared to receive the new beam. The beam threads are knotted to the provisional threads. The knots are then threaded in as with usual knotting. In this way the drawing-in can be made in advance. A computerised control system allows the entering of the drawing-in data through the keyboard or a CAD system. The yarn is extracted from the cones by a hook, which transports it upwards and places it on a yarn support base.

The selecting needle passes through the reed, the heddles and the drop wires, hooks the yarn and pulls it back through the above mentioned elements, then secures the yarn end to two pieces of adhesive tape. A knotting station to be placed outside the weaving
machine is also available. In this way it is possible to prepare the new beam, complete with drop wires, healds and reed, outside the weaving machine.

5.2.7 Quick style change
The replacement of the beam on the weaving machine is a rather complex operation. Therefore devices have been studied to simplify this operation and at the same time to reduce weaving machine downtime. Efforts were made to carry out the knotting of the yarn ends of the empty beam with those of the new beam inside the preparation department, instead of onboard the weaving machine. The systems proposed vary according to the type of connection of the harness to the motion system.

The main style change operations are:

- the weaving machine points out to the preparation department that a new warp is needed
- the operator prepares the weaving machine for the removal of the warp by releasing the beam
- the reed is released, the harness is unhooked from the push rods and the winding device is disconnected
- beam, warp stop motion, harness and reed are ready to be mounted again on the weaving machine, using the special hydraulic beam truck. This group of machine elements is then placed on storage truck
- the weaving machine is now easily accessible for some scheduled cleaning and maintenance operations
- the beam truck takes from the storage truck the drawn-in beam and places it on the weaving machine scheduled to produce that particular article. The unloading and loading operation requires about 10 minutes. The beam truck is now ready for another operation
- within the loading sequence, the operator engages the beam, mounts the warp stop motion, fixes the reed in position, reinserts the tuck-in selvedge and leno device, places the temples back in working position and hangs the harness on the hooks again
- through the board computer, the operator recalls the data of the weaving machine and of the article to be produced and restarts the weaving machine. All this is carried out in less than 30 minutes by only one operator.

The various situations which take place in the weaving mills suggest an economic analysis before using these systems, taking also into account the substantial change which are brought to the organisation of the preparation and weaving departments. Also quick style change systems adaptable to already installed weaving machines have been studied.

Obviously the weaving machine has to be modified and prepared in all his elements, to make this system really valid from the operational and economical points of view.

5.3 Weaving

The weaving machine has the task of carrying out the interlacing of the warp wound on the beam and drawn-in into healds and reed with the weft, which is inserted between two series of yarns continuously changing position according to the programmed fabric pattern (Fig. 17).
The weft insertion systems which characterize the weaving machines made in Italy are:

- with negative or positive flexible rapiers
- with air jet.

5.3.1 Negative rapier weaving machine
The weft yarn coming from a cone positioned on the outside of the weaving machine is inserted by a double rapier composed of a yarn carrying gripper and a yarn pulling gripper. The first gripper seizes the yarn and brings it to the centre of the warp. The second gripper, which starts from the opposite side of the weaving machine, meets the carrying gripper in the centre of the shed, unhooks the yarn from the brake shoe of the first gripper, carries it to the other end of the weaving machine and leaves it at a certain distance from the last warp yarn.

The tail ends of the yarns are cut at the selvedge yarns, where the last warp yarns are bound with leno weave to prevent the protrusion of the weft out of the selvedge.

The grippers are operated by driven flexible bands. The bands are guided, inside and outside the warp yarns, by thin metal sheets of special shape, which penetrate through the yarns. There are also machines without inner guides, in which the gripper path is guaranteed by the band stiffness and by the laws of motion of the gripper, which do not cause any peak loads. The negative rapier weaving machine is characterised by high running speed: depending on the widths, the running speed ranges from 400 strokes/min to 700 strokes/min, which corresponds to over 1500 m/min of inserted weft yarn. The fabric width ranges between 1600 mm and 4600 mm.

The negative gripper weaving machines are mostly used to produce lightweight fabrics and yarns with lower mechanical strength.

The yarn feeding can take place according to various configurations:

- single beam with up to 1400 mm flanges, for raw fabrics or large lots
- twin beam with either differential drive or bilateral let-off motions
- two beams in bottom position, with the possibility of loading a third beam (electronic let-off).
The warp stop motion is electronic, as the take-up device which is controlled by the on-board computer and is synchronised with the let-off unit. Following devices are available for shedding:

• positive driven outer cams for up to 12 heddle frames  
• electronic or mechanical rotary dobbý for 12 to 20 frames  
• electronic or mechanical jacquard machine.

On request, the weaving machines can be equipped with special devices, such as:

• jacquard machines for name selvedge  
• take-up motion outside the weaving machine for large diameter fabric rolls  
• independent device for leno and tuck-in selvedge, with possibility of central selvedge forming unit  
• quick identification system of the broken yarn on the warp stop motion  
• weft tension control which, via computer, regulates the tension unit  
• recording system for broken yarns and their removal, followed by automatic restarting  
• feed of weft yarn in modular sections of reduced size for 4, 8, 12 and 16 colours, with microprocessor driven colour selection  
• electronically controlled speed variator, which enables quick adjustment of weaving machine speed according to type of yarn used.

5.3.2 Positive rapier weaving machine
The operating principle of this machine is similar to that of negative rapier weaving machines; the only difference is that the weft is blocked on the carrying gripper through a mechanical system, which gets unblocked at the center of the weaving machine when the yarn is taken up by the pulling gripper. This system permits to insert weft yarns of quite different counts and also fancy yarns, as slub yarns, knob yarns and similar yarns. This possibility makes this weaving machine extremely flexible. The auxiliary devices are the same for both weaving machines.

Noteworthy is also the possibility, utilized in terry weaving machines, of using reeds with integral beat. Their operation is based on two different reed beating positions without alternate warp motion, which ensures extremely regular loop formation. Other specialty machines are weaving machines for special articles as horse hair fabrics, metal strips or belts and elastic bands in up to 800 mm width.

On jacquard rapier weaving machines special ultrasound cutting devices have been fitted, specially for label production.

5.3.3 Air jet machine
In these machines the weft is inserted through a jet of compressed air. Other nozzles installed over the width of the weaving machine help the weft to position itself regularly on the whole width.

The weft is pre-metered before insertion and is controlled and cut as in gripper weaving machines.

This weaving system is characterised by a very high operational and insertion speed (respectively 2000 and over 3000 strokes/min). This performance has been made possible by the absence of complex mechanical units.

The air jet loom was conceived as a simple, cost-effective, user-friendly machine with a large production capacity for mass productions. It became later more flexible thanks to following ancillary equipment:

• device for weaving without split selvedges on both fabric sides  
• electronic control of the cloth take-up, of the let-off motion and of the running speed  
• tuck-in devices specially conceived for high speed weaving
• weft feeding for up to 8 colours
• heddle frames drive through cam motion or dobbby with up to 16 frames
• back rest rolls with positive drive
• automatic removal of broken wefts

The air jet machine is also used successfully for weaving terry fabrics. Its operation is based on the use of two different reed beat-up positions, without any warp traversing motion. This solution offers the maximum machine efficiency and the formation of a very regular loop surface, with a loop height up to 9 mm. Two pile heights can be automatically selected. Patterning is performed either by dobbby or electronic jacquard. For the production of fancy borders, 4 different weft density values can be selected. Weft selection is independent of the shedding motion and up to 4 colours can be inserted. Other types of weaving machines which use the air jet technology are:

• air jet looms for tyre cloth weaving
• air jet looms for label weaving
• air jet looms for technical fabric weaving

5.4 Auxiliary machines and ancillary equipment

5.4.1 Shedding machines
All shedding machines (dobbies or cam motions) have been improved in order to cope with the increasing speed of the weaving machines. Efforts were concentrated on reducing the vibrations to avoid frame and heddle breaking, on increasing functional reliability and on facilitating setting. The latest dobbies can run at a speed of approximately 1000 rpm. The trend is to give up the use of negative dobbies with with release springs in favour of electronically controlled positive dobbies, which permit higher running speeds. Positive dobbies with 12 to 20 jacks have been developed to run at 1100 strokes/min, equivalent to 2200 m/min of inserted weft. Jacquard machines enable shedding by individual drive of the single yarn. The development of electronic systems was generalized and permitted to attain a speed of 1000 strokes/min. Various problems were tackled and solved: the weight reduction, the balance of the masses in motion, the reduction of the vibrations and the strengthening of the machine structure. Furthermore the Italian producers consolidated the trend to the use, for the connection of the electronic drive system with the harness lifting system, of modular elements in replacement of the lifting hooks used by mechanical jacquards.

5.4.2 Weft feeders
Weft feeders have the task of avoiding in the weft yarn the tension variations which originate during the weft unwinding directly from the cones. The yarn is taken up on a drum, where it forms a reserve; this is later on drawn-off and unwound by the grippers under virtually constant tension. Another advantage is that the cone is maintained independent of the weaving machines and that therefore the head-and-tail piecing system can be used, thus avoiding stopping the loom when the cone runs empty. In the case of gripper weaving machines, the weft feeder is a weft accumulator, whereas the air jet looms use weft metering devices which can wind the yarn on the drum with separate or with contiguous coils. These systems attained a considerable reliability and versatility level and meet fully the requisites of high speed weaving machines.
New modular braking systems were developed, which brake the yarn at its outlet of the feeder, reducing the stress on the weft yarn and therefore the number of breaks. This brake is self-cleaning.
For flax and wool yarns, motor driven dispensers of lubrication liquid are used to ensure an even distribution of lubricants, moistening and antistatic agents over the whole length of the weft.

5.4.3 Air conditioning
Weaving operations cause the friction of the yarns, particularly warp yarns, with each other as well as with the metallic parts of the machines. These actions originate, specially in case of staple fibre yarns, the detaching of parts of fibres from the body of the yarn, with consequent formation of static electricity, sticking yarns, difficult shedding and difficult weft colours selection, but also fibre fly accumulation on all most delicate units as braking elements, weft control devices and even the grippers.
It is therefore essential that the air conditioning system is designed in a way as to ensure an efficient control of temperature and humidity, differentiated for weaving preparation and weaving departments. Dust is removed from the machines by travelling cleaners, moreover the air in the working rooms is exhausted under the machines continuously or intermittently.
The air is conveyed to the conditioning stations and filtered on rotary filters, then re-moistened and conveyed into the working room again. The humidity level affects considerably the possibility of reducing the electrostatic charges, and has to be adjusted also according to the processed materials.

5.4.4 Production control
The collection of the operational data of the weaving machines and their assessment permit to control not only production, but also, through the analysis of the machine stops and of their causes, the quality of the yarns and of the weaving preparation. All weaving machines are equipped with efficient and complete board computers deputed to acquiring these data, which they successively transmit to central control systems through a bi-directional communication.
In this way also the planning and scheduling of the process are improved, and it is possible to reduce downtimes during pattern and style change.
These monitoring systems are available also in versions linkable to the textile design system (CAD). The monitoring of the production progress is integrated with the warping systems and with the fabric finishing and inspection systems.
6.1 Foreword

The definition of knit fabric reads as follows: “a pattern of curvilinear yarns where it is sufficient to have one single constituent element arranged horizontally (weft like) or vertically (warp like)”. This pattern is achieved by creating loops linked one to the other through the action of needles.

Knit fabrics can be classified, in accordance to their formation, in weft or loop knit fabrics where a single yarn forms in a sequence all loops, and warp or cast knit fabrics where a warp forms all loops together along the whole width of the fabric.

In weft knits, the yarn which binds together two consecutive loops is placed horizontally, and if a loop breaks a hole is made which starts a run. In warp knits the yarn is laid vertically and the fabric does not run when a loop breaks.

Weft knitting is the traditional construction used for outerwear, underwear and hosiery. In addition weft knitting is also applied in other sectors such as furnishing or technical textiles. In the past, warp knitting was largely employed in the production of womenswear fabrics, and today is above all used for particular kinds of fabrics such as laces and hems for furnishing fabrics.

Chart 10 – General classification of knitting machinery

6.2 Weft knitting

The production of weft knitted fabrics – by far, the most common knitted goods - is achieved using two types of machines, each characterised by a particular needle, and consequently by a different operating technique:

KNITTING LOOMS: these machines incorporate spring beard needles which move simultaneously and are closed using external devices (a press) during the working cycle.

KNITTING MACHINES: incorporate latch needles (or similar needles) which can be moved individually; it does not need external devices to form the loops, as the latch opens and closes the hook during the working cycle.

As regards the form of the bed, i.e. the area where the needles are arranged, we have flat or circular knitting looms and machines. On the market, we currently only have flat looms, while knitting machines are available as flat and circular models. In addition,
according to their size and the bed type, circular machines can be divided into large-diameter circular machines for the production of continuous fabrics, large-diameter circular machines and with variable bed width for the production of shaped fabrics, medium-diameter circular machines for the production of shaped underwear bodies, and lastly, small-diameter circular machines for hosiery.

The figure below details the classification of knitting machines. The flat loom is not included in the chart as it is a very specialised machine which represents a technical niche on its own and has a limited application range compared to the other types. Also the small-diameter circular machines for hosiery have been excluded as they are manufactured in a large number of versions with particular technical solutions, and are therefore described in a separate section.

**Chart 11 – Classification of weft knitting machines**

Italian producers have shown to be able to manufacture high quality machines in all the possible variants. Traditionally, they have always been the undisputed world leaders in the hosiery machine field, and are currently leaders also in the flat knitting machine segment: in fact these machines are offered in a wide variety of models able to satisfy all modern production requirements; in the field of circular knitting machines, Italian producers offer interesting technical solutions for particular problems in knitting. Electronics is widely used both on board for commanding machine motions, and on the workstation for the creation and design of patterns and models.

### 6.3 The structure of knitting machines

In order to understand the different technical solutions adopted by the different manufacturers for their knitting machines it is necessary to learn (at least schematically), the structural features and the main components of these machines.

**The bed**

The bed of a knitting machine can be flat or circular, and is made up of a steel body with grooves where the needles slide. In flat machine types, the bed is a steel plate where the needles are arranged parallelly one beside the other. In circular models, the needles are accommodated in milled grooves obtained along the generatrices of a cylinder or in radial grooves milled on a metal disk.

**Flat-bed machines** always incorporate two beds which form a 90° angle with respect to one another and a 45° angle to the horizontal plane. The bed which is nearest to the operator standing in front of the machine is called front bed, while the other is called back bed.

**Circular machines** can be **single-bed**, i.e. have a single cylindrical bed, or **two-bed**, i.e. have two beds placed at 90° with respect to one another called dial and cylinder, respectively, which can be assimilated to the front bed and the back bed of flat machines. There also are two-bed circular machines - the **two-cylinder** models - which are now produced in small quantities and feature two cylindrical beds placed at 180° with respect to one another. These two beds are called lower cylinder and upper cylinder and correspond to the front and back bed of flat machines.
The needles
The needle type which is most commonly used for flat and circular machine types is the latch needle. This needle does not need any external component to close and open the hook during the loop formation. A variant of the latch needle which was largely used on circular machines especially in the past, is the compound needle, with sliding closing element. In the compound needle, the latch (in the form of a sliding blade) moves along a groove in the needle stem independently of the movement of the stem itself. This technical solution speeds up the needle movement during the loop formation, because it is no longer necessary to wait that the latch is completely closed to continue the working cycle. In addition, the loop aspect is improved as the yarn is not subject to straining. However, the use of this needle requires complicated mechanics for two separate command systems, one for the needle stem and one for the sliding element, respectively.

The two-bed circular machines with 180° beds where the loops of purl stitches are formed on both cylinders, require a particular needle type, called the double-latch needle, which incorporates a steel stem of adequate shape and two hooks with their latches at both ends.

Gauge
It is a technical parameter fundamental for the classification of knitting machines. The gauge is the spacing of the needles, and refers to the number of needles per inch. This unit of measure is indicated with a capital E.

The flat and circular machines now available from the different manufacturers are offered in a vast range of gauge sizes. For example, flat bed machines are available in gauge sizes from E 3 to E 18, and large-diameter circular machines from E 4 to E 36. The vast range of gauges meets all knitting needs. Obviously, the most common models are those with middle gauge sizes.

Width
This parameter describes the size of the working area. On circular machines, the width is the operating length of beds as measured from the first to the last groove, and is normally expressed in centimetres.

Flat bed machines are available in various widths according to the end product. For example, machines with a width of 20 cm are used in the production of hems and trimmings, whereas those with 250 cm of width produce a large cloth or more cloths at a time. However, the most common models are the so-called short or compact machines with a width of about 100 cm, which are designed for the high-performance manufacturing of shaped knitted goods, as well as the traditional long-bed machines with bed widths of over 200 cm for the production of semi-shaped knitted goods.

In circular machines, the width size is the bed diameter in inches. The diameter is measured on two opposite needles. Large-diameter circular machines can have a width of 60”, however the most common width size is the 30”. Medium-diameter circular machines feature a width of about 15”, and the small-diameter models are about 3” in width.

Some large-diameter models incorporate adjustable beds, in which the bed width can be set freely, as a result varying the number of working needles and using a yarn cutting/nipping device at the end of every course.

System
In knitting machine technology, system is the set of mechanical components which move the needles and allows the formation of the loop.

The output rate of a machine is determined by the number of systems it incorporates, as every system corresponds to a lifting or lowering movement of the needles, and therefore, to the formation of a course. The technical progress has led to the
manufacturing of machines with an increased number of systems. However, it is necessary to remember that more systems means a more complicated machine and thus more malfunctions.

The system motions are called cams or triangles (lifting or lowering according to the resulting movement of the needles). The systems of flat bed machines are arranged on a machine component called carriage. The carriage slides forward and backward on the bed in a reciprocating motion. The machine models currently available on the market feature 1 to 8 systems distributed and combined in various manners (number of carriages and number of systems per carriage).

Circular machines rotate in a single direction, and the various systems are distributed along the bed circumference. By increasing the diameter of the machine, it is then possible to increase the number of systems and therefore the number of courses inserted per each revolution.

Today, large-diameter circular machines are available with a number of diameters and systems per inch. For example, simple constructions such as the jersey stitch can have up to 180 systems, however the number of systems incorporated on large-diameter circular machines normally range from 42 to 84.

**Yarn feeding**

The yarn fed to the needles in order to form the fabric must be conveyed along a predetermined path from the spool to the knitting zone. The various motions along this path guide the yarn (thread guides), adjust the yarn tension (yarn tensioners), and check for eventual yarn breaks.

The yarn is taken down from the spool arranged on a special holder called creel if placed beside the machine, or rack if placed above it. The yarn is then guided into the knitting zone through the thread guide, which is typically a small plate with a steel eyelet for the yarn. In order to obtain particular designs such as intarsia and vanisé effects, the machines are equipped with special thread guides.

A uniform feeding tension is fundamental for obtaining regular loops. On flat-bed machines, this parameter is controlled through the yarn tensioner, which consists essentially of a metal arm adjusted by means of springs in order to contrast and level off the spool unwinding tension peaks. On circular knitting machines, the yarn feeding control on the various systems is performed with various methods. The most effective is the positive feeding method, which employs small pulleys moved by belts, or gears etc., to exactly control the yarn feeding speed and keep it constant.

**Fabric take-down**

On knitting machines with latch needles, this motion carries out two distinct functions. At the beginning of the knitting cycle, it opens the latches and, at the same time, creates a tension on the course being formed. During the knitting cycle, the take-down motion winds the fabric with adequate tension.

The take-down tension is a fundamental parameter for the knitting process, as it affects the length of yarn used for the loops, and consequently, affects the final geometry of the fabric.

On flat bed machines, the take-down motion normally incorporates a main roller which takes up the fabric delivered by the beds, plus a number of counter-rollers arranged by sectors with adjustable pressure in order to guarantee a uniform tension on the whole fabric width.

On large-diameter circular machines for the production of continuous fabrics, the fabric is delivered in tubular form which must therefore be flattened for subsequent winding on the take-up roller. This step is particularly delicate because it can cause fabric distortion. In order to avoid these problems, a spreader is added to the take-down motion which by increasing artificially the width of the fabric in the pre-folding zone, equalises the
lengthwise and crosswise tension and therefore improves the fabric geometry. The **take-down rollers** and the **take-up roller** are arranged below the spreader.

### 6.4 Flat knitting machines

The new fashion trends of knitted outwear are based on ever more attractive and creative articles, and on the creation of three-dimensional models of great impact. The fully-fashioned technique has become increasingly popular. With this technique, the machine produces an article which require a minimum amount of sewing work and, in some cases, even complete of small hems, buttonholes, pockets and other trimming. The fully-fashioned technique presents the double advantage of reducing making-up costs and increasing the quality level of the article, which is manufactured on a single machine.

Furthermore, during the last few years, the field of knitwear has seen a boom of the use of new materials, especially blend yarns obtained with fibres of different characteristics or particular surface effects that are able to provide aesthetically interesting final results. The success of this trend is partly due to the close cooperation between the Italian makers of knitting machines and spinners, which have contributed to the relaunching of knitwear making it possible to manufacture, on flat knitting electronic jacquard machines, a wide range of stitches and models, both complex and highly intricate.

To manufacture high quality articles, especially when employing fancy yarns and stitches, flat knitting machines must be equipped with specific mechanisms properly controlling the most important working parameters, and in particular the so-called LFA value (the yarn length absorbed by each loop), as well as the yarn feeding and the take-down motions.

In addition to this, in order to carry out complex knitting jobs for the production of knitted goods with a high style content as far as the model and the design are concerned, and therefore distinguish the products of the Western world (and in particular Italian-made products), from those manufactured in emerging countries, it is necessary to have machines equipped with technically advanced solutions to control some functions or specific working steps. All the flat machines offered by Italian manufacturers incorporate these innovative features, and thus guarantee the production of a large range of designs from the simplest to the most elaborated.

Analysing the most important structural features, all the Italian flat knitting machine manufacturers offer compact machines with **bed lengths** of 115-130 cm and long-bed machines over 200 cm, equipped with 1 to 6 **systems** (except for a new-concept flat bed machine introduced in the early 1999, with 4 heads, each equipped with two systems and bed length of 106 cm). The systems are arranged on the carriage, which slides backward and forward on the bed. The combinations between the number of carriages and systems per carriage are virtually countless. There are traditional single-carriage machines with 1-2-3-4 systems, machines with 2 or 3 carriages with one system per carriage, and newer models with 2-3 carriages (which can work individually or linked with another carriage) and 1-2-3 systems per carriage.

When all the carriages work together, a single fabric is produced on the whole bed width. This is a high-performance operating mode, as every carriage stroke produces as many courses as the total number of systems. When the carriages work in individual mode, the machine delivers a fabric per working carriage, and each stroke produces a number of courses equal to the number of systems on each carriage. This function is the tandem mode and improves the machine flexibility enormously, and can be exploited to ensure, according to the production requirements, high output rates or full-fashioned fabrics, or vice-versa.

The necessary flexibility and the reduction of processing costs and times have led to the application of **variable-stroke carriages**, a concept which allows the automatic variation of the carriage stroke according to the width of the fabric produced. This technical
solution cuts processing times and increases the number of courses produced per minute.

In all Italian-made machines of the last generation, the carriage allows **three technical work ways**, that is to say the possibility of separately selecting - on each system and each needle - the position knot stitch, tuck stitch and miss stitch. Some machines also integrate, besides the three traditional technical ways, two additional ways to vary stitch density and therefore to knit long or short stitches, tuck short or long stitches and miss stitches. The **density**, or the length of stitch, is adjusted through special lowering triangles which, in the most advanced versions, are made up of two parts, each separately programmable with electronic devices both in each course and during the carriage stroke. In addition to the three technical work ways, the systems of electronic flat machines incorporate **three technical transfer ways** to transfer stitches, receive them, or remain inactive.

**Stitch transfer** is another important parameter, as a higher number of transfer modes mean more possibilities of making structured designs and shaped fabrics where the stitch is transferred from one bed to the other or within the same bed. All the electronic flat bed machines manufactured in Italy offer the double stitch transfer option, i.e. from one bed to the other and vice-versa, independently of the carriage direction. In addition, some manufacturers have equipped their machines with an **extra bed** arranged above the machine bed and provided with special points to receive and transfer stitches on other needles with great freedom of movement. In addition to facilitate the knitting of cloths with braids or embroideries which require the stitch transfer, the third bed also allows significant advantages in the production of shaped fabrics as the narrowing stitches are transferred on this bed and not on the back bed, diminishing the straining and improving the process conditions. At the Itma '99 fair in Paris, an Italian manufacturer introduced some models including an extra bed with individually selectable points which operate on the front and back bed needles independently for the lateral transfer of stitches.

The production of high-quality knitted fabrics – i.e. of homogenous aspect as a result of a smooth knitting process and the absence of holes and barring - essentially depends on the application of certain technical solutions which are now adopted by all the Italian manufacturers, sometimes with mechanical variants (patented or not).

As for the type of **needle** used, Italian flat machines incorporate latch needles which operate according to the drowned butt principle. This kind of needle remains in idle position with its heel completely drowned in the needle bed groove without being involved in the action of cams and retains the loop, which, in this case, is not subject to strain.

**Press-foots** also carry out an important function. These devices are mounted on almost all machines and are used for pressing and constantly keeping under control the loops while they are formed, and allow the stitches to be taken off the needles even under the hardest working conditions. Their application is particularly useful in the production of complicated designs which require the transfer and retaining of some loops so as not to hinder the knitting process.

Another technical device adopted by some Italian manufacturers which improves the aspect of the fabric is the so-called **hole-repair motion**, i.e. a device which avoids the formation of holes in the event that a loop is not inserted by the needle.

All Italian makers of flat knitting machines pay special attention to the fabric **take-down device**, which is fundamental for giving the fabric a smooth appearance and allowing the knitting of complicated designs which require fabric press-off and stitch transfer. As a general rule, the take-down device includes a section-type large roller with counter-rollers that can be adjusted separately and two small rollers close to the beds which stretch the fabric and facilitate the carrying out of particularly complex jobs. Some models are equipped with a reed which is used for starting the knitting process when the needles are still empty. An Italian manufacturer offers machines with a patented
electronic take-down device with two sets of grippers that take the cloth at about 2-4 mm below the loop formation area, pull it and retain it. Cloth taking down and retaining are the functions of the first set, while the second set acts as a press-foot during the lifting travel of the retaining grippers. The gripper set is followed by an adjustable-speed spiral roller which keeps the take-down tension constant even when several systems are used at the same time.

To meet the requests of a fashion market which proposes, according to the season, heavy pullovers with intricate designs or fine lightweight sweaters manufactured with different yarns or in complicated jacquard designs, the flat bed machines offered by Italian builders cover a vast range of gauges from E 3 to the recent E 20 exhibited at the Itma ’99 in Paris, and are equipped with numerous thread guides (up to 16 on four holders) for traditional jacquard styles. In addition, special guides can be used for particular designs such as the intarsia or vanisé. The creative aspect of intarsia and jacquard combinations has been studied accurately by an Italian manufacturer that offers a technically advanced machine with 28 thread guides for intarsia, thus allowing the production of fabrics with 28-colour intarsia.

All the major manufacturers of electronic flat machines in Italy have developed their own software for the programming of the machine and for the creation of pattern and models. Many of these graphic workstations are supported by a Windows operating system, and are thus easy to use, and do not require large investments in hardware and personnel training.

Despite the fact that the market increasingly requires high-performance and flexible electronic machines, Italian manufacturers also continue to produce single-selection machines with few systems, needle selection with low or high butts, or mini-jacquard sinker versions which allow the knitting of basic designs or uncomplicated operated fabrics. However, these machines are technically advanced and their functions are computer-controlled.

Another major segment includes flat knitting machines for trimmings, ribs, cuffs and trimmings on full-fashioned knitting frames and linking machines. It is a series of electronically programmable, automatic flat knitting machines for the manufacture of trimmings which the production of patterned borders.

In conclusion, it is worth underlining that Italy also has a manufacturer of full-fashioned flat knitting frames. This manufacturer offers a computer-controlled model with traditional selection and five thread guide bars, and a fully electronic model with needle-by-needle selection and 10 thread guide bars. The latter allows the production of full-fashioned knitwear of excellent quality with all types of stitches and jacquard and intarsia patterns.

### 6.5 Large diameter circular knitting machines

Most of the knit fabrics in the world are manufactured on large diameter circular knitting machines. The high performance typical of these machines, the many possible uses of the materials and the wide variety of designs are some of the reasons which have ensured the market leadership of cloth knit fabrics. The different types of fabric manufactured on these machines are suitable for many applications: outwear, underwear, household, without forgetting the various uses in the industrial textile field.

Italian manufacturers of large diameter circular knitting machines offer a complete range of high-tech products which are extremely flexible and productive, and ensure high value for money. Manufacturers above all specialise in electronic single bed and double bed machines with monitoring of the whole knitting cycle, as well as in the research of technical solutions dedicated to facilitating the users, such as:

- A solid, but compact, machine base whose configuration facilitates the access to the machine components for the typical interventions carried out during the setup and production stages.
- **AC inverter drives** (i.e. with electronic speed variation) to set the optimum working speed and allow that the acceleration and slow-down steps are carried out in an optimum manner.

- The machines incorporate **cams** with a special profile designed for ensuring a continuous control of the needle operation and for easy replacement with other cams when changing style. Easy style change procedures are particularly desirable, as users have to produce increasingly smaller lots of fabrics and frequently change product type according to the fashion trends.

- The machines have **lateral creels** for yarn spools in order to facilitate the operator in spool changing, and at the same time improve yarn feeding by using guide tubes with separate cleaning devices.

- **Suction and/or blowing devices** in the feeding and knitting range for the abatement of flying fibres and dust.

- **Positive feeding devices** for yarn types that are particularly difficult to knit: this applies in particular to stretch yarns which are increasingly used in the production stage.

- Introduction of electronic **lubricating systems** for the knitting head, often featuring a spray pump.

- Introduction of fabric **take-down and winding systems** which allow the handling of larger fabric rolls to reduce the number of changeover cycles. At the Itma '99 fair in Paris a manufacturer also introduced an innovative open-width winding device for 30" circular machines.

The **measures adopted to increase output rates** deserve a particular mention: these improvements are obtained by increasing either the number of feed systems or the machine speed.

As regards the general tendency to increase the machine **diameter** in order to introduce more systems, it is worth underlining that all the Italian manufacturers now offer single and double bed machines up to 36" in diameter, and some have also developed single-bed machine models with a bed diameter of 60". Then latter can deliver fabrics wide enough to be cut along the two borders so as to have two separate cloths and avoid the problem of the central fold always present in the single cloth fabrics, and particularly evident on stretch fabrics.

Compared to foreign machine manufacturers, Italian manufacturers have not yet considered very much the machine **speed** aspect. Despite that, high-speed machines are also available from Italian manufacturers. In order to guarantee optimum quality, these models incorporate electronic speed variators and a central stitch density control device with an electronic yarn feed counter.

As regards **production possibilities**, Italian manufacturers offer machine models able to carry out all the typical knitting jobs of circular machines. A manufacturer, in particular, provides special-purpose models for specific jobs.

**Single-bed machines** are offered by all manufacturers in **traditional versions**. These models can be used for the manufacture of jersey, jersey with stretch vanisé, single and double plush, piquet fabrics. **Mini-jack circular knitting machines** are suited to the production of Jacquard fabrics. Some models are equipped with selection systems with 39 levels, 37 of which are for Jacquard selection and the other two for set selections, e.g. 1x1. The selection is accomplished through a plug-in cartridge or PVC cards which can be easily changed and programmed separately. Some firms also offer single-bed **full Jacquard** models with electronic needle-by-needle selection to carry out Jacquard and operated motifs with virtually unlimited pattern repeats.

In addition, an Italian manufacturer has developed a single-bed circular machine for the production of **striped jersey** fabrics, in versions with 44 four-colour electronic stripe pattern motions, a model for **open-worked Jacquard** fabrics with a diameter of 36" and gauge 20-22, as well as a vast range of fully electronic single-bed models for plain or striped three or four colour jersey fabrics. This manufacturer also offers a special single-
bed machine for Jacquard samples, introduced at the Itma '99 fair, with a diameter of 4", two systems and two six-colour electronic stripe pattern motions, with needle-by-needle selection to produce the prototypes of Jacquard patterns with enormous time and yarn savings, as it avoids the repeated setting up of a full-size production machine for the various samples.

Lastly, this manufacturer also produces a single-bed machine for pile fabrics. This machine is equipped with needle-by-needle selection, available in the 24" and the 38" version, gauge 10 to 16, and with a feeding cylinder for the manufacturing of plain and Jacquard pile fabrics. This machine has very few competitors at a world level. Particular attention was devoted to the design of the cams and the sinker ring, which is provided with a cleaning device for needles, jacks and knock-over sinkers. Using compressed air rich of lubricant, the dust is blown through the sinker rings from the inside to the outside.

The Italian market offers a large choice of double bed dial-cylinder machines. The traditional rib stitch and eight-plate interlock stitch models for are available from all manufacturers in the classical 30", 34" and 36" diameter and up to E 28 gauge versions. A manufacturer also offers rib-stitch machines with middle-size diameters from 8" to 13".

In addition, almost all manufacturers offers double-bed mini-Jacquard machines with a diameter of 32", 72 systems for Jacquard fabrics and pattern repetition limited by the 37 selection levels. The pattern execution can be either mirror-type or diagonal-type. Some manufacturers also produce double bed full Jacquard machines, with integral electronic control and needle-by-needle selection to manufacture large operated and Jacquard patterns.

The pervasive presence of Italian manufacturers in all the categories of large diameter double bed machines is guaranteed by another company which produces a double cylinder machine for purl (links-and-links) knitting. This machine has a diameter of 33", 12 systems, gauge E 5-12 and fully electronic four-colour stripe pattern motions; unlike the other machines of this category, both cylinders rotate while the cams and the feeding device are stationary. The needle-by-needle selection mode gives the possibility of three technical work ways. In addition this model can produce continuous cloths or open cloths with separation thread.

Italy’s supremacy in the field of large diameter circular machines is particularly evident in the category with variable bed width, i.e. those machines which do not deliver continuous tubular cloths, but a number of open cloths of the desired width divided by separation threads. The cloth width is adjusted by modifying the number of working needles and thanks to a thread cutting-retaining device at the sides of the knitting zone. The advantage of this machine type is that it combines the typical high output rates of circular machines with the possibility of producing semi-shaped fabrics like a flat knitting machine. All the models currently available from Italian manufacturers incorporate avant-garde technical solutions in the field of electronics and information technology and allow the manufacturing of cloths rich in style as required by modern outerwear fashion. The most advanced equipment has a bed diameter of 40 and 42", which correspond to a cloth width of 277 and 291 cm, respectively, 18 working systems and one transfer system or 12 working and six transfer system, or 18 integrated systems, gauge from E 5 to E14, five stripe pattern motions, needle-by-needle selection and three technical work ways. There is also a simpler version with bed diameter of 42", 24 working systems and one transfer system, gauge from E 10 to E18, four stripe pattern motions and needle-by-needle selection. All versions include double transfer in electronic selection mode on both the cylinder and the dial, which allows purl effects. The cylinder and dial rotate, and knocking-over delay can be adjusted on the dial for each system.

In conclusion, it is worth pointing out that the traditional division between large diameter and medium diameter circular knitting machines is gradually disappearing, as the major manufacturers of large diameter machines also produce body-size knitted goods with diameter from 10" to 15". However, some Italian firms manufacture special-purpose machines specifically destined for the production of underwear, swimsuits,
sportswear and medical products. This category of special machines will be described in the next chapter of this section.

6.6 Small and medium diameter circular knitting machines

Over several years now, Italian builders of hosiery machines have been occupying a leading position in the world market, both for the number of companies involved in this business and for the wide range and high quality offered in their models. Even in this field, this success is in part determined by the strict cooperation existing between the machine builders and hosiery manufacturers. In fact, the fast growing interaction between the surging of new requirements and the time needed to develop new machines and equipment, and the production time and problem solving time, is very advantageous for both industries and brings out many practical and fruitful results. Furthermore the machines in this field, more than the other knitting machines, are subject to the continuous and fast changing fashion trends. Therefore the builders must follow all development trends which permit the realisation of machines simple, but at the same time, highly productive and able to adapt to fast changes in design and models. Consequently it is essential to apply computer technology which allows to monitor and control all machine functions through direct programming from the keyboard. The so-called “electronic chain” allows to store and recall up to 5 different stocking models in 8 or more sizes each. The computer technology also allows a great flexibility concerning the different types of yarns to be used and of the designs to be adopted: naturally, in this case, the software must not be general and polyvalent, but specially dedicated to hosiery. A classic example is the use, by some Italian firms, of a software package that has transformed the yarn monitoring in a global monitoring system of the machine linking the control device of each thread to a computer. The hosiery field is subdivided, usually, in three areas according to the type of product and of machine necessary to create it:

- women’s stockings and tights (single cylinder fine gauge machines)
- sports and men’s socks (single cylinder coarse gauge machines and single cylinder with needles in the dial machines)
- men’s high quality socks (double cylinder machines)

In the field of fine stockings and tights, further to the trend of making the machine fully electronic, the trend was towards the direction of limiting the number of systems to reduce the number of the mechanical parts, simplify the machine and lower production costs. The models presented have usually 4 systems and reach a speed of 1500-1800 rpm, diameters are up to 5 1/2” for the market segment addressing large sizes. Italian firms also offer, for the manufacture of large quantities of basic articles, models with 6 systems; in this case speed is reduced to 1200 rpm so as to avoid wear of needles and of the other knitting elements and to manufacture articles of satisfactory quality. The most productive model has 8 systems, a 4 1/2” diameter and operates at 800 rpm. (600 in the case of insertion of elastomer thread); this machine is able to manufacture socks, tights and knee-highs working on all net types, flat stitch and dotting. The major technological innovations adopted on this type of machines are: the diagonal path of thread feeding to improve its precision, and the new movement transmission systems for the cylinder and the dial which no longer require gears. This same trend towards simplification and construction of compact machines, already outlined in the fine gauge single cylinder machines, can be found also in the coarser gauge ones for the manufacture of sports and men’s socks.
A very advanced Italian model is a fully electronic machine, with 6 systems and 6 actuators, which presents a compact framing and has a productivity of 48 dozens of pairs in 8 hours. The articles thus manufactured are sport socks with alternated or sack heel. Almost all Italian builders of coarse gauge hosiery machines have replaced their mechanical functions with computer controlled systems.

The individual selection of needles, together with the plating devices, has made possible to produce patterns and designs completely new and never before used in hosiery. There is a type of single cylinder machine with needles on dial, for the manufacturing of true rib socks 1:1, 1:3, 1:5, and delivering plain knit models with float loop effect and models with up to 8 colour designs, three of which in addition to the background colour. Another innovative machine, addressing the trend of widening the design options, has 3 systems, each with 3 plating stations and able to carry out the 3-way working technique (floating, retained, mesh). The machine has 17 small compact actuators which have been patented and developed by the machine builder and presents a new positioning of the thread guides which are mounted on the needle ring of the cylinder, rendering machine operations easier. The control of the various functions is fully electronic.

The field of hosiery manufactured on double cylinder machines, has suffered strong competition from the coarse gauge single cylinder machines with needles in the dial. There are few builders left which offer these double cylinder, small diameter circular knitting machines. In any event, even in this field the leadership is all Italian. The technical evolution in this field has been directed towards the increase of speed while maintaining the traditional 2 or 3 systems. The maximum speed of the 3 system models is 350 rpm. in the case of rib production and 300 rpm in the case of purl loop; the models with 2 systems reach a speed of 400 rpm.

A new model proposed by an Italian company has been the first of the new double cylinder machines with full electronic control. It is a machine with 3 drops without drum, with direct control motor-cylinder and needle-by-needle selection, for the manufacturing of socks in purl loop, rib, and tights with heel and toe or tubular. A series of 2 systems machines, with electronic control for rib socks, simple links and jacquard, is able to reach a speed of up to 300 rpm and a model of the same variety produces rib socks and links with speed up to 400 rpm.

In the hosiery field the real innovation is represented by the continuous research for technological solutions which allow to manufacture, automatically on the machine the closed toe. Currently, some Italian firms propose machines equipped with the automatic toe closing device.

The technological solutions in this field follow two trends: the first is the Lin-Toe method based on the use of a compact robot attached to the machine, which has the duty of closing the toe of the socks manufactured in the traditional way starting from the border or the cuff and reaching the toe. The second trend, proposed by the more innovative models, is based on the inversion of the traditional manufacturing cycle of socks; in this case we start from the toe and finish at the cuff, and the closing of the toe is carried out with the partial capsizing of the hook dials.

Surely, any solution we may adopt (the first or the second production mode), the closed toe manufactured automatically is currently the most significant feature which influences the design of machines for socks, and which will determine in the future a change in the commercial balance of the field.

In the traditional cycle of hosiery manufacture, the Italian builders offer a wide range of machines and equipment for final operations. The machine produced by an Italian company for tights assembly, for toe closing and for the gusset insertion can be considered a strong point of the knitting machine sector. We start from an assembly unit for tights linked by a robot to the automatic machines for sewing of toe and cotton panty so as to make it possible for one operator to take care of
the whole assembly process. There is also a robot which links automatically the toe closing with the semi-drafting machine. The line can be also linked to the unit for the automatic packaging in dyeing bags.

On the modern hosiery production lines, to obtain the best results, a centralised suction system mounted which carries out a constant depression on the machines; the total suction of cut threads and waste and generates an environment with constant humidity and uniform temperature, with a reduced volume of air conditioning which allows to keep under control the operating costs.

The various fans on each machine are, in this way, eliminated, and a single large fan is installed outside the machine workroom, with the advantage of reducing noise level, heat load in the work place and maintenance costs.

With the ever growing importance of the lingerie and swimwear markets, it cannot be neglected the great developments of the small-medium diameter circular machines able to produce tubular narrowed cloths for underwear.

The technologies derive from those adopted for socks circular machines, and, in fact, the medium diameter machines can carry out all traditional manufacture of hosiery industry, such as: insertion of reinforcements, lace patterns, alternating designs etc. Even for this type of machines electronics has played a leading role, offering the possibility of a programmable selection of the main functions to be executed during the knitting processing.

Particularly, an Italian builder has addressed his attention to the set up of a wide range of machines designed to meet the specific requirements of the knitter. The models have diameters ranging from 6” to 33”, gauges from 7 to 28. For example: a version equipped of 8 stripers, and able to manufacture jersey jacquard and terry cloth jacquard with the option of the three technical work ways, has 4-8 systems, gauge 18-28, diameter from 6” to 15” and is used to manufacture underwear, swimwear and sportswear.

A new model is the double bed circular knitting machine jacquard, with electronic selection of the cylinder needles and option of unlimited transfer from the cylinder to the dial, construed to manufacture continuous fabric similar to jaquard. It is realised with diameters 12” to 22”, gauges 14 to 18, and 4 to 8 systems.

An Italian firm has specialised itself in the production of medium diameter machines for underwear, ensuing from those for the manufacture of ladies’ stockings. The main model is a single cylinder machine, with full electronic control, 8 systems and it can manufacture a wide range of articles using natural, synthetic and elastomer fibres. Each of the 8 systems has an electronic selection group needle-by-needle and 16 actuators. In addition to the option of working on jersey, vanisé and terry cloth, there is the possibility of shaping, obtained with needle spacing and of the floating thread sheared and retained.

A well-known Italian concern recently introduced 3 technologically innovative, middle diameter electronic machines for the production of underwear, outerwear, bathing suits, sportswear and medical knitted goods. One of the two single-bed models is designed for continuous production and is therefore fitted with an interesting take down and winding system; the second can separate each individual garment.

Both machines are available in various diameters (from 10” to 15”) and gauges (from E 16 to E 32); they have 8 systems and 7 thread guides for each system. The double-bed model for continuous fabric production, is available in 14” to 22” diameters and in 12-14-15 gauges.

In the field of small-medium diameter circular knitting machines we can also find those with a single system, addressed to the manufacture of tubular articles for technical, medical or tubular knitwear (women’s underwear) uses, and those with 2 drops for the manufacture of two-coloured cabled threads (4 mm) to be wound on hosiery cones.

These examples confirm that, in the small-medium diameter machines, the Italian machinery is able to satisfy any request and it fully deserves, the world leadership it holds.
6.7 Warp knitting machines and crochet machines

Even though in Italy there are no builders of machines for the manufacture of warp knitwear, there are companies specialised in the construction of ingenious and innovative machinery, with particular features, which allow to combine the advantages of the flat knitting machines with those of the warp knitting ones.

A type of flat knitting single-bed machine with 2 systems, controlled by a microprocessor and equipped of a mobile bar with small shaped tubes which replace the needles, can manufacture special fancy jersey fabrics with warp knitted insertion, mosaic fabrics with symmetrical and asymmetrical patterns.

**Crochet machines** represent a highly specialised and well known segment in the textile machinery market, where Italian technology occupies a leading position.

Crochet machines are considered a category of warp knitting machines as they produce single chains of warp threads which are then tied together by horizontal weft threads. The weft threads can be moved in order to create the design pattern.

The traditional products which can be manufactured on these machines are laces, bands, ribbons (conventional and stretch type) and trimmings.

In the last few years, the technical development in this segment has enlarged considerably the range of products that can be manufactured on crochet machines: fancy yarns, medical products, technical textiles, special outerwear fabrics and furnishing fabrics.

Machine models are available with lever-type, glider chain or electronic control, or equipped with Jacquard machines (mechanical or electronic).

The crochet machine structure allows the use of spring-beard needles, latch needles and compound needles to process every kind of yarn. In addition, they produce basic patterns such as closed tricot, open tricot, closed chain stitch, open chain stitch.

The advantages of crochet machines are ease of use, easy maintenance, high output rates and rapid style changes (which make them suitable for small and large production runs). But above all, a crochet machine is an extremely flexible piece of equipment which can produce a number of different goods.
7.1 Introduction

Finishing includes the following essential stages:

- pre-treatment;
- dyeing and/or printing
- finishing.

Chart 12 - General diagram of finishing operations

1. **Staple, tow and top**
2. **Dyeing and printing**
3. **Yarn and ply yarn in package or in hank**
4. **Optional yarn operations**
5. **Optional warp dyeing**
6. **Weaving**
7. **Control and rolling**
8. **Pretreatment (cotton or wool)**
9. **Piece dyeing and/or printing**
10. **Wet or dry finishing (cotton or wool)**
11. **Final inspection, rolling and packing**
12. **Flat and small diameter knitting**
13. **Large diameter circular knitting**

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For the pre-treatment and the finishing stages, a further distinction must be made between wool and cotton, even though the number of modern multifunction machines presented on the market is increasing, and they are continually extending their flexibility and versatility. In fact, these are two “key” words in modern finishing, which allow the finisher an almost unlimited range of effects which, coupled with the product quality, increases the value of the product. In fact the trend goes towards special and new products to avoid the pressure coming from the competition of low-cost countries. This entails the use of extremely versatile machines suitable for small lots.

7.2 Staple, tow, top, package and hank dyeing and printing

Dyeing and printing can be carried out not only on fabrics but also during previous phases (Chart 13):

- continuous filament (tow)
- sliver (top)
- yarn package
- yarn hank
- yarn beam

Chart 13 - Dyeing and printing operations before weaving

7.2.1 Tow treatment

Dyeing, steaming and finishing lines have been added to the washing machines for treating the acrylic tow. Particularly, the dyeing machines assure an optimal fastness and uniformity of dye with a reduced floorspace, reduction of operation costs and a high mechanical and hydraulic efficiency. They are available for one, two or three tows.

The dye process consists in plunging the tow in a vat where the dyestuff is loaded and automatically fed. The dyebath is forced through the fibre by a device assuring an elevated speed of exchange and homogeneous treatment. The automatic loading system for dyestuffs allows short times for colour change and a high reproducibility.
7.2.2 Top dyeing
The traditional systems of dyeing in tops (wool or wool blends) are the following:

- dyeing in tops in bobbins or bumps after pressing of the same on perforated spindles held in a dyeing basket which is loaded on a dyeing machine (vertical dyeing beck).
- dyeing in tops in bobbins or bumps after pressing of the same on dyeing spindles which will have to be loaded on an horizontal dyeing machine made up of various individual vats, single, and of small diameter.
- dyeing in tops in bobbins or bumps loaded and pressed in a perforated stainless steel basket, similar to the stock dyeing basket (pack dyeing).

To these three methods, lately, there has been the addition of a new fully robotised range. The tops are placed in a special perforated dyeing basket containing approximately 100 kg of material. The system is fully modular, as each dye batch can weigh more or less than 100 kg, simply by reducing the load of a machine or linking various machines. The plant has been realised for the dyeing of wool, wool blend, acrylic and polyester tops, and can be used for any type of stock dyeing, therefore being useful also for materials destined to woollen spinning.

7.2.3 Driers for tow and staple
A wide range of machines are available for drying:

- of staple using a high production conveyor drier for washed, mechanic, dyed fleece wool, cotton, rayon, rags, waste, synthetic fibres etc.
- drying ovens and thermofixing for continuous or plaited polypropylene tows and polyester tows.
- drum dryers for tows and tops in the continuous dyeing process with tow delivery in cardboard containers (plaited) and tops (wool, acrylic, polyester) delivery in cans.
- drum dryers for stock loading after hydroextraction, or coming from continuous processes.
- drying tunnel with high frequency heating.

7.2.4 Package dyeing
Before reviewing the package dyeing systems, it is important to stress that the extraordinary progress in the dyehouses has come from automation and the use of robots, which has made very easy, secure and of better quality the handling of tow, tops, cones and yarn hanks. In particular the handling of hanks has been reduced to the minimum since the loading and unloading of the carriers of the material to be dyed is carried out by means of simple and extremely reliable robots. The standard dyeing system is based on vertical or horizontal modular devices where, on interchangeable material carriers, any type of yarn with different diameters, heights and weights can be dyed.

In these devices the dyeing bath is pushed under pressure alternatively and according to programmable times from inside of the spindles and vice-versa; this ensures a uniform spreading of the dyeing agent.

The pneumatic system is made of pumps with capacities that grant a perfect distribution of the bath thus ensuring a perfect uniformity of the dyeing.

Special machines equipped with horizontal or vertical pipes and with modular ring spin-drying dyeing system are now available on the market.

This systems are still equipped with vertical heating system which is highly flexible since it can dye packages in the most different sizes as well as warp beams thus combining an extreme easy-handling with an effective cost-saving.
With reference to warps it is worth mentioning that those destined to bulk production, such as denim fabrics used for jeans manufacturing, are continuous dyed not only with indigo, following a special technology, but also with other classes of dyeing agents.

The operating cycle of the dyeing devices for package yarns varies according to the different fibres and according to the dyeing agent class used; it is completely automated and controlled by microchips or by a PLC which start valves, adjust times, temperatures and quantities and grant the perfect running, top quality and absolute process repeatability.

Completely automatic and robotised are also the subsequent drying (carried out through automatic-cycle hydro-extractors) and dehydrating (which is obtained by means of fast dryers or forced-air circulation or even in a high-frequency heated tunnel).

7.2.5 Hank dyeing

Owing to its costs, this process is almost exclusively employed for cotton yarns which are treated under tension in a caustic soda solution using special "hank mercerising machines".

In this case the process includes:

- cone singeing;
- reeling for skein preparation;
- mercerising;
- bleaching and/or dyeing;
- drying;
- unwinding with eventual waxing

...to obtain bobbins ready for feeding weaving, hosiery or knitting machines.

This process also produces yarns with:

- improved luster
- improved strength
- improved absorbency of the dyebath.

Bleaching and dyeing are carried out in special containers for hanks while the drying process takes place in hot air tunnels (following the hank squeezing process) or by means of spin-drying or repeated high-frequency passages in a tunnel.

Other beam-to-beam continuous mercerising systems have been developed.

7.3 Wool fabric finishing

The fundamental operations can be grouped in the following sub-cycles:

- wet finishing, which can include also piece dyeing and printing for greige fabrics (Chart 14)
- dry finishing (Chart 15).
Chart 14 - General diagram of wet finishing operations for wool

Standard finishing can be classified in three large categories:

- sheared finishing, proper of the worsted fabrics, especially the summer ones, obtained without milling and with in-depth shearing
- milling finishing (Melton), used mainly for woollens
- raised finishing, usually used for previously milled woollens; it is characterised by napping
7.3.1 Rope washing
Washing removes all impurities accumulated during the previous operations and causes a first slackening of the internal tensions (setting) with an effect on the handle (Figure 18).

The choice between rope washing and open-width washing is dictated mainly by the type of fabric to be treated. The effectiveness of the washing is surely better when the fabric is rope treated, since the larger mechanical action favours both washing and slackening of tensions. Having to treat very fine articles like the fine worsteds, whose structure can be altered following the mechanical actions to which they have been subjected, it is advisable to use open-width washing, even if more costly, so as to avoid the danger of rope marks and creases.

The modern quick rope washing are suited for treating wool warp-and-weft and knitted products.

Some models offer a certain flexibility, since they do not only carry out simple washing, but can provide an effect of light or medium milling with soft and bulky touch, coupled with the softening of the fine worsteds.

This result is reached through the high speed beating (up to 4000 m/min) of the pieces against a milling plate at the back of the squeezing cylinders followed by an automatic rinsing process.

7.3.2 Washing milling machine
The traditional milling operation, intended mainly for items manufactured with a woollen cycle, is particularly expensive, due to the downtime for loading and unloading operations: many articles must be scoured before milling and all must be washed after it, to remove the various additives used. Various machines have therefore been designed to group all these operations in one single passage. Furthermore, these machines can process many ropes, like in the washing process, and have deeper vessels, to contain the necessary quantity of bath for best washing.
7.3.3 Rope opener
At the end of the rope washing, the tubular fabric must be opened to allow the piece, in all its width, to reach the following operations. The same operation must be applied to tubular knitted fabrics, and serves also for the operations of hydroextraction and cutting of the materials coming from the dyehouse.

7.3.4 Open-width washing
The discontinuous open-width washing is decidedly less productive than rope washing and this can explain, on the one hand, the great success obtained by the rope delicate action machines and, on the other, the development of new continuous washing plants in accordance with the operation requirements. It has to be noted that these lines can be suited both for pre-treatment (scouring) and for washing after pad-batch dyeing and after printing. The treatment speed ranges from 25 m/min (total plant length of 10 m) to 50 m/min (total length of 13 m). A further flexibility is given by the fact that this line can be used coupled with rope treatment units (Figure 19).
7.3.5 Carbonising

The carbonising process of woollens is subdivided into 5 phases:

- acidising
- pre-drying
- carbonising
- dry beating
- neutralisation

These operations are carried out in continuous and in open-width except for final neutralisation carried out through normal rope washing. Plants based on pre-scouring of the fabric in solvent which removes contamination from acid bath and assures a more uniform and complete carbonisation are also used. Furthermore, there are no problems of air pollution, thanks to drying/carbonising areas hermetically closed. The lower absorption of acid by the fabric, reduces its consumption and damages to the wool. Finally, the lower water consumption in post-washing results, in an easier, faster and therefore more economical operation.

7.3.6 Piece dyeing

The fabric in the form of ropes is circulated inside the machine by means of jet-flow or over-flow devices allowing the fabric to be dyed without tension thus avoiding the formation of creases and pilling (little fibre flocks) on the fabric.
The latest technological developments have led to the introduction of machines where a single rope passes through various vats and flow-jet devices ensures repeatability, uniformity and reduction of dyeing times (Figure 18). These machines can be completely automatic and equipped with microchips for an automatic control of the various steps. These machines can be used alternatively at atmospheric pressure or under pressure according to the specific dyeing need.

7.3.7 Discontinuous crabbing
This technology is used for fixing the shape of the fabric by immersing the fabric beam in the boiling vats containing hot water charged with a wetting agent. A reversible volumetric pump ensures a gentle and smooth bath circulation inside outside and vice versa. After the squeezing, the fabric passes through nozzles that spray cold water producing a strong thermal shock.

![Figure 20: Rope dyeing machine](image)

7.3.8 Continuous crabbing
To enhance productivity of the crabbing operation and to prevent the problem of end-to-end differences, several continuous treatments have been developed. Higher mechanical pressures and temperatures can now be obtained thanks to the special use of new materials for the belt. Also available is a very versatile model which can be used for wet crabbing and as a dry presser/calender.

7.3.9 Pile fabrics
Up to now, the category of medium-heavy pile fabrics had not been taken into consideration; usually the process sequence is as follows:

- scouring/milling
- crabbing
- dyeing
- drying
- raising
- shearing
- wet brushing
- drying
- steaming/continuous decating
7.3.10 Surface mechanical treatments
These operations is aimed at obtaining a uniform pile fabric. The treatment of pile fabrics begins with **raising**.
The main factors influencing the process are the following:

- fabric tension
- rotation speed of drum
- rotation speed of pile cylinders
- rotation speed of counterpile cylinders
- fabric speed

The fabric tension is a fundamental parameter since the surface of the fabric which comes into contact with the cylinders varies thus diminishing or increasing the treatment effect (Figure 21).

**Figure 21 - Raising/emerising machine**

Loading cells are used today to control the tension while electronic systems control the speed and to enhance to the uniformity of the treatment both longitudinally and transversally.

The **shearing** is the first operation usually carried out in a dry situation but, as shown, in pile fabrics this is carried out on a wet cloth, after raising and before wet brushing (Figure 22).

**Figure 22 - Raising machine for knitted fabrics**
In a shearing machine there are usually three types of brushes having, respectively, the functions of: cleaning the back of the fabric, lift the pile in a regular and orderly way to prepare it for the contact with the blades, and to lower the pile after shearing. Since the shearing process takes quite a long time due to the many passes required, there is the possibility of carrying it out (front and back of the fabric) in a single run with two shearing modules overlapped.

**Wet brushing** for pile fabrics, is carried out after napping and shearing. It consists mainly of a wet brushing to give a final and uniform direction to the pile fabric lifted by the napping operation.

### 7.3.11 Drying

Various fabric drying systems (stenters) are available:

- flat stenters, with horizontal chain
- vertical stenters,
- horizontal multi-layer stenters
- tensionless stenters for knitted fabrics

Great results have been obtained with regard to shrinkage control, feel and dimensional stability. Machines have undergone progressive updating of fabric driving chains, machine accessibility, electronic controls and components. In accordance with modern trends, motors are powered by alternating current and operated by inverters. One of the main features of a stenter, is the chain on which are placed the elements holding the fabric, i.e. pins, clips or pins + clip plates. Usually the pin version is used for knitwear and for fabrics that must shrink warpwise, and for wool fabrics where all possible clip marks must be avoided. For the heating of the stenter, various systems can be used: amongst them the direct methane combustion is the most efficient and cost-saving.

### 7.3.12 Steaming and decating

This operation is aimed at stabilising the fabric, giving it dimensional stability and decreasing the thickness. The steaming and decating process is carried out on woollens, pure wool worsteds and or wool/polyester blends as well as on other man-made fibres. The fabric undergoes (in sequence):

- treatment by means of saturated steam under pressure at temperatures up to 135°C;
- cooling with surface/dimensional stabilisation

Various systems can be used: the non-continuous treatment in an autoclave or the continuous one at atmospheric pressure. Continuous systems under pressure are the most used to obtain a finished fabric with no further operations thus making the process more cost-saving (Figure 23).
7.4 Finishing of cotton fabrics

7.4.1 Pre-treatment of cotton and other short staple man-made fibres
The pre-treatment stage (Chart 16) is divided into:

- **Mechanical pre-treatment** - Woven as well as knitted fabric passes through a shearing machine which brushes the fabric to eliminate raised yarns on the fabric surface. This operation is usually carried out for all fabrics during the weaving process together with a thorough table inspection. This operation determines the destination and use of the fabric according to the faultiness quality of the fabric. The fabric subsequently undergoes a singeing operation; the fabric passes through a singeing machine with one-or two gas-flame areas which remove all projecting fibres from the fabrics. The machine also features a brushing and dust-suction area.

- **Wet treatment** - This treatment is used to remove on one side the foreign matters from the fibres and from the other one the substances applied for the manufacture of the fabric such as sizes, oils, spin finishes. Continuous treatment machines are used for singeing/desizing/bleaching operations.
7.4.2 Washing
Washing is an operation carried out during various steps of the fabric finishing process and more precisely during:

- pre-treatment,
- after-dyeing treatment
- after-printing treatment
A model has been developed for use both in washing and in desizing. It allows a thermal swelling action of the fibres and of the sizes present on the fabric, with consequent size splitting.

This enormously facilitates the action of the enzymatic desizer, which acts upon the starch particles that, being very small, can be better attacked. At the same time, a strong mechanical washing action is produced by special finned pipes, thereby starting the elimination of the substances made soluble.

The thermal action takes place with the transformation into steam of an overheated liquor jet (130°C) which comes out from the nozzles placed over the fabric, next to the upper pipes. The nozzles are staggered to guarantee maximum uniformity of the spray across the whole width.

The pressure of approximately 3 bar is obtained using a pump. With these pressure and temperature conditions, the spray is transformed right away in steam, allowing a fast thermic exchange with the bath wetting the fabric.

Other lines are set up for scouring and washing, or for open-width or continuous washing and mercerisation, with one or two-way versions.

7.4.3 Jigger
This machine (Figure 24) is still the most economical and versatile for the pre-treatment, bleaching and dyeing of small batches (3000-3500 metres). Some Italian firms boast a long experience in building jiggers for dyeing and bleaching natural fibres. The machines are available in two versions: atmospheric and high-pressure. The tensionless treatment also permits the dyeing of silk fabrics.

7.4.4 Mercerisation
It is a treatment with caustic soda whilst the material is held under tension. The chain machine is the most suitable to realise a perfect mercerisation and market trends now go towards the use of cylinder machines because they are more compact and have a higher yield than those with chains.

Mercerisation is important for fabrics, and even more for loose or tubular knitted fabrics. In addition to the saving of dyestuff during dyeing and printing, it is also useful to provide the fabric with an optimal luster, a good dimensional stability, and a better resistance.

7.4.5 Polyester causticisation
It is a treatment with caustic soda. This process is aimed at obtaining a refinement of the filament count and an increase of their surface. These factors imply substantial variations in look, hand and drape of the various fabrics, providing them with similar characteristics to silk fabrics. There is a system which couples the washing/neutralising alkalisation.
plant with a tensionless relaxation-dryer, as the right combination to obtain optimal results (Figure 25).

The exhaust process is used for smaller lots, and employs the usual discontinuous machines for dyeing (on beam). In this case, causticisation takes advantage of the constant control of hydraulic parameters, of the control of beam variations during work processes, of the automatic adjustment of pressure/load differential to the changing of the characteristics of the treated material.

7.4.6 Rope dyeing: flow, overflow and jet machines
The vast range of flow and overflow atmospheric pressure machines, has been outlined in the previous chapters concerning the dyeing of wool fabrics. It is necessary to specify that almost all models are available in equivalent versions at high temperatures under pressure for rope dyeing of woven and knitted synthetic, natural and blended fabrics. Pure overflow allows to treat fabric without tension and to avoid pilling. It should be pointed out that that machines are supplied in two versions: a fully automatic model, on which the whole process is monitored by a microprocessor control system, and in less sophisticated versions to favour an easier approach to automation as regards both investment costs and personnel training.

7.5 Printing
The printing systems available are the following:

- carriages for table printing with different automation degrees, and sampling machinery of single and versatile use
- rotary tables, each having flat and/or rotary screens
- continuous flat screen printing machines
- continuous rotary printing machines
- transfer printing machines
- tops and yarn printing machines
- digital printing machines

Furthermore, in Italy are offered also the colour kitchens and the auxiliary machines (washing machines for rotary printing), the computerised systems of colour separation, and photoengraving systems.

In the case a high quality printing is requested, the table with automatic carriage is perfectly suited to all requirements, with limited costs. Electronics governing it, allows an optimal use with great downtime savings. The single squeegee is programmable both in sloping and in pressure, and it allows good control of colour transfer in the proper quantity.

The introduction of rotary tables in printing mills, has revolutionised the flat screen printing concept, improving quality and productivity, while reducing floor space and labour.
The new machines are equipped with “open space” printing stations, which can use both the traditional single squeegee with magnetic hook, or the double blade squeegees. They can be equipped with two or three flat printing stations, and by one to four rotary print heads. Their main feature is the original system of reading and error control installed on the printing stations, which allows an automatic positioning of the same during the repeating operation and automatic error correction during printing. The large flat screen machines built in Italy combine printing quality and production speed never before reached. The speed can reach up to 30 m/min with limited values of feeding and squeegee process. The integrated drive, control and monitoring system is made up of the digital communication network (Profibus) to which are linked all logical subsystems of the machine.

**Figure 26 - Flat screen printing machine**

![Flat screen printing machine diagram](image)

The operator monitors the machine functions through the videocontroller which is the general interface of the system (Figure 26).

In the field of continuous machines for rotary printing, we can find non-electronic models, which are the object of an updating process capitalising on the experience acquired during the last few years, and which have given a great impulse to the technological development of rotary printing. The electronic models of rotary machines, have revolutionised the concepts of: economy (change of colour in 7 minutes; change of plot, for 12 colours, in 20 minutes), environment (washing waste water recovery), technology
(all controls and drives of the machine belong to a LAN network based on digital communication using optical cables).
Printing speed reaches 90 m/min, the colours can be up to 36 and the width of the fabric can reach 3.4 m. A new series of dryers represents the ideal finishing of the rotary printing machine. The 2 metre chamber has been completely redesigned obtaining a ventilated surface of more than 20%.
Each printing sequence (working cycle) is always preceded by variant or plot changes, and, consequently, of washing the doctor knives, cylinders and pumps, creating dead times which have a negative influence on the high productivity of the rotary machines.
A newly patented washing system consisting of new doctor knives which can be washed directly on the machine avoids these problems. The washing sequence is activated at the end of the variant, without removing the doctor knives and the rotary screens of the machine.
New ink-jet printing systems applying the plotter technique for paper colour printing have been introduced on the market in the last few years. These systems avoid any preparation of cylinders or screens thus meeting the market demand for shorter work times. Unfortunately these machines still allow limited printing speeds. The use of these systems for the preparation of samples is also restricted because of the difficulty to reproduce identical colours on bulk productions.

7.5.1 After-printing steaming
After the printing process the colour must be fixed on the fabric by means of a steaming treatment (Figure 27).
The fabric piece is folded in order to increase the treatment time inside the steaming chamber.
The operation is extremely delicate since the fabric has to be folded when it is still wet; it is necessary not to touch the printed side of the fabric. For this operation, chain and transfer cylinder recirculation systems are used. The use of saturated steaming chambers allows, for most cases, to eliminate the use of urea with the consequent reduction of the environmental impact.

7.5.2 Washing and drying after printing and dyeing
The same washings used for pre-treatment are very efficient even after dyeing and printing. Several systems are more suitable to these specific operations. The open-width rope plant made up of forced washing elements and relaxation modules on stocking belt, with small loops and a rope treatment module equipped with a conveyor dryer, especially conceived to obtain the maximum fabric shrinkage together with a progressive and gentle drying.

Figure 27 – After-printing steaming machine
7.5.3 Transfer printing
Transfer printing concerns a wide range of uses, from knits to polar fleeces, to polyester nonwovens. The systems used are:
a) continuous thermoprinting, by calender, of articles with a maximum width of 3200 mm
b) large size presses for thermoprinting pullovers, T-shirts, sportswear before making-up, and small presses for badges and small designs.

7.5.4 Dyestuff dispensing systems and colour kitchens
The preparation of printing colours and pastes is now completely automated. In modern industrial dyehouses and printing mills a valid recipe prediction is absolutely fundamental to reduce working hours and to ensure cost savings. Only an automated "colour kitchen" can ensure a valid dosage of the recipe ingredients and the repeatability of the recipes. These systems include also the dosing of auxiliaries that are a fundamental part of the dyeing and printing process.

7.6 Laboratory
The laboratory is considered as the central and determining feature for the technical-commercial success of a modern dyehouse. Many builders of dyeing machines, have, in their production programs, a series of sampling equipment, with very low capacities. Furthermore, complete systems controlled by the main computer and by the software, are available for a fully automatic management of the laboratory: from the preparation of solutions, to handling of dyestuffs and/or auxiliary products for plant feeding (with relative analysis of recipe costs), to automatic dispensing of the products themselves (management of records of recipes in the laboratory) and "colour matching" integration, colourimetry for control of liquid dyestuffs and integration in the computer system of the dyehouse.

7.7 Inspection and packing
Inspection and classification of defects on the fabrics are now carried out by means of inspecting machines which can be traditional machines improved by systems that allow to manually set the frequency and the type of defect to automatically obtain the classification of the inspected fabrics. Completely automated control systems equipped with modern camera viewing systems and image matching have been used in the last few years. The inspecting machines are usually equipped with automatic computer-controlled metering, rolling-up, strapping and storing systems.
Silk processing technologies

8.1 Introduction

Nowadays Europe and especially Italy imports – mostly from China – large stocks of both pure silk in hanks and many kinds of silk wastes, including defective cocoons. Thus silk processing – the only continuous yarn existing in nature – begins with hank because the previous stages are performed in the production countries, whereas silk waste processing under the form of staple is made with machines used in the cotton and wool processing to obtain Schappe yarns or silk bourette yarns.

8.2 Hank-to-spool winding

As the yarn to be wound is extremely delicate, special hank to spool winding machines are required. The slipperiness of the silk yarn requires the use of tapered bobbins. Take-up packages may be flanged bobbins, bottle bobbins or cops, depending on the subsequent use. The reel on which the hank is positioned can be rotary (deroulé winding) or fixed (défilé winding).

On these machines the yarn is controlled by means of adjustable mechanical flanges. These machines feature tensioners equipped with rotary flanges with pressure variable according to the spool diameter and to the desired density. The flanges of the tensioner can also be motor-driven.

As the doubling process is a crucial operation which influences the following two-for-one twisting, great care has been devoted to the development of a silk doubling machine with yarn take-up on flanged tubes. This series, which can double four ends and optionally six ends, is equipped with magnetic sensors on each end to be doubled, which stop the head when there is a yarn lack or break. Moreover, there is another model characterised by a purpose-designed tensioner; here the sensors have been replaced by a spiral throwing device. In this way, the last end is twisted around the other already doubled ends. The operation ensures an improved yarn strength in the following throwing process. The sensors for the three ends already doubled are electronic, whereas for the fourth end there is a diapason device. Tension is controlled by a ceramic split yarn clearer.

Two new silk machines are built by a producer of twisters and other winding machines. The doubling machine couples two, three or four ends prior to throwing, ensuring an excellent yield. The machine can couple the ends by a special process that imparts a cohesion effect. On the two-for-one twister, this fact improves yarn unwinding from flanged bobbins. The machine is equipped with electronic sensors which control each end, stopping the head in case of breaks or lack of yarn. Optionally, the machine can be equipped with a non-contact optical system which automatically stops and raises the single take-up positions when the preset diameter has been reached. The gearbox operates through a sophisticated system to produce flanged bobbins without hard edges.

The two-for-one twister has spindles in oil bath, specifically designed for silk. Energy consumption has been minimised. The take-up speed can be adapted to both high and low twists. Two types of flyers are available for unwinding low and high twist yarns.
8.3 Warping, weaving and circular knitting

Silk yarn warping can be performed on electrically controlled section warpers which allow to handle the delicate silk yarn. For the weaving process the looms must be suitably adjusted bearing in mind that silk is not a "speed-friendly" material. The same goes also for circular knitting machines.

8.4 Degumming and dyeing of yarns and silk fabrics

Silk is a protein fibre formed by firm and continuous filaments coated with a gummy layer called sericin. Silk yarns are highly sensitive to alkalis and mechanical stresses. If during finishing silk should be simultaneously subjected to these two factors, damages would be
irreparable. The selection of suitable machines and chemicals, together with a reliable and well-proven operating sequence and procedure, is of fundamental importance.

As degumming reduces weight up to 25%, during dyeing it is necessary to increase the weight by adding metallic salts and other finishing agents. However the increase must not exceed 5% of the weight of the goods after degumming, otherwise the product has to be marked as “weighted silk”.

This weighting operation can be performed also on fabrics, and it is of a great significance for luxury yarn dyed fabrics to be used for tie manufacturing, because it results in a better hand and a firmer cloth.

Investigations showed that degumming and dyeing – carried out with a liquor ratio of 1:8 with short cycles and low amounts of chemicals in the same machine without intermediate handling – provided good weaving performance on the modern looms, thus the best standards of fabric quality can be achieved.

Packages degumming and dyeing can be carried out on horizontal and vertical machines whereas fabrics are dyed on beams or star machines according to three different degumming processes.

The models of vertical and horizontal autoclaves are currently the most technologically advanced. Degumming, dyeing and weighting of “soft” packages can be performed in the same machine, in continuous succession, without any manipulation. After dyeing there comes hydroextraction and drying on hot air dryer (discontinuous cabinet with horizontal and vertical geometry) or by radiofrequency (continuously on conveyor belt). There follows re-winding on one of the models already described.

Machines are constructed with modulating pneumatic and on/off valves which can be driven by a microprocessor for the fully automatic or semi-automatic running of dyeing cycle. An automatic device allows the control flow of and/or the pressure difference through a butterfly valve and/or variable speed motor. Machines are available with diameter from 400 mm to 2000 mm with a capacity from 10 kilos to 1000 kilos or more because all the machines can be coupled with devices which assure the complete exchange of dyebath.

Silk processing on horizontal and vertical autoclaves from another builder, contemplates silk winding on stiff cylindrical tubes for an outer diameter of packages of 150 mm and density of winding of 380 t/dm3, bidirectional liquor circulation. The heart of the horizontal device is the innovative pump of heliocentrifugal liquor circulation assuring a superior dyeing uniformity. Machines have a modular length to contain one, two or three material carriers (from 200 to 600 kilos). Machines can be equipped with automatic linking between two or more machines. Liquor ratio remains constant for each kind of package.

Different systems of drying with completely automatic cycles are available; they operate with an automatic system of humidity control.

The vertical machines of the same origin operate with the material completely soaked in the liquor, whose flow is bidirectional to obtain a superior quality of dyeing. Pressurisation is generated by a compressed air cushion in the superior part of the autoclave which is one of the characteristic of these machines. The air cushion is automatically controlled for compliance with a pre-determined value. The air never comes into contact with the yarn. One of the technological advantages of this pressurised system is that the expansion volume is inside the dyeing autoclave and the external tank of expansion does not exist. The device can be pressurised at low temperature. Pressurisation with air cushion allows to “inject” dyestuff and chemicals directly in the principal liquor circuit. Through automatic controls of the liquor level, the liquor ratio is adjustable to optimise the process conditions. Controls are usually continuous and the height of liquor in the basin can be determined in all its height.

The horizontal machine operates with a low liquor ratio from 1:4 to 1:8 according to the density of yarn in the package. If a higher liquor ratio is adopted in the washing phase, the solubility of unfixed dyestuffs improves. During the continuos rinsing the machine is completely filled with water. One of the advantages of this type of autoclave is load flexibility going from half load to partial load, to complete load, keeping constant the
liquor ratio. The vertical apparatus can optionally be equipped for hydroextraction through compressed air directly in the dye autoclave. This operation comes after dyeing and before unloading the material carrier (whose load decreases) in one of the two different kinds of centrifugal hydroextractor available in the series of processing machines on packages of different kinds, among them the beam for fabrics. Also for natural silk fabrics processing, a new and complete line of machinery and technologies is used both for degumming and for dyeing. When an optimum standard of quality is required a star machine can be used. The latest models (atmospheric pressure) are provided with variable speed stars, a device for centralized fabric shrinkage control, as well as with an anti-release device allowing to hang a longer yardage of cloth. Whenever degumming and bleaching are followed by printing, continuous washing can be performed on a line equipped with a semi-automatic system to transfer the cloth from the star frame to the continuous washing machine. Only one operator is sufficient for piece unloading from the star and feeding into the washing machine. The feeding section is equipped with a piling-up tank and may be connected in series with 6 or more star degumming machines, thus realizing a highly rational modular system. The washing unit assures the most suitable tensionless treatment and high efficiency thanks to geometry, cylinder layout and speed control system.

8.5 Degumming at high temperature

The processes and the related machines for natural silk processing at high temperature represent the greatest technological innovation for a traditionally conservative sector. Among the traditional machines at atmospheric pressure, a new series has been presented both for yarns and fabrics. After detailed lab tests the results of the first analyses have been confirmed on industrial scale. It has been proved that a temperature rise over 100°C (at neutral pH, and in absence of auxiliary products) has a strong dispersing action, more specific towards sericin than fibroin. Moreover, whereas a low alkalinity tends to progressively destroy silk fibres (in function of persistence time and temperature), it doesn’t appear that treatments of more than one hour at temperature higher than 100°C have caused damages to the dynamometric characteristics of silk fibres. The possibility of controlling silk scouring only through times and temperature without any chemicals, opens up new horizons and allows to obtain different advantages, among which the most evident and immediate are:

- shorter operation and lower energy consumption,
- easier final washing operations,
- reduction (or elimination) in chemicals use,
- reduction of specific areas necessary for product unit in time unit,
- lower pollution rate in waste water,
- sericin recovery from effluents or, alternatively, dyeing in the same scouring liquor using the sericin as auxiliary levelling agent.

Whereas the use of high temperature in the scouring of silk yarns on bobbins has been possible for the above-mentioned vertical and horizontal machines, slightly modified in some parts by the builder to make them suitable for the new use conditions, a new scouring star apparatus has been designed for fabrics to overcome the following two problems:

- the construction of pressure autoclaves, able to contain stars of particular form, size and characteristics,
- the regular bath movement through circulation. In the open stars a reciprocating vertical moving of the hanging fabrics is possible.

The stars of the series “Silk at high temperature” allow to obtain all the advantages of atmospheric star scouring and, at the same time, those of the processing at high
temperature. The liquor circulating system allows an optimal distribution of the scouring conditions even reducing the liquor ratio (from 1:60 to 1:30), scouring times (from 4 hours to 30 minutes) eliminating the use of chemicals. Delicate items dyeing can be done successfully in the same scouring liquor, achieving an extremely rational, economical and quality production cycle.

8.6 Silk and blend fabrics dyeing

Natural silk dyeing, as well as scouring, must be practised without any tension and mechanical stress. Other dyeing systems are available depending on the kind of fabrics, the requested colour, the qualitative standard as well as the atmospheric and high temperature star frame.

Winch becks - They are extremely simple machines which, thanks to the new motor-driven oval yarn winch and the regular adjustment of fabric in the tank allow an economical treatment and a wide application field above all in the sampling and in the production of small lots.

Beam dyeing machines - These machines are recommended for heavy fabrics and subject to volume increase like shantung, twill, pongées, taffetas and crêpe marocain. The flow and the persistence, the beam characteristics and the automatic control of the section and of the differential pressure make possible a very delicate treatment of the fabric, evident above all in the very dark colours.

Overflow - The model of overflow at atmospheric pressure is recommended for natural silk processing. The limited height of the draw winch, the water cushion overflow, the electronic control of the start and stop speeds and transistors avoid every kind of tension and mechanical stress. The regularity of the process and the correct fabric passage in the tank are due to the overflow geometry, the possibility of flow regulation and the particular double-bottom tank.

The scouring and dyeing of blends, such as silk-wool, silk-acetate, silk-viscose, silk-linen, can be carried out in the same machine. In this case scouring is followed by washing and dyeing without intermediate handling of the fabric, thus the complete processing cycle takes place in only one machine.

For liquor ratio from 1:25 to 1:40 a model has been studied and built purposely for silk fabrics processing; the limited characteristics are draw winch with large diameter and the particular design of overflow device. These characteristics and other structural elements allow the processing of very delicate fabrics in the "softest" way.

Another soft flow silk at atmospheric pressure allows to dye woven and knitted fabrics, whose weight goes from 50 to 200 g/m2. The machine presents hi-tech solutions to avoid crease formation, abrasion and other faults, such as a lowered friction roller large diameter, lessening the distance between the rope inlet and the innovative nozzle arrangement which provides careful, gentle treatment. It is also to be noted the use of an inverter to synchronise the rotating speed of the roller with the pump delivery, thus avoiding the fearful rope marks due to possible jam of the rope at the inlet into the feed nozzle.

8.7 Printing

Large quantities of standard qualities, such as silk crêpe de Chine, pongée and twill are printed.

Although the different models of printing machines are not linked to a particular kind of material, if one speaks about rotary tables, one thinks immediately of silk. The introduction of rotary tables in printworks has completely changed the concept of manual printing, improving the quality, the productivity and reducing at the same time the occupied space and labour.

For this type of commonly printing – called à la lyonnaise – various solutions have been proposed. The new machines are provided with “open space” printing units which can
use both the traditional single squeegee printing with magnetic hooking and double squeegee with blade. They can be equipped with two or three flat printing station and from one to four rotary heads. Their main characteristic is the original reading and checking error system applied to the printing station which allows the automatic positioning of the same during repeating and the automatic correction of errors during printing.

Flat bed printing machines are largely used for printing silk fabrics, especially for ties.

### 8.8 Steaming, washing and drying after printing and dyeing

The quality of the steaming is very relevant for fixation of prints on silk. Silk which in the most cases is discharge printed, requires a high level of humidity to let colours fix in an optimal way. In practice steam must be used in conditions near to condensation without any condensate formation on the fabric. Traditional steamers of a company specialised in after-print treatment are equipped with dampening ducts purposely developed for silk and with computerised temperature controls assuring constant conditions during treatment and an optimal yield of dyestuffs as well.

A new approach to washing technology is based on the vibration principle, which exploits the shock waves of the washing liquor generated by the rotation of two concentric cylinders having suitable geometrical and mechanical characteristics. The outer cylinder shows a perforation which has been experimented to be optimal for an even distribution of the washing liquor across the full fabric width.

### 8.9 Silk fabrics finishing

The market development leads to a continuous improvement of the machinery and technologies and consequently the finishing of fabrics. Fashion trends have introduced new looks and touches in silk, that specialists could neither imagine, nor think possible. Washed and sand-washed silk brought new criteria in silk finishing.

The traditional finishing of silk is based on many finishing machines, that are used and combined according to the article to be produced. Generally these machines have been updated especially with the application of microcomputers to better manage the process; however, the principle of their action is still the same.

On stenter frames overfeeding is important, as many styles, especially crèpes, enter the first field in an overstrained state.

Calender processing has the aim of breaking hard finishes, in special cases it is performed to increase brightness or to produce "moirè" effects if engraved rollers are used.

Decatising machines may be used both in the continuous and discontinuous versions. The fabric remains tensionless between wool felts while steam is flowing through the machine, enabling a further relaxation. A better fabric appearance is reached, and creases are flattened.

Inspecting and rolling-up machines with metering and cutting devices are available to complete the silk fabric manufacturing as well as tie reversing machines and tie ironing units.
8.10 Silk waste spinning

A distinction can be drawn in waste spinning between the Schappe (combed) system and bourette (carded) system which can include blends of silk with other fibres, such as wool, viscose, and even cashmere or kid mohair (Chart 18).

Chart 18 - Silk wastes steeping and spinning

Silk to be spun is made from the loose outer layers of reeled off cocoons and from imperfect cocoons. They are not reeled but spun after scouring and combing, in a way similar to the process used for wool and cotton. Wastes obtained from combing, called “noils”, can be spun according to the carded system and are also suitable for blending with other fibres, thus the machines are those already described for woollen and worsted spinning.

In the traditional process silk wastes are opened on cotton-openers, then cut, blended and then carded on special wool cards with a special feeder. Then one or two pre-combing passages are performed on drawing frames, followed - according to the fibre length - by an optional passage on rebreaker and another pre-combing passage.
Combing is performed on a flat comber, followed by a post-combing drawing frame, and again a second passage on flat comber and two post-combing passages of intersecting. Alternatively a single combing can be performed followed directly by two post-combing intersecting passages.

For preparation to spinning, first drawing frames are used; they are very important and can be chosen among those with several heads (2-4 heads) and many draft control versions. In particular the process for fine and extra fine yarn counts, where control disk heads have been changed with a compound system.

The preparatory passages are followed by flyer and ring spinning machines, winder and twister.
9.1 Introduction

The nonwovens technology involves the manufacture of textiles by using fibres directly without passing through the production of yarn i.e. the product is bonded in different ways.

The use of nonwovens was initially focused on providing cheap replacements for traditional woven and knitted fabrics. The difficult introduction into the market led to the development of new applications and new markets: agriculture, automotive, civil engineering, geotextiles, special clothing, home furnishings, military, filtering and health care.

A large range of raw materials are used such as viscose, polyester, polypropylene, polyamide, cotton, short staple wool, combed waste, linen and jute spinning waste, and reclaimed fibres from rags and making-up cuttings.

These products can be “engineered” according to the specific end-use: they can provide absorbency, liquid repellency, resilience, stretch, softness, flame retardancy, washability, filtering, sterility and bacterial barrier.

9.2 Web formation

We explain below the basic methods to form the web, involving both staple and continuous filament yarns.

9.2.1 Dry laid processes

- Carding - Here a traditional system to prepare the wool is used involving the fibre opening mixing and carding. Cards can process synthetic and natural fibres up to 150 mm long. Nonwovens cards widths range from 2,500 up to 3,000 mm. The web is collected and conveyed to a crosslapper, and subsequently to a bonding group.

- Spunlaid - This means that the web is directly obtained from extrusion. The polymer chips pass through a spinning die and can be processed through two different systems (Chart 19).

- Spunbond. The webs are spunbonded in continuous filaments. The spunbonding process is adopted mainly for products where moldability is a key requirement and for polyester fabrics used for roofing applications for bituminous waterproofing membranes.

- Meltblown - The molten chips pass through the spinning dies; blown with hot, high-velocity air the filaments are then cut in short lengths. The short fibres, thereby created, are spread onto a moving belt or screen, where they bond to each other on cooling, to form the web.
Both spunbonded and meltblown webs are bonded by passing them between smooth or embossed cylinders under pressure. Systems have been developed to produce both spunbonded and meltblown webs, depending on the end use. Other systems have been developed for manufacturing multidenier and microfibre nonwovens.
9.2.2 Wet laid process
In a wet laid process, fibres are suspended uniformly in water, with concentrations of 0.01 to 0.5% by fibre weight, and collected to form a sheet by filtering onto a screen, as in papermaking processes. The screen can be in the form of an inclined cylinder or in the form of two metal belts where the fibre suspension is fed onto the screen. The wet web is squeezed between the rolls to remove most of the water and dried further by conveying it through ovens. The wet laid process permits adding chemicals, binders and dyestuffs.

9.3 Fibre reclaiming
Also regenerated fibres can be used to manufacture nonwovens. The re-use of waste generated during the various textile processes - including cuttings from the making-up industry - is becoming increasingly crucial both from an economical and environmental point of view. The use of this material has been made possible thanks to specialised machinery. Two systems can be adopted to treat wastes and rags - wet and dry (Chart 19).

9.3.1 Wet system
After carbonising, a new machine with combined action allows to obtain at the same time tearing and efficient washing of wool and wool blend rags. The plant consists of a big masonry tank with a central islet containing electrical motors and control devices, and up to three tearing groups. A large exhaust manifold for the tank also provides for constant water level during the working phase. The dry rags are put into the channel and taken by the running water to the first tearing group. In their way from a tearing group to the next one, rags are so subjected to a continuous and deep washing action. After drying, the carbonised fibres are ready to be blended and prepared for further processing.

9.3.2 Dry system
This system includes rag cutting, blending, and tearing.

9.4 Waste recycling
Complete lines for the recycling of waste are offered including rotary cutters for bales and loose waste; guillotine cutters for fibres, rags and waste; rag beaters and dust extractors; automatic boxes for the blending and storing of cut rugs and textile fibres and for the automatic feeding of rag tearing machines, cards, and similar machines; automatic volumetric hopper feeders; pre-opening groups; universal tearing machines suitable for any type of textile waste; oil spraying systems; inclined multiple step cleaners; cutting machines for tow, and a large selection of bale pressing units, horizontal and vertical, hydraulic presses for rags and reclaimed fibres, automatic presses for waste from centralised dust filtering systems. Also roving waste openers and beaters for carbonised wool are to be found in the programmes of some builders.

9.4.1 Tearing lines
A particular mention is to be devoted to a modern model of tearing machine with automatic feeding. The line may be composed by up to five machines put in series. Another well-proven model is specially designed for tearing wool, cotton, and jute, and thanks to the large diameter drums (1,400 mm) it perfectly opens all types of synthetic fibres. Also this machine can be supplied with one, two, three or more working units in three standard working widths.
A typical example of the regeneration of textile wastes is represented by the following plant for the processing of low-grade waste made of miscellaneous fibres and blends,
and designed to the production of fibres for nonwovens with different end uses. The raw material state is particularly critical due to a large quantity of impurities and dust. The raw material bales are directly fed to the rotary cutter for bales, and from this to the rotary cutter for loose waste, so that the material is reduced to pieces of suitable size for the following tearing. In the oiling chamber the cut rags are then moistened with a water/antistatic oil emulsion lubricant, so that danger of fire, electrostatic charges and overbreaking of fibres are reduced.

To reach a more uniform composition and colour the cut rags are now spread into two automatic boxes for blending and storing. From the boxes the material is sent to an automatic feeder and the pre-opening unit which is equipped with a tearing drum with sturdy clothing. Its task is to coarsely open the waste, and preparing fibres for subsequent impurities removing. In the cleaning/blending machine and the cyclone the material is beaten and dedusted, and much of the impurities are removed. The partially opened product is then conveyed to the tearing machine by means of a chute-feed unit, so that complete opening of the fibres is provided.

At the inlet of the tearing machine a further moistening of the fibres can be carried out by means of an oiling device. During the running of the material through the drums of the tearing machine and the second cleaning/blending machine a final removing of the tiniest and difficult impurities is assured. The material which is now a raw fibre again can be either stored into the automatic boxes for fibres, and directly fed to the card, or pressed in bales for subsequent later processing. When used, it can be mixed with virgin staple.

Being the above description only an example, it is to be underlined that the builders of both reclaiming fibres line and preparation to web forming – opening and blending with other fibres (a proportion of polyamide staple is usually added to reclaimed fibres as a reinforcement) – are ready to study in co-operation with the user the right plant lay-out and machine selection for the right end-use, so that the complete plant supplied can meet particular requirements of productivity, quality, cost-efficiency, and control simplicity.

In preparation to web forming and prior to carding, there is an array of machines, that can be chosen to form the lines, because if several types of fibre are used in the feed web, efficient blending is essential, and the web must be clean of foreign matters to avoid damaging in the bonding process. A key-machine is the fine opener, which is offered in different versions by most of the builders of lines for preparing fibre for nonwovens operations. For its specific characteristic it may replace the opening willow or the carding willow (fearnought) in all blending rooms where a more effective opening and cleaning of the fibres is requested.

The units are usually available in widths of 1 m., 1.5 m, and 1.9 m. Most models are or can be equipped with an automatic device that ejects trash and impurities, and put in cycle again the fibres not properly opened.

9.4.2 Carding

Cards may have volumetric feed or they may be linked with an electronically controlled hopper feeder. Some models feature the cross-lap of the web. Card automation systems enable every program to be started gradually and very gently, but with each step being phased for rapid acceleration.

As for nonwovens carding machines they are offered in the range of widths from 2,500 and 3,500 mm. A specialised builder for nonwovens roller cards offers different models for new fibres, and for regenerated fibres equipped with a data processing system for the fully automatic control and management of the production programmes.

A combined plant of the latest generation is composed by cards built with a modular structure allowing large possibility of choice in composing the carding unit in respect of the different types of fibres to be processed. The card may be fed either by means of an electronic micro-weight hopper feeder or a newly designed volumetric tower, which is controlled by pressure switches regulating air pressure inside the two sections of the
tower. For medium to lightweight webs a card with double combing cylinder is used followed by an electronic lapper equipped by an overfeeding patented device to compensate for the drawing at the web centre, and the crushing towards the sides resulting in a weight loss caused by the needling action. Even broader widths – in the range from 2,000 mm up to 4,000 – are available from another specialised card builder suggesting appropriate composition of the carding line according to the range of raw material to be processed and the final product, that can be felts, waddings, disposables, with weight from 10 to over 1,500 g/sqm. So it may be chosen a single card, double card, tandem cards, sets of cards with random-fibre condenser of the web. A striking innovation is an “injection" card, which is employing a system utilising the airflows generated by ventilation of the drums. The unit can process fibres of less than 1 den. without creating neps in the web. In addition to the cards for thermobonded, spray-bonded and water entangled fabrics, the same builder manufactures carding machines for the production of carpets, felts, filters, geotextiles, waddings, and so on in line with crosslappers and with web drafters.

### 9.5 Web bonding

Spunbond and meltblown fabrics show intrinsic strength due to the bonding that occurs during the web forming stage. Therefore, they can be handled after forming even if they will be subjected to a further bonding step. However, webs made by other processes have little strength in the unbonded form. Latex bonding was to be the most common technique, but now the trend goes more towards mechanical and thermal bonding (Chart 20).

#### 9.5.1 Latex bonding methods (coating)

In latex bonding processes, the web supported by a moving belt or screen, has an adhesive binder applied to it by dipping the web into the latex and removing the excess, or by spraying, foaming or printing the latex onto the web. Hence the following basic methods are used: saturation, gravure printing, screen printing, spray bonding, foam bonding.

A large selection of drying units and systems is available – ovens, tunnel dryers and drying chambers, drying conveyors, drum drying machines – to be used at the end of latex bonding lines. A great deal of coating is done with foam. The usual polymers and other additives are pumped through a mechanical foamer producing a very fine foam that can be stable, or one that collapse when exposed to heat. This type of coating increases coating weight control, decreases water content (for energy savings in drying), gives greater opacity in coating and forms a sponge surface in the fabric.

A series of foam coaters applies the foam through cylinders, doctor blades, and a combined system for the application of foamed or liquid resins. The mixing heads are designed and sized as a function of the volume of products to be treated so that high quality foam can be achieved avoiding dangerous overheating of the products. The basic machines are manufactured to obtain two-component foam (one liquid and one gas), but thanks to the modular construction is possible to obtain multicomponent emulsions. One of the machine models is totally electronic controlled, so that a controlled and constant production is assured, including a continuous flow of foam having the desired characteristics. Mixers are also offered together with a laboratory foam machine. Coating lines can be fitted with a combined roller-knife coating head to ensure greater versatility.
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9.5.2 Mechanical bonding and stitch bonding

It is a technique for consolidating a web by entangling fibres to give strength to what are usually dry-laid webs. The most common methods are needlepunching, hydroentangling and stitch-bonding.

In needlepunching, barbed or fork needles are punched vertically through the web, hooking tufts of fibres across it and thereby bonding it in the needlepunched areas. The whole needlepunching process, which is largely used also for spunbonded, is well represented by Italian machinery, including laboratory scale lines. The cycle starts with an electronic controlled cross-lapper. There are two sources for these machines, and both are equipped with a microprocessor-controlled system to automatically compensate weight differences due to web lapping and needlepunching action. High flexibility of use is claimed as a model can be optionally supplied to process two card webs, either from a double doffer card or two independent cards.

A new model has been equipped with a unique system based on “arranging apron conveyors” able to improve performances - input speed are said to increase from 70m/min of the previous models up to over 120 m/min.

The most critical phase of the needlepunching process occurs during the transfer of the wadding from the cross-lapper to the first row of needles as weight, thickness and cohesion of the wadding have to be maintained. Infeed devices provide a right solution consisting in a set of fingers and extremely fine speed adjustment. Infeed devices are supplied either as integral part of the pre-needling loom or as a free-standing unit.

The pre-needling loom is equipped with a single top needle board, in which are fitted from 2,000 up to 6,000 needles per linear meter. As for needling machines there is a complete selection of options, from single up to two top and two bottom needle boards. Different models suitable for particular end-uses, feature upwards or downwards, alternated or simultaneous needle board movement. All drives are microprocessor-controlled.

Producers of carpets and automotive carpeting can also find patterning needling models, included a new random velours machine available in working width 1,800, 2,600 and 3,500 mm. The machine is fully electronic controlled and the max. stroke frequency reach 1,500 rpm. Special brushes have been designed to obtain a quality product.

9.5.3 Spunlacing (hydroentangling)

This technique uses fine, high speed jets of water to impact onto a web and thereby cause the fibres to curl and knot about each other. No binder is therefore required. The process is used predominantly on dry laid webs, but also wet laid webs can be successfully bonded. Investigations confirmed that hydroentanglement is the most interesting and rapidly developing field of mechanical bonding for use in composite structures obtained from combinations of various types of precursor webs, such as dry-laid/meltblown, wet-laid/meltblown, two different meltblown layers, carded/meltblown/carded, carded/meltblown/wet-laid.

9.5.4 Stitchbonding

For the sake of completeness, also stitchbonding, better known as Malimo technique, is to be mentioned. However it should be remarked that, according to ISO 9092/1988, most types of these products are not recognised as nonwovens, as long as they incorporate stitching threads in their structures.

9.5.5 Thermal bonding

Thermal bonding techniques have now become important, mainly because they avoid the use of chemicals, and new synthetic staple fibres of the bicomponent sheath/core type have been purposely developed. There are various methods to heat-bonding a
nonwoven fabric. One is to heat the material to such a degree that all fibres become just plastic. By exerting pressure on the material the fibre will interconnect. After cooling the fibres remain connected at their point of contact.

A second method adds in the blend a certain percentage of other fibres (which can be also of the bicomponent type), having a lower melting point, than those of the original material. Being the temperature in the calender set at the degree of the melting point of the bonding fibres, the latter provide effective bonding. Being resin-free, these products can be applied in medical, hospital and food areas where the chemical nature of the fabric must avoid problems associated with possible toxicity and irritation.

A third method does not add fibres but synthetic powders. This powder again has a lower melting point than the other material and this will again effect bonding of the nonwovens. All methods require very precise temperature control in order to obtain satisfactory bonding of the nonwovens, without affecting the specific structure and the properties of the material. These requirements are met by many Italian builders of calenders, that provide precisely uniform temperature and pressure of the cylinders across its full width. Besides calendering, another common fusing method is through-air heating where a perforated drum is used.

Complete plants with belt-oven are also offered.

### 9.6 Ancillary equipment

Hot-cutting device complete the machine range for wadding. Combined longitudinal and cross cutting can be carried out for waddings and nonwovens up to 3,000 g/s.qm of weight, while a shear cross-cutter can be used especially for products impregnated with abrasive synthetic resin which cause rapid wear of the blades in traditional cutting. At the end of the cycle there are three options: either a piler for felts which can be combined with the previous cutting, or a plaiting machine, or a rolling-up machine for making rolls up to 1,200 mm diameter.

Further suitable windup units are offered both by the makers of the various type of lines, and also by a specialised company. A peripheral winding unit, pope reel type, is equipped with automatic devices for parent reel change and web cross cut. An Italian company for the longitudinal cutting employs an unusual unit, i.e. an independent multiple counter-knives instead of the more usual splined cylinder. Advantages are a lighter weight unit, longer working life of the components, and fast positioning facilities. The actual positioning is programmed and governed by a computerised system, which can store a wide range of settings for different slitting widths.

Two new models of special packing machines for wadding and nonwovens rolls have been developed by an Italian company. The model for nonwovens wraps up rolls with thermoshrinking polyethylene film. The rolls have 1,200 mm of diameter and are 2,000 mm long and are arranged vertically in the packing machine. The other model is able to compress the volume of the wadding, reducing the roll diameter from 1,100 up to 600 mm.

### 9.7 Finishing

Emerising, napping, and brushing are traditional means of creating highloft surfaces on textiles. These techniques are also applied to nonwoven substrates. Particular interest is being devoted to the automotive sector, both for carpets and car lining. In Italy these techniques are in full evolution and many mechanical finishing machinery builders offer many type of new machines, but some of them are particularly co-operating with manufacturers of nonwovens (needlepunched and hydroentangled) to apply a further surface interest to car lining and mats.
10.1 introduction

The term “chemical fibres” applies to synthetic fibres and man-made fibres as well. Man-made fibres are obtained from a raw material that in the natural status is fibrous, yet it cannot be used by the textile industry until it is “regenerated” by means of a chemical process. Synthetic fibres originate from non-fibrous material and become textile raw material through a polymerisation synthesis process. Technologies to produce those fibres and to process them into textile goods differ very much, as well as the equipment needed.

10.2 Complete lines for synthetic filament yarns, tow and staple

Basically, two concepts are applied in plants for chemical fibres, which are however identical from a technological point of view. On one side short spinning systems for the production of staple fibres, polyester and polyamide mainly in the field of spun dyed fibres. The daily capacity is low and is used for small lots.
On the other side, high capacity plants are usually supplied on a turn-key basis including not only the installation of machinery and plants but also the necessary starting technical assistance, assistance for operator’s training and product know-how. They concern the whole range of processes:

- spin-draw-texturing for bulked single or multi-colour continuous filaments for carpet yarns
- spin-winding equipment for partially oriented yarn (POY) for textile applications
- spin-draw-winding equipment for fully drawn yarn (FDY) for semi-industrial and textile applications
- spin-draw-winding equipment for tyre cord and industrial yarns.

The spinning process also includes upstream steps such as continuous or non-continuous batch polymerisation starting from monomer, and polyamide and polyester solid waste recycling.

10.3 Polyester (PET) process

For the polyester continuous manufacturing, today producers mainly use TPA (terephthalic acid) in chips. Other spinning plants starting from the melt coming out directly from the polymerisation unit show a clear economic advantage by reducing investment costs and energy consumption, thus improving product quality.

10.4 Polyamide 6 and 6.6

Polyamide fibres, 6 and 6.6, are spun by a melting process; POY or FDY can be obtained, while there are some difficulties in obtaining FOY yarns with satisfactory characteristics. When producing tow with the two-step process, in the case of polyamide 6 polymer it is necessary to insert a washing phase between the two steps of the process. Nylon staple is widely used in blend with wool.

10.5 Compact extrusion plants

This system is used to produce polyester, polyamide, polypropylene and bulked continuous filament (BCF). The process started from chips coming from a melting tank, starts in a heated screw feeder where chips are kept in a molten state; the material, after passing through the dispensing pumps runs through a unit equipped with a single-hole or multiple-hole disk (depending on the number of filaments that make up the yarn). At the exit of the unit the yarn coagulates inside air cooling pipes and is then collected on winding heads. The winding speed is adjusted according to the type of drawing wished which can be partially oriented (POY) or fully drawing (FOY) heads depending on the specific end use. If the yarn if fully drawn, the collecting heads can reach a winding speed of 6,000 m/min. Several yarns are collected on the same spindle (from 4 to 8) according on the count and on the weight required. Heads are equipped with an automatic yarn splicer.

10.6 Acrylic fibre processes

The main difference among the various processes lies in the polymerisation system, the spinning system and in the solvent. The choice for the acrylonitrile polymerisation is between slurry polymerisation and solution polymerisation. In the first case the reaction takes place in a single reactor. The output is a slurry that has to be filtered, dried, milled, blended, metered and re-dissolved
before it is ready for spinning (wet or dry). In contrast to this, the reaction in solution takes place in mild conditions, and more than one stage is usually required to get a good conversion. The “dope” (polyacrylonitrile in solvent) thus obtained is ready to be filtered and sent to wet spinning directly. This simpler process is advantageous on both the investment and production costs, and the most modern techniques of process control (DCS) can easily realise an impressive evenness of the characteristics of the final fibre. Contrary to polyester, nylon and polypropylene, acrylic fibres are practically produced only in form of staple or tow. Acrylic fibre production is divided into four main stages: polymerisation, solvent treatment, spinning, finishing. During polymerisation catalysts are used to trigger the reaction of acrylonitrile and vinyl acetate (raw materials). The resulting product is a white, lightweight powder (polymer).

In the solvent treatment stage dimethylacetamide is usually used to make the polymer spinnable. As far as the spinning process is concerned, the wet spinning is currently the most used worldwide. Compared to dry spinning, the wet process is simpler in start-up, gives lowest production cost and allows the fibre to be spun, draw and even dyed on-line, upon request, with the gel-dyeing technique. In addition the wet spinning process has the further advantage of not necessarily needing the steam-set after drying giving this also fibre relaxing. The use of DMF as organic solvent has many advantages if compared to other solvents like nitric acid, sodium thiocyanide, zinc chloride, etc. In addition to this, in the wet spinneret the performance of the fibre washing has been improved. The standard size of a single line allows to produce up to 20,000 t/year based on 3.3 dtex acrylic tow and up to 24,000 t/year staple

Wet treatment machines for acrylic tow are in the programs of some manufacturers of textile finishing machines. After having begun with machines for washing treatments, dyeing, steaming and finishing units have been added, some of which characterised by very new technical solutions. Particular care has been given to energy consumption reduction, increasing of washing efficiency and improvement of the working conditions with the aim to make the start of the line easier. New gel-dyeing technologies have been developed, and the dyeing process can now be under control of a fully automatic dosing system allowing short time for colour change and high reproducibility. The machines for steaming after dyeing are available in configurations suitable to the working speeds and the number of the tow to be processed. Automatic presses for the baling of compact tow and crimped tow are available. Acrylic tow can be transformed in staple by cutting with special cutters. Acrylic fibre can be blended with many natural fibres, but wool is its preferred mate.

**10.7 Tow-to-top**

For the acrylic process, the top (a continuous filament yarn) is passed onto hot plates and drawn until breaking. A top is thus obtained; a further step foresees a passage through an integrated drawframe and the collection in cans.

The acrylic yarn, passed in hot water or hot air shrinks; by blending the drawn fibres with other fibres already stabilised, the first ones shrink and bulk the yarn thus curling the stabilised ones. This operation is carried out on special automatic continuous cross winding machines equipped with a hot air heating chamber. The yarn wound on movable ropes passes through a forced circulation hot air heating unit where a further yarn shrinkage occurs; the yarn is then waxed and wound on packages, perfectly suited to any knitting process. Polyester yarns are cut by means of special adjustable-step rotary knives. The polyester yarn blends with the wool fibre yarns. For cotton blends, the top passes through cutters, which cut the fibres into short-staple fibres like cotton, while the blending operation is carried out during the spinning process preparation.
**10.8 Draw-warping and draw-warp-sizing**

These warp beam preparation processes can be successfully performed both with polyamide and polyester filament yarns. As already mentioned also polyester microfibres are now processed in a draw-warp-sizing plant (Figure 29). The process has been drastically simplified by keeping the high standard of yarn quality and performance of the machine. The wet-drawing process has been replaced by steam drawing and air ovens are nowadays used instead of radiofrequency dryers. Between the steam oven and the sizing box an intermingling board with individual air jet nozzles for each thread is fitted to provide optimal cohesion among the individual filaments of each synthetic thread.

The draw-warp-sizing process of new generation has gained further advantages compared to the draw-twisting and spin-drawing technology, mainly due to lower costs and higher yarn quality especially with respect to better dye affinity values for microfilament yarns.

**Figure 29 - Draw-warping machines**

Warp-drawing machines are also offered, and operate in the dry state, producing warps wound on fractional beams for use in warp knitting.

**10.9 Lines for viscose filament yarns**

For viscose filament yarns, including microfilaments, a multi-section machine is used. The viscose filament in a molten state is forced through a coagulation bath and then wound on a drum where it is washed, sized and dried. Successively the filament passes from the drum to the winding head forming a cylinder-shaped package exceeding 10 kg in weight.

The machine features a modular structure; each module takes up 5 filaments. The spinning process takes place in a closed spinning equipment in order to avoid any harmful gas leak. The spinning speed is of about 160 m/min. The finishing treatment is adjusted according to further operations to be processed such as weaving, twisting or air texturing.

**10.10 Take-up units and draw-winders**

Take-up winders for winding nylon polyester textile yarns are designed to wound up to 8 packages; the count range goes from 10 den to 200 den, the spindle length is of 900 mm and the winding speed ranges from 2,500 to 6,000 m/min.

The spindle speed is adjusted by means of an inverter-controlled drive.

The packages wound up on the same spindle can be 3, 4, 6 or 8.

If yarns must go through a further drawing and twisting process, drawing and twisting machines are used, however with some limitations as far as the collecting package is
concerned. If yarns must only be drawn, the machines can be modified by applying collecting heads that prepare the packages, with the following advantages:

- heavier package
- improved machine performance
- less package change cycles, and consequently less labour.

10.11 Texturing and draw-texturing

The purpose of this process is to swell nylon or polyester continuous filament yarn by imparting a false twist. The yarn is then fixed so as to swell each filament (Figure 30).

Figure 30 - texturing and draw-texturing machines

The yarn from the spinning spindles is heated in an electric oven or a diathermal oil oven, and then passes through a friction texturing unit equipped with rotary disks. The ratio between the yarn diameter and the disk diameter is exploited to create the false twist. In this way, it is possible to insert a high amount of twist. Polyester yarns pass then into a stabilisation oven. Polyamide and polypropylene yarns instead pass through only one oven. The yarn is then wound into cylinder packages with taper ends up to 5 kg in weight.

These machines are equipped with:

- automatic doffing of full packages and loading of the empty tubes on each head;
- oven temperature control systems;
- fast redrawing-in system at each lot change and whenever the yarn breaks;
- microprocessor control system;
- meter counter;
- systems to check the evenness of the treated yarn;
- systems to avoid ribboning effects and hard edges.

Air-texturing systems are used to carry out the same process on nylon, polyester, polypropylene and other 1 or 2 ply thermoplastic twisted yarns (plain, parallel core-spun and fancy yarns).

Each position is equipped with an air nozzle, a stainless steel feeding system and adjusting valves. The machine fronts are independent. A different temperature can be set
for each oven to grant maximum flexibility. The yarn is fed from creels on both sides of the machine while an end-tail system ensures the continuous feeding of the machine. Automation on texturing machines can be achieved in three different stages:

• 1st stage - Texturing machine with individual automatic doffing, equipped with tension monitoring system. The system is directly interfaced with the machine computer to automatically reject faulty bobbins. On request, an automatic device is available for threading the yarn into the first oven with related opening and closing of the oven doors.

• 2nd stage – Collection baskets for full bobbins and an automatic dispenser for empty tubes are added, as well as robotised doffers for bobbin unloading and empty tube loading.

• 3rd stage - connection by means of radio-controlled doffers of the texturing room with the POY yarn magazine upstream, and with the sorting, packaging or palletising room downstream and the subsequent storage in the warehouse of finished products.

The different automation stages allow the user to adopt specific solutions according to his investment plans.

New short-cycle (*dow therm*) ovens or high-temperature electric ovens are also available.

**10.12 Covering machines**

These machines have been developed to manufacture covered yarns. Yarns generally have an elastic (spandex or lycra) core, covered with a natural or synthetic yarn. The covering can be double or single type (Figure 31).

**Figure 31 - Covering machine**
The covering yarn is wound on a flanged bobbin. Special winding machines are used to carry out this operation. These elastic yarns are used for pants, men's sock borders, narrow stretch fabrics and stretch fabrics, corduroy and elastic bandages. The most suitable core yarns and covering yarns must be accurately identified for each specific end use and according to the machines employed. The machines are equipped with quick covering yarn change systems, as well as adjusting systems for core drawing value, spindle speed and cross winding speed. The settings can be then viewed on an LCD display. The covering process can be also performed by means of airjet intermingling of elastic core and covering yarn. Covering machines are also provided with a hot/cold drawing unit for POY yarns.

10.13 Twisting machines

The most widespread continuous twisting technique is the two-for-one twisting system with feeding from bottle bobbins or simple bobbins. The spindle is generally driven by a tangential belt. Tyre cord spindles and big spindles can be equipped with independent motors. Hollow spindles are used for cellulose and synthetic filaments on two-for-one twisters for the production of fancy yarns. The take-up packages can be driven by a central motor and have thread guides, or driven by independent oil-sealed heads with overfeeding godets and special yarn tensioners.

10.14 Automated handling

Since synthetic fibres are a highly delicate product, it is most important that human hands do not touch the yarn during the handling and packing processes. Advanced and complete automation systems have been developed for this specific application. The plant layout can be divided in four distinct areas: production, storage, packing and warehouse. In the production area, automatic doffers running overhead or on ground rails pick up the full packages from the winders by means of a vertically moving mandrel unit. The co-ordinated movement of each winder mandrel is stored in the machine electronic memory by means of a simple self-learning procedure. The next step consists of transferring these packages to the transport shuttle units running on a closed overhead monorail loop. Each shuttle consists of a motorised doffers with a structure having a number of package-holder pegs. Shuttles have an on-board PLC, and are equipped with an anticollision system. After rotating through 180°, the doffer mandrel aligns itself with the first shuttle peg and pushes off one package. The bobbin aligning and ejection sequence is repeated for all pegs. The full shuttle is then released and conveyed to the storage area. On the way, it passes through a visual inspection station where packages are inspected, the quality grade assigned and, if necessary, eliminated. In the third step, packages are unloaded from the shuttle and transferred to flat disks travelling on an automated conveyor line which transports them to the packing station, or to another shuttle which takes them to the texturing machine. These automated flexible lines are available in a number of different versions.

10.15 Ancillary equipment and accessories

Ancillary equipment for the manufacturing of chemical fibres - especially spinnerets – play an important role for the quality of the textile product.
The spinneret range includes:

- Spinnerets for polyester, polyamide, polypropylene and polyethylene fibres for the production of monofilament, multifilament, microfibre, industrial filament and staple yarns.
- Spinnerets for wet spun fibres (i.e. acrylic). High-quality alloy spinnerets with 200,000 holes with a diameter of 35 micron are available for viscose staple and filament products.
- Stainless steel spinnerets for the production of acetate, triacetate and elastane yarns.

Specialised builders also manufacture:

- distribution plates and other auxiliary components for spinnerets;
- two-for-one twisting spindles;
- perforated spindles
- cylindrical tubes for draw-twisters and flanged tubes for perforated spindles;
- machines for removing (by means of automatic systems) yarn residues from spinning machine tubes, cops and flanged bobbins.
Technologies for the clothing industry

The Italian clothing industry has a leading position in the European and international context. Synergies among Italian makers of machinery, as well as systems and plants and the clothing industry aim both to the optimisation of the garment and to its suitability to be used according the customer’s demand.

As a consequence organisation of the production on one side, methods applied, machines, and component materials (from the fabric to the accessories) play a synergetic role which determines the product quality. Organisation and information management, logistics, as well as specific hardware and software packages for CAD and CAM systems are representative of the high technological level offered by the Italian manufacturers.

Chart 21 - Technologies for the clothing industry

11.1 Receipt of goods

At their reception, all pieces must be immediately provided with a bar code with the following information: fabric variant, colour variant, real fabric width, total length, net length after detection of flaw lengths, entry date into the warehouse.
Today also the clothing manufacturing companies need to have a range of equipment for printing labels and bar codes. These printers through a serial or parallel port can be connected to any system.

11.2 Fabric inspection and detection of faults

Fabric inspection involves the control of a series of characteristics, such as dimensional stability, shade uniformity, colour stability at fusing and ironing temperatures, light and stain removal fastness, weft squareness, consistent tensile strength, wear resistance, resistance to seam sliding pressure. Finishing products must not hinder fusing, and must not cause fabric stripiness and creases; selvedge must be regular, not too loose, not too tight or too large.

To make these controls easier Italian inspection machine makers offer a series of options, suitable both for woven and knitted/elasticiised fabrics. Programmable automatic winding machines are also offered for cutting optimisation.

An interesting development is a final control for measuring and controlling colour directly on any type of inspection table for any type of textile product. Thanks to an advanced system of colorimetric quality control an exact interpretation and evaluation of the readings is provided. Advantages include automatic calculation of tolerances, instrumental control of colour differences (center/selvedges, header/end), no need of tests for sample sets, and speeding up of the control process.

11.3 Piece transport from storehouse to spreading department

A keen problem is “what to do” with the flaw lengths appearing during spreading. A solution is the CAD marking system, which is able to study and calculate the various possibilities for fault cutting-out, and the number of superimposed fabric layers needed after flaw removing. This information, together those concerning length of marking, number of layers for each single step, size, fabric/colour variant, is to be stored in the central computer for subsequent use not only by the spreader but also the robotised truck (which has to draw pieces from the warehouse), and the carousel for feeding individual piece to the spreader.

Many options of spreading equipment provide flexibility in fabric handling, and are available from Italian manufacturers, either with cradle or programmed loading of the rolls without the help of the chuck.

Special solutions are offered for tubular fabrics, big rolls up to 400 kg, home linen. A high tech solution is a two-roll spreader, which may be used to obtain the multilayer stack for laser cutting the car safety air bags. This technology can be also applied for simultaneous spreading of the three layers composing the tie material or to couple already during spreading filling and fabric of windcheaters.

New fabric spreading technologies are becoming popular: these technologies are the natural answer to a more and more pressing market request, that is tailor made clothing.

Customers who are no more satisfied of already made-up suits are increasing more and more; they require tailor made clothing with fabrics and sizes chosen by them. To satisfy these requirements, new completely automated lines are being planned for the motion of fabric rolls, spreading and cutting of predetermined length fabrics which will feed the systems for shape cutting. These lines, inserted in CIM systems, allow the making up of “tailor made” suits at low costs and in short time.
11.4 Pattern grading and marking

For these two operations, in the sector of CAD for the clothing industry, a wide range of the most recent and known software packages has been developed enabling high operating speed thanks to personal computers of the latest generation. The system is composed of a workstation with digitizer table, where the identification of the pattern design is performed. The subsequent step is carried out on a workstation for the construction of the basic model and the marking. After completing these operations, the system is arranged for interfacing with automatic cutting.

11.5 Cutting systems and cutting machines

For the cutting room various systems are offered so to meet the most diverse requirements not only of the medium and big clothing manufacturers, but also for small sized companies.

The wide range of machines offered can handle the cutting of single-layer fabrics up to 15.5 cm stocked piles.

11.6 Sewing machines

The sector of sewing machines shows continuous updating and improvement. The trend is towards the use of more and more flexible and automatic sewing units able to perform some sequential sewing operations. On the other hand there is still the need to manufacture low cost sewing machines for the developing countries.

Since present day fashion needs lead more and more to continuous model changes, clothing manufacturers very often have to increase the number of machines, with consequent high investment. This problem finds a solution in adopting a flexible modular system putting together three basic units: a cylinder bed sewing machine, a cutting-sewing machine and a flat a flat bed unit that can be completed by a series of universal kit for loop stitch goods (used for underwear, corsetry and knitwear). Advantages claimed for this system consist in: a complete production system that carries out sewing operations with very high performance, possibility of modifying the initial configuration, adapting it to new production needs, possibility of technological updating without having to replace the machine, justifiable investment also in case of fashion changes.

A machine with shortened cylinder bed on the left of the needles and differential feed is offered for top stitching of pre-existent seams. A new subclass unit for top stitching the seams on medium-heavy knitwear has been prepared for smoothly sew crossed seams with high thickness. It equipped with thread cutting device. Also launched a brand new unit for flat topstitched assembly seams with bartacking on light and medium outerwear in a single operation.

The automatic units adopting a multistitch method allow to reduce operation times by about 50/60%, reduce the operation steps and hence the dwelling time of the semifinished garment in the cutting room. A series of units carries out the flat and topstitched assembly seams in one single phase without interruption. They are equipped with two heads, the first one with horizontal needle bar for the assembly seams, the second one with vertical needle bar for topstitching. The sewing system adopts a new method for the introduction of the fabric into the automatic unit. In fact the two fabric edges to be assembled are presenting themselves in open state, with the right side turned towards the operator, making easier the coupling of striped and chequered fabrics. For attaching pockets on shirts, working clothes and pyjamas etc., machinery with flexible systems controlled by microchips that can fold pockets, sewing them, and pile the garments in an automatic cycle. These machines offer high productivity, constant quality and the possibility to programme various sewing patterns that can be adapted to the different pocket models. The wide range of models offered include high frequency “sewing” systems for synthetic fabrics, which fuse by means of an 800 W ultrasound
generator and a vibrating ultrasound group. The fusion speed can programmed up to 50 m/min and is driven by means of a treadle.

11.7 Quilting

Quilts are a popular home decoration element. Electronics broadens potential of quilting machines making them more versatile. An Italian company is engaged in the production of a series of models which mount a serious challenge to machine embroidery. The newest models of quilters, can operate at around 1,000 stitches/minute and are built with a quilting width up to 114 ins (290 cm). With three needle bars the patterning potential is immense. Giant rotating hooks with 700-mm bobbins are used in this machine which has tack and jump mode. This is a means of still further creating more interesting surface effects.

Developments on these machines is aimed to a system of automatically cutting embroidery threads, and this will serve to conserve thread when a needles produces a discrete pattern and then needs to travel to a different position to perform its next task.

11.8 Embroidery

The Schiffli embroidery machines are now offered with computer control. The design preparation for multihead embroidery machines is today a normal practice. Besides punching of patterns on graphic screens and advanced systems for data processing of machine programs, one can use laser discs containing 20,000 patterns each, and affording to immediately write the embroidery design on the machine disc, so that production can start at once.

11.9 Knitwear linking

The knitwear linking is carried out exclusively to sew full-fashioned knitted goods which are loaded onto pins so that the ribs of both webs perfectly match thus avoiding the risk of sliding.

Linking machines can be quipped with one or two needles and hook- or straight-shaped needles (different stitch formation obtained). Linking machines can have internal needle (the stitch is loaded from the plain side) or external needle (the stitch is loaded on the reverse side).

The working speed can reach 1,500 stitches per minute; the quantity of needles per inch ranges from seven to sixteen; in special machines it can range from 2 to max 24 needles per inch. It's also worth mentioning that some knitwear linking machines are equipped with microcomputer to synchronise all the speed values: adjusting sewing speed, pre-feeding of rib borders, and positive drive pullers, which are controlled individually by conventional motors, in order to allow accurate alignment of the ribs.

11.10 Ironing and pressing

This sector includes a great number of units that are used for different purposes, and sees the leadership of Italian makers.

There are automatic, pneumatic and rotary ironing presses for all pieces of clothing; ironing systems for intermediate and final ironing include pneumatic toppers for trousers ironing, steaming dummies, finishing cabinets, heated vacuum boards, and the blow-ironing units.

All ironing machines and systems are now equipped with electronic systems so that crucial parameters such as speed, temperature and pressure may be set. The safety systems installed have been further improved for a better safeguard of the staff operating on the machines.
**11.11 Finishing**

The importance of finishing is becoming more and more crucial in the textile/clothing sector thanks also to the new "informal comfort" standard suggested by the fashion dictations in the last few years which started in the past with a new kind of treatment for jeans.

Now the finished garment needs to be a "high-profile" piece of clothing not only from a purely technical point of view but also in terms of esthetical content, which must be in line with the visual, hand, and colour trends.

A wide and continuously evolving range of washers and tumblers especially studied for garment washing, dyeing and drying have been developed to allow many kinds of treatments such as bleaching and stone washing, and to obtain delavé and used look.

Also worth remembering is the continuous evolution of drum type washing machines and the driers, available in a vast range of models specifically designed for washing, dyeing and drying operations on garments.

**11.12 Folding and packaging**

At the end of the production line, garments are arranged with reference tags, put into a bag and packed according to the forwarding specifications. These operations are carried out by means of folding and packing machines (for shirts, home linen, and underwear the complete process of folding and packing is carried out automatically in only one operation). A series of other systems are used to pile-up, pack, wrap-up and tie-up the garments.
The textile maintenance sector

In parallel with the desire for a new and improved quality of life - which undoubtedly includes better health and hygiene conditions, as well as the cleanliness of one’s person and clothes - an increasingly tangible and concrete “cleanliness culture” radiates from the more developed countries to developing or economically weaker countries in which more limited economic possibilities are counterbalanced by practically unlimited possibilities for this activity.

This “cleanliness culture” leads irresistibly to the development of the textile maintenance sector, with a consequent demand for machinery in the three main technological areas involved:

– laundring machines,
– dry cleaning machines,
– machines and equipment for ironing, finishing and re-shaping.

Flexibility of products

In this sector, the Italian industry has always been strongly represented on the international market because of its extreme flexibility both in the range of products and innovative technical solutions, characteristics arising from the need to adapt to various economic situations in importing countries.

Products of highest technical sophistication for the most industrialised countries, where performance quality is an indispensable requirement, second only to the need of high production levels, safety and respect for the environment.

For products designed for these markets the object has been the reduction in labour obtained with the advanced automatism of the machines in operation and maintenance phases.

The use of computerised programming tools and complex but safe sensor technology offers a large range of specialised and personalised cleaning cycles that can be perfectly reproduced.

This sophisticated programming offers the possibility of adapting to the enormous variety of materials encountered in textile maintenance.

The high degree of modularity has thus allowed notably different products to be developed, calibrated for different markets, but with a single matrix of efficiency and perfectly compatible with the other production lines.
Figure 22 - Laundering/production cycle

1. **RECEIPT OF GOODS**
   - Sorting, weighting and counting machines
   - Labelling and marking machines

2. **SORTING LABELLING**
   - Washing machines
   - Centrifugal extractors

3. **WASHING**
   - Continuous washing machines
   - Water extracting presses
   - Washer extractors

4. **DRYING**
   - Tumbler dryers
   - Feeding and preparation units
   - Flatwork ironers
   - Folding machinery

5. **IRONING FINISHING**
   - Tunnel finishers
   - Folding tables
   - Ironing presses and ironing machines

6. **PACKAGING**
   - Stackers
   - Wrapping and packaging equipments

7. **STORAGE**
   - Storage systems

8. **DELIVERY**
12.3 Cutting the costs and protecting the environment

It is important to note how these products share a common denominator: low running costs, particularly referred to energy costs.

One of the factors that promoted evolution in this sense is the geographical and economic characteristic of Italy, which, in this case, allowed trained manufacturers to create such products.

Italy, a country in which natural and energy resources are notoriously scarce but rich in specialised workers, ingenuity and good industrial tradition, made textile maintenance machinery manufacturers search for solutions to reduce running costs, initially to fulful the requirements of the domestic market and then as a preference factor for all foreign markets, also favourably attracted by substantial savings in operation costs.

An interesting example is provided by closed circuit dry-cleaning machines, which allow an extremely low degree of polluting emissions and decreased consumption, thanks to the most advanced but also user-friendly technologies created essentially to reduce at the minimum emissions and wastes, to obtain shorter cycles and to globally reduce the garment treating time thus obtaining considerable direct and indirect energy savings.

In the dry-cleaning field already at the end of the 1980’s together with the development of machines operating with traditional solvents, studies were going on to develop machines suited for the use of alternative, less polluting solvents such as solvents started from hydrocarbon to be used for washing any type of fabric, especially delicate fabrics and leather goods. Italian manufacturers have first developed this new technology which allows to achieve the same performances at costs equal to those of machines using conventional solvents with the big advantage that, as hydrocarbons are not biodegradable, the ecological and toxicological aspects fade into the background.

12.4 Autonomy and modular composition of production lines

A further and equally important factor in the success of the Italian products is maximum autonomy of the machines, which allows a substantial reduction in installation and related costs.

Significant examples are again provided by the dry cleaning machines which do not require external steam generators and related structures such as boiler room, fuel tank, generator and steam distribution and control equipment.

The same situation occurs in the ironing sector where single autonomous units allow the rapid and economic creation of elastic and multiform pressing lines.

For all the examples given, one electricity supply line is sufficient, requiring no maintenance and not subject to dispersion of thermal energy as well as offering the savings in supply and equipment and space requirements mentioned above.

“Italian style” production lines are characterised not only by maximum elasticity in their composition but also by the adaptation of their component parts to the production necessities of the moment, by lower investment costs and by less reserve machinery required in case of damage or during servicing.

When made up in manufacturing units, Italian machines allow small lines for tiny communities to be progressively developed, with no limitation in size.

At the same time, considering the particularly reduced need for additional equipment, each successive production expansion may be satisfied by just increasing the number of production units.
Chart 23 – Dry cleaning/production cycle

Receipt of goods

Sorting & marking

Pre spotting

Dust removing filters
Evaporation units
Criogenic air purifiers
Activated carbon air purifiers
Cartridge stripping units
Contact water purifiers

Dry cleaning

Dry cleaning machines for clothing and allied goods
Dry cleaning machines for furs and leather
Solvent finishing machines

Post spotting

Post spotting units
Spotting tables

Ironing and finishing

Ironing presses and ironing machines
Formers and toppers
Ironing tables

Packaging & storage

Monorail conveyor systems
Wrapping and packaging equipment

Delivery

Labelling and marking machines
Pre spotting units
Spotting tables
12.5 Safety

The “philosophy” of Italian manufacturers is based on three concepts: quality, efficiency and safety, developed from real situations in which “quality” guarantees continuous operation, even in locations lacking in adequate service, where specialised staff cannot easily get to.

“Efficiency” ensures that the investment is paid off soon, creating the conditions for rapid business expansion, and acquiring large segments of the population which until now have not enjoyed this kind of benefit, still regarded as superfluous.

The high degree of “safety” for operators, users and the environment is ensured both in areas lacking technically trained staff, and in those where control authorities are active and involved.

To this regard it is important to point out the creation, in the European sphere (CEN/TC214), of two technical committees for the drawing up of safety standards concerning textile maintenance machines.

Coordinated by ACIMIT, the Italian firms of the sector have constructively cooperated to these projects, allowing the publication of Safety Standards for dry-cleaning machines using perchloroethylene (ISO 8239) and for industrial laundering machines (ISO 10472).

They take also an active part in the definition of similar standard for machines employing HCS (hydrocarbon solvents), which is now in an advanced stage of development.

This “philosophy” has undoubtedly allowed this sector to develop a massive presence of Italian machines abroad, also on crucial and very demanding markets such as the European Union.