man-made fibres

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by Cesare Andreoli, Fabrizio Freti

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REFERENCE BOOKS OF TEXTILE TECHNOLOGIES

edited in
collaboration with

CENTRO TESSILE
COTONIERO e
ABBIGLIAMENTO S.p.A.

by
Cesare Andreoli
Fabrizio Freti

FONDAZIONE
ACIMIT

Ente Morale dell'Associazione Costruttori Italiani di Macchinario per l'Industria Tessile
Moral body *of the Italian Association of Textile Machinery Producers*

Via Tevere 1, 20123 Milano (Italia)
Tel. +39 024693611, fax +39 0248008342
e-mail: info@acimit.it, http//www.acimit.it

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Introduction

I am pleased to present the fifth "Notebook" on textile machine technologies, which Fondazione ACIMIT decided to prepare for the Italian textile technical institutes.

The subjects of this Notebook are the machines and the technologies for the processing of "man-made fibres", an industrial sector which sees Italian companies and their know-how holding an unquestionable leading position, also at international level. The Notebook offers a wide and thorough survey on the main types of man-made fibres, both artificial and synthetic. Its realization had been entrusted to a qualified textile organization, Centro Tessile Cotoniero e Abbigliamento at Busto Arsizio (Varese), which gladly took on this demanding task.

This Notebook, which is dedicated to "man-made fibres", follows up the Notebooks reserved to "spinning", "weaving", "knitting" and "finishing" technologies, all of which found such a favour, as to justify the publication of a second and even of a third edition, for a total of 14.500 copies.

The success of this initiative convinced us also of the opportunity to translate the Notebooks into English, in order to ensure their circulation also beyond the Italian borders with the leading textile institutes and universities. Moreover, considering the very high vocation and the age-long tradition of China as a textile country, we decided to publish also a Chinese edition.

The exigency of realising the Notebooks came from a series of meetings which Fondazione ACIMIT started with the headmasters and with the teachers within the framework of the various undertakings aimed at developing relations with the school world.

In fact we had been informed that the text-books presently available were not updated to the steady and rapid technological development which characterized the textile sector in these years.

We of course welcome any suggestion and correction which the teaching staff, the company technicians, etc. might address to us in order to enable improving further the service offered by these publications.

March 2004

Alberto M. Sacchi
President of Fondazione ACIMIT

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Fondazione ACIMIT feel bound to thank Centro Tessile Cotoniero e Abbigliamento of Busto Arsizio and in particular General Manager Ms Grazia Cerini and Technical Manager Ms Gabriella Fusi, who kindly accepted the assignment of producing this "Man-made Fibres" Notebook.

* * *

The drafting of present work was entrusted by Centro Tessile to Mr Cesare Andreoli and Mr Fabrizio Freti, to whom Fondazione ACIMIT owes a special thank for the time and enthusiasm they dedicated to the production of this Notebook.

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A survey of man-made fibres history

Man-made cellulose fibres

The first man-made fibres which were developed and produced used polymers of natural origin, more precisely of cellulose which is a raw material available in large quantities in the vegetable world.
The beginning of industrial production of man-made fibres goes back to the year 1890, when the French Count Hilaire de Chardonnet started up his plant for the production of "Chardonnet silk" (initial output: 50 kg per day), using the cellulose nitrate process.
As it happens in general in the case of technical-scientific developments, this achievement was the result of previous studies and researches (since approximately the year 1840) focused mainly on the chemical properties of cellulose.
In particular the researchers found the way to treat cellulose (a material insoluble in usual solvents and inflammable) with nitric acid (nitrification), to dissolve the derivative with solutions of alcohol-ether, to prepare suitable extrusion devices (spinnerets) and finally to regenerate cellulose through saponification in alkaline baths (denitrification) in order to eliminate the danger inherent in the nitro compound (inflammable and explosive).
Actually the birth date of the "artificial silk" (such was the name given to this fibre at its introduction) is said to date back some years before (1884) when an Englishman, Mr Swan, produced small quantities of nitrocellulose which the researcher gad in mind to use for the development of incandescent bulbs.
More or less in the same period another way had been searched for to make cellulose capable of being spun, after being discovered that cellulose could be dissolved in a mixture of copper oxide and ammonia (Schweitzer's reagent, 1857).
In fact this principle had been the basis in Germany for the production initially of incandescent bulbs (1891), then of cuprammonium fibres (1897) via the so-called "cupro" process, which was improved with the draw-spinning process (1891) and resulted in the production of Bemberg cupro yarn in 1909.
Meanwhile a patent had been registered in England by the researchers Cross, Bevan and Beadle (1892) for the production of sodium cellulose xanthate and for its dissolution in dilute caustic soda. In this way the bases were laid for the production of a man-made cellulose fibre, now called viscose, which remained for decades the main process in use for the production of man-made fibres.
The first industrial plants were built some years later in England and in Germany (early 1900), and contributed to the rapid decline and giving up of the Chardonnet process, which was left off in Germany in 1911).
One of the various chemical properties of cellulose which found particular interest was the possibility of esterificating with acetic acid the three hydroxylic groups contained in the glycosidic group of cellulose; the first product to be obtained was triacetate (1894) which, as it was later on discovered, could be partially hydrolized (1905) into a product which was easily soluble in acetone.
However only later on the most was made of the capacity of cellulose acetates to be transformed into fibres; the fibre which attained more relevance was cellulose diacetate (1919-1921), commonly named acetate, whereas triacetate (produced since 1914) found limited commercial interest owing to its difficult dissolution, restricted only to chloroform.
Cellulose fibres were produced with said processes in form of continuous filament yarns, as the primary objective of the researchers was the reproduction of the morphology and, at least

partially, of the properties of raw silk (from which the term "artificial silk" originated). In 1920 the fibre was made available also in form of staple fibre ("Vistra", Germany) and as such attained in time relevant market importance.
Recent years saw the development of a process for the production of cellulose fibres using a solvent specifically studied for cellulose (N-methylmorpholine-N-oxide), which on one hand safeguarded to a greater extent the inherent properties of the original cellulose structure and on the other permitted the use of processes less polluting than traditional ones.
In this connection we cannot but emphasize the role played by the Italian industry within the sector of cellulose fibres.
The first factories sprang up at the beginning of last century thanks to the initiative of French chemical groups and in 1914 could supply 150 tons of rayon (this was the name given to the continuous filament fibre).
The first post-war period saw the successful coming on stage of the company SNIA which, through the concentration of various production units, became at the end of the 20's one of the major world producers of viscose rayon and later on of viscose staple fibre.
In 1927 the production of cuprammonium yarn was started on behalf of the company "Seta Bemberg S.A.". In short, the Italian production rose from 320 tons in 1919 to 32,500 tons in 1929, so that Italy became the leading producer in Europe with a 16% share on world production. At the outbreak of the 2nd World War the Italian production had reached 120,000 tons.
The post-war period recorded a recovery of this industry, which reached its peak with 226,000 tons in 1964; from that date on, at first slowly and later at a quick pace, artificial fibres made room for synthetic fibres. As regards artificial fibres, it needs to be reminded that this group of fibres includes also fibres which have as raw materials natural polymers other than cellulose, like fibres derived from proteins.
A considerable historical significance was attained in Italy by protein fibres derived from casein, which were produced initially by SNIA in 1936 (researcher: Ferretti) under the name Lanital, later on renamed into Merinova.
Protein fibres of animal origin (casein from milk) stopped to have commercial significance, whereas still to-day a certain interest is enjoyed, especially in USA, by protein fibres of vegetable origin (maize, peanuts).

Man-made fibres

The development and production of synthetic fibres (obtained by synthesis of chemical compounds) are a rather recent achievement. The delay in developing these fibres is to be ascribed to an insufficient knowledge of the structure of natural polymers (such as cellulose, rubber, natural fibres), which were difficult to be studied from the chemical point of view because they were nor fusible, nor reactive and not even soluble, in short they were completely different from usual chemical substances.
The basic studies carried out in the 1920's by Staudinger, a German researcher, brought out the fact that natural polymers are formed by linear macromolecules, that is by long thread-like chains, reproducible through the reaction of suitable, relatively simple molecules. Even if the date of birth of synthetic fibres is traced back to the production in 1931 of a chlorovinyl fibre (PE-CE, Germany), the fact is that the first real synthetic fibre in industrial production which would have a heavy impact on the market was the polyamide fibre, launched by the company DuPont under the trade-name "nylon" (experimental production in 1938).

The fibre came to success when the researchers obtained a product (polymerised amide, from which the name polyamide) by condensation of molecules presenting two reactive aminic groups (hexamethylenediamine) with molecules characterised by two carboxylic reactive groups (adipic acid).
In order to be differentiated from other polymers belonging to same chemical class, this polymer was marked with the acronym 6.6 which indicates the number of carbon atoms (that is 6) in the two molecules forming the repetitive polymer unit.
In that same period (1939), as a result of researches carried out in Germany by Mr Schlack in 1938, starting from caprolactam, a single molecule of basic monomer, a new polyamide fibre was produced under the name "Perlon" (type 6).
In those years, starting from terephthalic acid and glycol ethylene, polyester fibre was invented (Whinfield and Dickson, Great Britain, 1941) along with acrylic fibre (German and American patents, 1942); owing to war vicissitudes, the industrial plants were however started up only in the early 50's.
It is quite remarkable that in so few years all man-made fibres of primary importance for the textile sector (polyester, polyamide and acrylic fibres) were developed.
Only later on an Italian researcher, the Italian Nobel prize Giulio Natta, discovered the possibility of synthesizing polypropylene according to a principle of structural regularity (1954), thus laying the bases for the production of polypropylene fibre (1959).
This survey on man-made fibres was recently integrated by some fibres of considerable importance, introduced into the market by the company DuPont: the elastane fibre "Lycra" in 1959 and the aramidic fibre "Nomex" in 1962.
On the scenario of synthetic fibre production, Italy made its appearance in 1939 with the production of small quantities of nylon (company Montecatini).
The war blocked every development, but the production of polyamide fibres started up again in the post-war period, to reach 7,500 tons in 1956.
In 1955 the company Rhodiatoce started the production of polyester fibres under the name "Terital"; in 1959 the Edison group produced the acrylic fibre named "Leacril", followed in 1961 by the industrial production of the polypropylene fibre named "Meraklon".
The producers of man-made fibres renew in the 60's the great effort made by the producers of artificial fibres in the 30's, bringing in the years 1960-1970 the share of the Italian production on world production to about 5%.
However, starting from the years 70's to 80's, a slow decline took place owing to lack of rationalisation of the production plants, to insufficient research and development activity, to overproduction, to the oil crisis and also to production delocalization from old-industrialised countries (Europe, USA, Japan) to the newly-industrialized countries of the Far-East (China, Taiwan, South Korea).

PRODUCTION DATA

About one century ago, when the world population was estimated at 1,5 billion persons, the fibre production was practically limited only to natural fibres; cotton represented a production of 3,160.000 tons and wool production only 730,000 tons. In addition to these quantities, the production of silk (small quantities) and of other natural fibres (mainly hard or bast fibres) has to be taken into account.

Man-made fibres were still at their dawn; in fact historical data mention also a small production of artificial cellulose yarn (1,000 tons)

The present scenario has of course changed considerably owing both to considerations of general nature (demographic growth combined with economic development) and to the coming of new man-made fibres.

Even considering possible deviations within the data coming from different sources (mainly due to the exclusion or not of some types of fibres or of some application sectors), in 2002 (see Table 1, source Assofibre) 55,3 million tons were produced, with a 63% participation of man-made fibres and 37% of natural fibres.

To complete this picture, also other natural fibres such as silk (90,000 tons) and bast fibres (flax, hemp, jute, ramie – 4,2 million tons) should be mentioned, even if they are normally not considered by the statistics; in such case we reach a total figure of about 60 million tons, which corresponds to an average pro capita consumption of almost 10 kg per year.

The development of the various types of fibre

Figure 1 and Table 1 show clearly the development in terms of percentage and of absolute figures for the various groups of fibres, starting from the 50's.

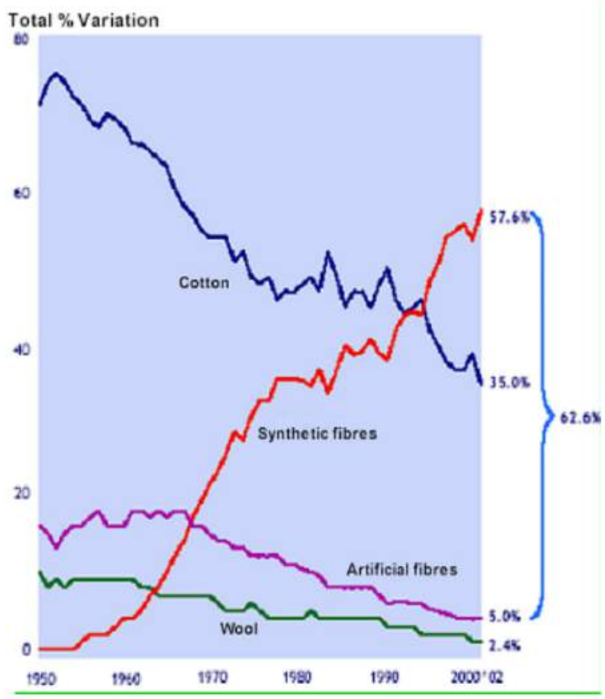


Fig. 1 World production of textile fibres – Percentage shares (Assofibre)

FIBRES	1970	1980	1990	2001	2002 (*)	% Var '02/'01
			.000 tons			
SYNTHETIC	4.818	10.625	16.191	30.113	32.040	6,4
ARTIFICIAL	3.579	3.557	3.189	2.693	2.766	2,7
MAN-MADE	8.397	14.182	19.380	32.806	34.806	6,1
COTTON	11.784	13.844	18.997	21.516	19.173	-10,9
WOOL	1.659	1.599	1.927	1.316	1.304	-0,9
TOTAL	21.840	29.625	40.304	55.638	55.283	-0,6
			% share			
SYNTHETIC	22,1	35,9	40,2	54,1	58,0	
ARTIFICIAL	16,4	12,0	7,9	4,8	5,0	
MAN-MADE	38,4	47,9	48,1	59,0	62,959	
COTTON	54,0	46,7	47,1	38,7	34,681	
WOOL	7,6	5,4	4,8	2,4	2,359	
TOTAL	100,0	100,0	100,0	100,0	100,000	

(*) estimates

Tab. 1 World textile fibres production (Assofibre)

Cotton

In the space of a century the production became practically more than sixfold and accounts for 34,7% of the global fibre production (19,2 million tons in 2002).
The previous year recorded an exceptional crop (21,5 million tons), but the consumption in last years maintains a level of about 20 million tons. Apart from production fluctuations due to economic and climatic reasons, which are anyhow typical of a raw material of agricultural origin and are of strategic relevance for many producer countries, cotton still shows a slight upward trend (11,8 million tons in 1970; 13,6 in 1980; 19,4 in 1990) and stands for the most important fibre (along with polyester), in a position to influence prices of concurrent man-made fibres (polyester staple fibre, viscose staple fibre). The major producer countries are at present China, USA, India, Pakistan and the Central Asiatic countries (ex-USSR).

Wool

In the space of a century, the production has practically doubled (from 730,000 tons in the year 1900 to 1,304.000 tons in 2002).
We wish however to emphasise the fact that the production, apart from normal fluctuations, increased slowly till end of the 80's (reaching its peak in 1989 with 1,955.000 tons), when it began to decrease, with a consequent inexorable reduction of the percentage share on the fibre total (10% in 1960; 2,4% in 2002).
The major wool producers are at present Australia, China and New Zealand.

Artificial cellulose fibres

The artificial cellulose fibres can be considered as a group of fibres situated in-between natural and synthetic fibres; their importance, which was considerable from the 30's to the 70's, eroded to a great extent by the advent of synthetic fibres.
In fact, apart from intrinsic lack of properties, they also suffered the consequences of remarkable ecological problems connected to the production processes.

A separate consideration is necessary for Lyocell, a newly introduced fibre which technology overcomes above mentioned limits; it is however today a niche fibre (in staple form) with limited applications.
The global production of cellulose fibres amounts to 2,8 million tons (including 550,000 tons of acetate tow for cigarette filters) and confirms their slow decline starting from the 80's (3,5 million tons in 1980); much more significant was however the drop in the market share, which fell from 18-19% in the 60's to 5% in 2002.

Synthetic fibres

The industrial production becomes considerable from the 60's upwards (702,000 tons in 1960); from this moment on, the growth of these fibres became overwhelming and they gained market shares to the detriment of all other fibres (Figure 2).
Various problems, such as unrestrained growth, excess of production and energy crisis, slowed down their development for some years from 1973; their growth began again later on in a convincing way thanks to polyester and polypropylene fibres.
We may consider as reference points the year 1968, when the production of synthetic fibres (3,75 million tons) exceeded the one of cellulose fibres and the year 2002, when in only twelve years the production (32,0 million tons) doubled that of 1990 (16,2 million tons).
Beginning from the 80's a massive shift of the production sites from the old industrialised countries (USA, Europe and Japan) took place towards Asiatic countries of recent industrialisation (in particular China, Taiwan, South Korea) (Figure 3).

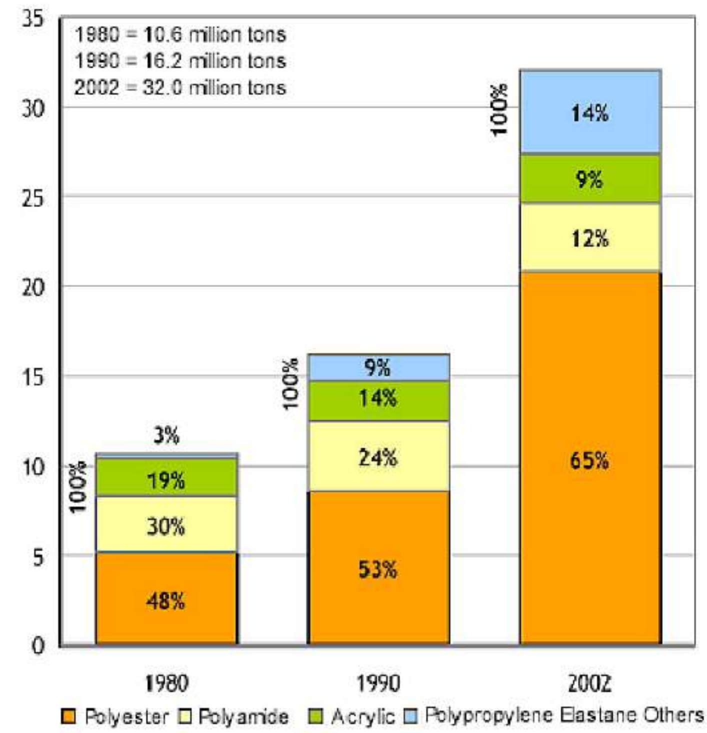


Fig. 2: Development of synthetic fibres world production

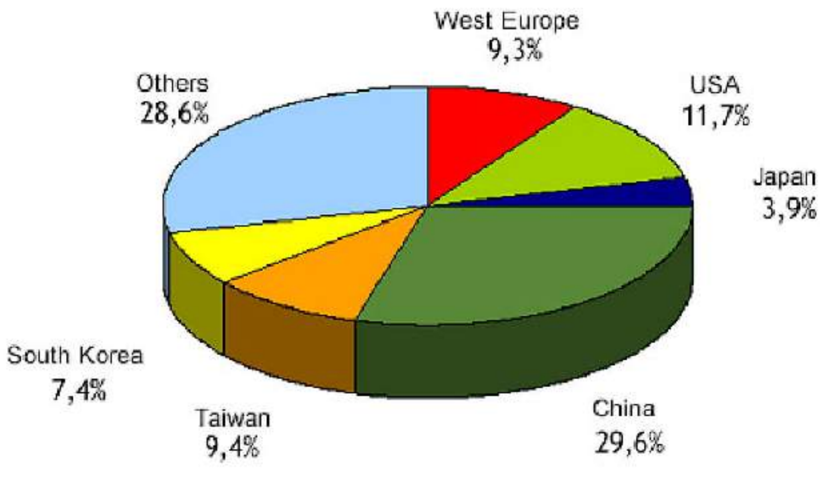


Fig. 3: Percentage sharing of synthetic fibres world production in 2002

Polyester fibre

This is the most important man-made fibre, with a production of 22 million tons in 2003 (58% continuous filament/42% staple fibre), which since some years overcame cotton production. The number of plants installed in the world is estimated already now at more than 500.

Another aspect of considerable importance under the geographic-economic point of view is the fact that 75% of the production is located in Asia. Polyester wrung the record of most produced synthetic fibre out from the polyamide fibre already in 1972, when it reached a share of 65% in the synthetic fibre market. Its success is due to its particular characteristics, to its versatility in the various application sectors and to the relatively low raw materials and production costs.

Polyamide fibre

This fibre category practically opened the textile market to fibres with no connection to the world of nature.

The production, performed world-wide by about 300 plants, amounts to 3,9 million tons (2003) and is distributed into polyamide type 6 (about 60%) and polyamide type 6.6 (about 40%); it is composed mainly of continuous filament (85%), against 15% of staple fibre.

The major producing countries are still Europe and USA (45% of the market).

Acrylic fibre

The production of this fibre is estimated at 2,6 million tons (2003) and West Europe is still today the area with the highest production (30%).

This fibre found its main use in the traditional wool sectors and is being produced in practice only in form of discontinuous or staple fibre.

It shows negligible production increases and consequently its share in the man-made fibre market fell from 20% in 1970 to 9% in 2002.

Polypropylene fibre

This is the last-born man-made fibre and, as it is used also in near sectors (as in the plastic industry), its importance in the textile sector was not always adequately monitored.

In fact, even excluding such sectors, the production for merely textile uses (carpeting, clothing, technical uses) can be estimated at 3,0 million tons and shows steady growth rates.

The most significant producer areas are Europe and USA.

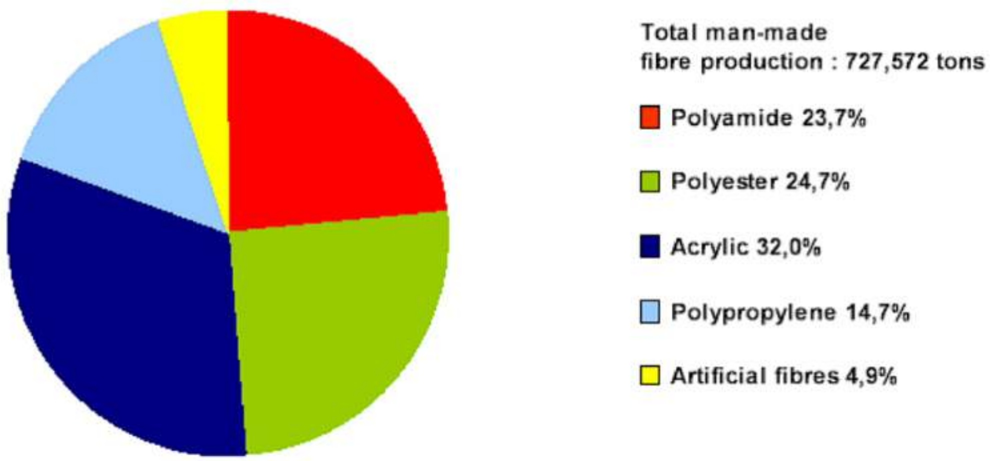
Other man-made fibres

Within the group of fibres with high-tech performance, the elastane fibre (spandex) stands out for its characteristics of elongation and elasticity: its consumption in 2001 has been estimated at 160.000 tons. Aramid fibres are appreciated for their mechanical and fireproof properties (consumption estimate in 2001: 33.000 tons), while carbon fibres are used in composite materials for hi-tech applications estimated consumption in 2001: 13.000 tons).

Elastane is produced mainly in Korea and in Taiwan (other producers: USA, Japan, Germany); aramid and carbon fibres are mostly produced in USA and in Japan.

The Italian production of man-made fibres recorded between 1990 and 2002 a global 20% drop (from 727,500 to 576,700 tons), with the only exception of polyamide which shows a slight opposite trend.
The decline of the man-made fibre industry in Italy might be better pointed out by the trade balance, which in 2002 closed negatively both in terms of quantity (- 185,000 tons) and of value (- 393 million Euro).

DISTRIBUTION OF MAN-MADE FIBRE PRODUCTION IN 1990



DISTRIBUTION OF MAN-MADE FIBRE PRODUCTION IN 2002

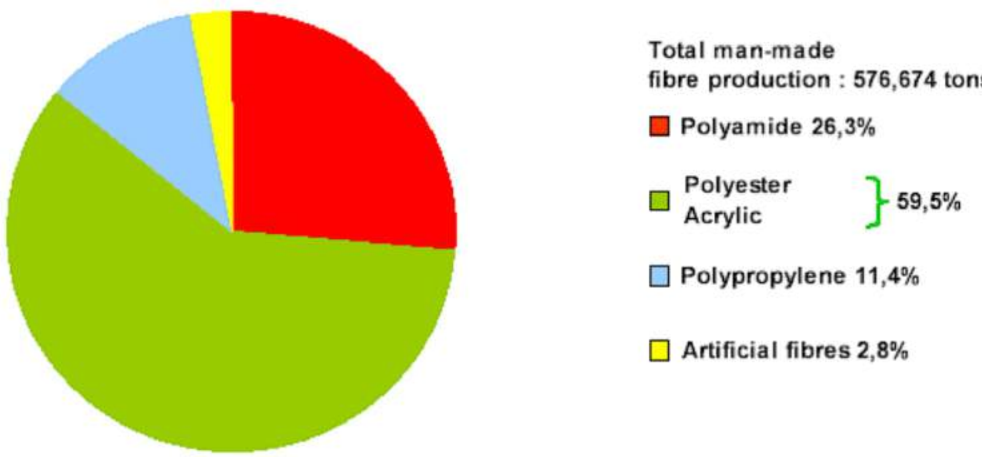


Fig. 4: Evolution of Italian man-made fibre production

CLASSIFICATION OF MAN-MADE FIBRES

The norm ISO 2076-1999 (E) provides a list of the denominations commonly used to designate the different categories of man-made fibres which are usually produced on industrial scale for textile uses and other applications.
Every common denomination is defined through attributes, normally based on chemical differences expressed with chemical formulas, which often have different distinctive properties (see list below).
In order to facilitate the technical and commercial exchange of information, the fibres have been identified with codes or abbreviations, based on their common names and composed by letters (from 2 to 4).
We wish to point out that generic fibre names, as used by the legislation for fibre content labelling, have to be distinct and not confused with the trade marks which each producer is free to use for the identification of his own product.

- Fibres
  - Natural
  - Man-made
    - Organic
      - By transformation of natural polymers
        - Acetate CA
        - Algin ALG
        - Cupro CUP
        - Rubber (Elastodiene)[1] ED
        - Lyocell CLY
        - Modal CMD
        - Triacetate CTA
        - Viscose CV
      - From synthetic polymers
        - Acrylic PAN
        - Aramid AR
        - Chlorofibre CLF
        - Elastane[2] EL
        - Rubber (Elastodiene)[2] ED
        - Fluorofibre PTFE
        - Modacrylic MAC
        - Polyamide PA
        - Polyester PES
        - Polyimide PI
        - Polyethylene[2] PE
        - Polypropylene[2] PP
        - Vinylal PVAL
    - Inorganic
      - Carbon CF
      - Glass GF
      - Metal MTF

[1] Previously called elastofibers
[2] Also called polyolefins

Table 2 – Classification chart of man-made fibres

GENERAL PRINCIPLES OF PRODUCTION PROCESSES

There is no substantial difference in the structure of natural fibres from that of man-made fibres: both fibre categories are composed of macromolecules or by linear polymers, that is by the repetition of several simple molecules (monomers).
Natural fibres are essentially composed of atoms of various elements, such as carbon, hydrogen, oxygen, sometimes of nitrogen and other elements (sulphur) in lower quantities; during their biological growth, these elements form the rings of long molecular chains. The development of man-made fibres was based on the knowledge acquired with natural fibres which structure was taken as a model; the difference between the two fibre categories is that natural fibres form macromolecules through biological growth, while the growth process of man-made fibres is driven through technical equipment (artificial fibres use instead natural polymers).

Polymerisation

The term polymerisation defines the process of macromolecules formation through repetition of basic units: it of course applies only to synthesis fibres. In general, polymerisation reactions are activated and controlled during the process by various parameters, as temperature, pressure, catalysers, reaction stabilizers.
The number of repetitive units is termed degree of polymerisation and is a parameter of great significance for fibre properties setting.
As the length of the single molecules is not constant, but varies according to a statistical model, the degree of polymerisation or the correspondent molecular weight has to be considered as an average value.
Depending on the various fibre typologies, the degrees of polymerisation may range from some hundred units in the case of polymers obtained through condensation (PA, PES) to some thousand units in the case of polymers resulting from poly-addition (PAN, PP).
Under a production and application point of view, the degree of polymerisation is controlled by measuring following parameters:

Relative viscosity η_{rel}= solution viscosity/solvent viscosity = flow time t_1/flow time t_2

Intrinsic viscosity η_{intr}= η_{rel} /c $\rightarrow 0$ (concentration vanishing)

Melt flow index MFI = speed rate of the melted polymer at pre-established conditions

Relative viscosity is a parameter which is mostly
used to identify nylon, while intrinsic viscosity (obtainable from the relative viscosity also by means of formulas) is used for polyester and the melt flow index for polypropylene.

There are basically two mechanisms of chemical reaction available for the synthesis of linear polymers:

Poly-condensation: with this operation two molecules of same type or of different types are joined together to form macromolecules by removing simple secondary products as water, hydrochloric acid, alcohol.

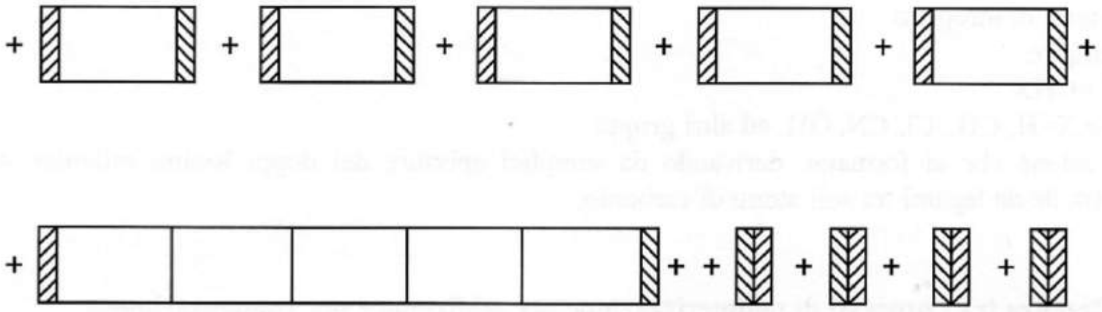


Fig. 11 Poly-condensation

The prerequisite for reactions of this type is the presence in the molecule (monomer) of two terminal reactive groups with functional properties.
The molecules composed of 2,3,4…n monomers are named dimers, trimers, tetramers (oligomers)…polymers.

Some of the mostly used monomers are:
Aliphatic di-acids HOOC-R-COOH (used for nylon 6.6)
Aliphatic di-amines NH_2-R-NH_2 (used for nylon 6.6)
Aliphatic amino acids H_2N-R-COOH (used for nylon 6)
Aromatic di-acids HOOC-Ar-COOH (used for polyester)
Diols (bi-functional alcohols) HO-R-OH (used for polyester)

Thus formed polymeric chains contain, besides carbon atoms, also various atoms (etero-atoms) resulting from the condensation reaction of the functional groups (e.g. nitrogen for polyamides, oxygen for polyester).

b) *Poly-addition:* this operation joins together
several molecules and redistributes the valence links existing in the monomers, however without removing secondary products.
Many unsaturated compounds which are characterized by the presence of a double link between two adjacent carbon atoms as ethylene and its derivatives, polymerise according to this reaction; within this category fall e.g. acrylic and polyolefin fibres.

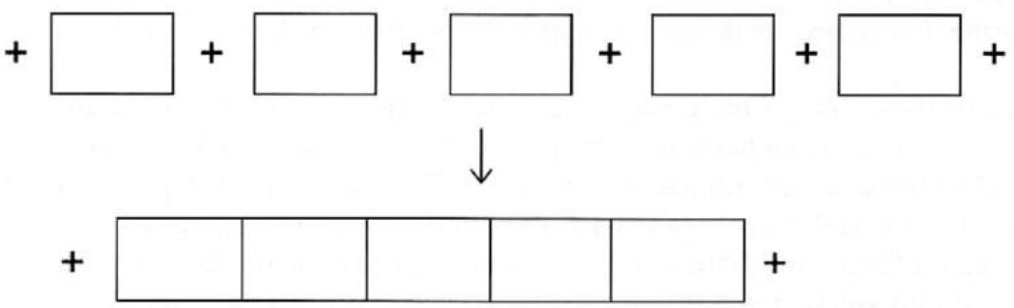


Fig. 12 Poly-addition

Among the most used polymers there are ethylene derived molecules with one or more substitutes of hydrogen atoms.
For example:CH_2=CHX
Where X=H,CH_3,Cl,CN,OH and other groups.
The chains which are thus formed originate from simple openings of double ethylene links and are therefore characterized by links only among carbon atoms.

Difference between addition and condensation polymerisation processes
Through poly-addition not only secondary substances are removed: reactions follow a chain process, are quicker, highly exothermic and usually require lower temperatures.
Molecular weights (degree of polymerisation) are higher and it is more likely to have chains with cross or branched links.
Polymerisation, once it is completed, does not leave behind polymers of intermediate length (oligomers), but only non-reacted products (monomers).
Poly-condensation, on the contrary, is a process in several stages which leaves behind, among reaction products, also polymers with low molecular weight (oligomers).

Polymerisation techniques
From a processing point of view, the polymerisation can be carried out by mass treatment, solution or dispersion (suspension, emulsion).
From the engineering point of view, the process can be:

- discontinuous, where reagents are entirely pre-loaded into the reactor and, as soon as the polymerisation is completed, the products are completely unloaded. The "batch" technique is used in particular for the production of small lots or of specialty items.
- continuous, where reagents are introduced from one end and reaction products come out from the other (this process is used especially for large productions). The reaction can also take place within a stationary phase (as typical for poly-additions) or at subsequent stages (as in poly-condensations).

Whichever polymerisation method is applied, the reaction products (polymers) can appear as follows:

- in form of a solution to be conveyed to the spinning department;
- in form of a melted polymer to be conveyed directly to the spinning department or to be transformed into grains (chips) for subsequent use ;
- in form of a suspension, from which the polymer is separated and conveyed to the spinning department;

Along with the chemical reactants (monomers and possible catalysts) during the polymerisation stage or anyway in a stage preceding spinning, other additives can be added in order to provide the fibre with certain properties: a product of particular importance is a white dulling agent (titanium dioxide in grains), which is added in small quantities in order to give the fibres a "dull" appearance, which distinguishes them from the untreated fibres which, owing to their brighter and "synthetic" appearance, are named "bright".
Under this point of view, the fibre is termed on the basis of the added quantity of titanium dioxide (dullness degree) as follows:

- bright fibre: a fibre without or with minimal quantities of titanium dioxide;

- semi-bright fibre: a slightly delustred fibre
- semi-dull fibre: usually terms delustred fibres with 0,25-0.5% titanium dioxide contents
- dull fibre: fibre with 0,5-1% titanium dioxide
- superdull fibre: fibre with 1-3% titanium dioxide

Fibre	**Degree of polymerization**	**Average molecular weight**
CV	250-700	40.000-100.000
CUP	500-600	
CA	220-300	
PA (6 and 6.6)	100-180	15.000-30.000
PES	130-220	17.000-20.000 (textile fibre) 28.000-40.000 (HT fibre)
PAN	1000-2000	30.000-70.000
CLF	1300-1800	-
PP		200.000-350.000
EL		50.000-100.000

Table 3 Average degree of polymerisation and average molecular weights (indicative figures)

Spinning

The term spinning defines the extrusion process through bored devices (spinnerets) of fluid polymer masses which are able to solidify in a continuous flow.
The spinning process is sometimes designated as "chemical or primary spinning" to distinguish it from the "textile or mechanical or secondary spinning".
The polymer processing from the solid to the fluid state can take place with two methods:

1. by <u>melting</u>: this method can be applied on thermoplastic polymers which show stable performances at the processing temperatures (this method is used by 70% of the fibres)
2. by <u>solution</u>: the polymer is solved in variable concentrations according to the kind of polymer and of solvent, anyhow such as to produce a sufficiently viscous liquid (dope) (this method is used by 30% of the fibres)

Spinning via melting is definitely preferable as it entails a simple transformation of the physical state, however it can be applied only to polymer having a melting temperature (PA 6 an Pa 6.6, PES, PP), whereas spinning by solution is used in case that the polymers attain a thermal degradation at a temperature lower than melting temperature (cellulose fibres, PAN). This last method is evidently more complicated than melt spinning, owing on one hand to the necessity of dissolving the polymer in a proper solvent, and on the other to the necessity of removing and recovering the polymer after extrusion.
In the case of melt spinning, the extruded polymer, owing to its fast cooling, is transformed directly into a filament while keeping substantially unchanged the form of the cross-section resulting from the filament geometry; on the contrary, in the case of solution spinning the extruded filaments are subject to considerable structural changes brought about by the process for solvent extraction from the polymer mass.

Solvent removal can take place in two ways:

Dry spinning
Solvent is removed through flows of warm gas suitably directed to the extruded filaments; gas temperature should be higher than the boiling temperature of the solvent, which will be extracted from the filaments, recovered and recycled.
Filament solidification proceeds according to the extent of solvent evaporation; it takes place faster on the external yarn layers (thus creating a crust or skin), and successively slows down while proceeding towards the interior.
As a consequence of the mass exchange, the original (round) cross-section of the filament undergoes a contraction, thus generating cross-sections which characterize the various kinds of fibres and spinning processes.

Wet spinning
This spinning method is based on the introduction of an extruded polymeric viscose into coagulation baths where the liquor, usually water, behaves as a solvent towards the polymer solvent and as a non-solvent towards the polymer mass.
Practically the solvent which is contained in the fibre in amorphous state (gel) is spread towards the liquor and at the same time the liquid of the bath is spread towards the interior of the fibre.
The processing speeds are dependent on several parameters, as type and concentration of the polymeric solvent and of the liquor, which bring about structural variations in the fibre.
In particular the formation of an outer, gardened and more compact cortex (skin), similarly to what happens in dry spinning, slows down the coagulation mechanism of the inner filament portion (core), thus creating unevenness with a more or less porous structure (voids formation).
The fibre cross-sections result more or less modified, from the original round form to a lobated form, with a wrinkled surface.

General flowchart of the spinning process

The flowchart which applies to the various kinds of spinning methods (see Fig. 13) is the following:
the fluid polymer mass (melted or solution mass) is guided, through distribution lines, to the metering pumps (gear system), which guarantee a constant flow rate to the spinning positions, composed of a series of filters which purify and distribute the polymer; these are coupled with perforated plates of variable thickness and size, which are usually circular and made of special stainless steel (for melt spinning), but also of precious metals or of vitreous material (for solution spinning).
The holes (capillaries), the number of which on the plate varies depending on the kind of fibre and can reach several thousands, can have circular or special cross-sections (shaped or hollow sections).
The filaments extruded from the spinnerets, after being converted back to their original state of solid polymer, are interrupted and taken up in suitable packages (bobbins, cans) or conveyed directly to subsequent processing phases.
In the case of melt spinning, if the polymer does not derive already in melted state from polymerisation, the fluid polymer mass is obtained through melting of the solid polymer grains (chips).
This operation was originally carried out inside containers (pipes) which were electrically heated and equipped with grids to separate solid grains from the polymer during melting (grid

melting device). The use of such system is at present limited only to few applications and has been replaced by more reliable and efficient devices (screw extruder).

The relations which connect some spinning parameters one another (and are calculated for melted polymers) are the following:

Polymer flow rate:
$m_F = V_F T_{sp}/10,000$
where:
m_F = polymer quantity for each yarn (g/min)
V_F = take-up speed (m/min)
T_{sp} = linear mass of taken-up yarn (dtex)

If we know the linear mass of the drawn yarn (Td) and the draw ratio R, the relation becomes:
$m_F = V_F T_d R/10,000$

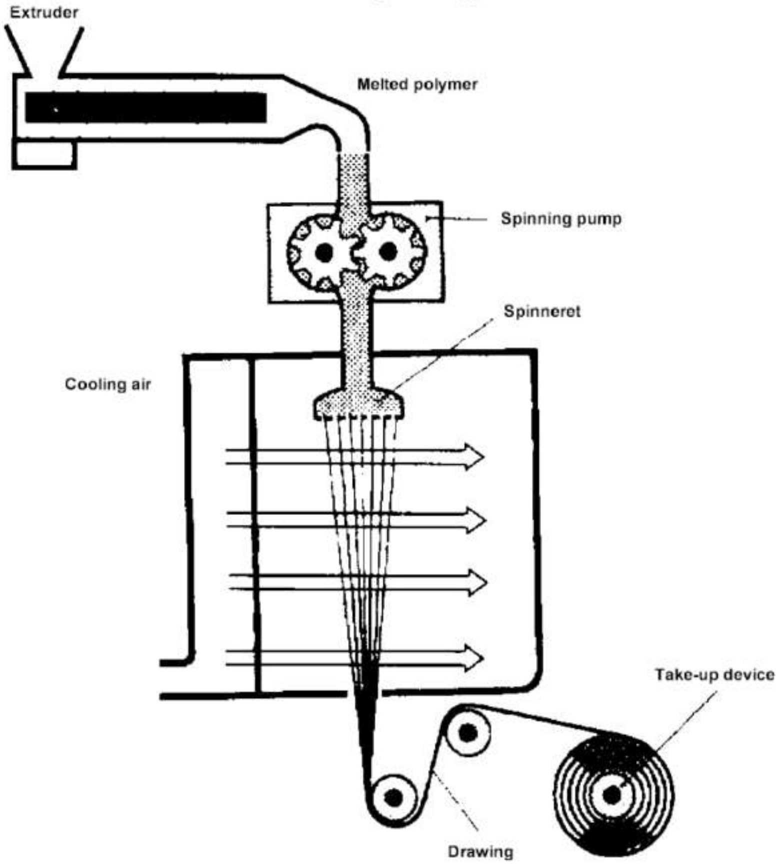
Extrusion speed of the melted polymer
$V_B = 4\ m_B/\pi d^2 \rho$ — V_B = extrusion speed at spinneret hole (m/min)
m_B = polymer quantity per spinneret hole (g/min)
d = hole diameter (mm)
ρ = density of melted polymer (g/cm^3)

Spinning ratio
$Q = V_F/V_B$

	Melt spinning	Solution spinning	
		wet sp.	dry sp.
Principle	Thermic exchange at temperature higher than melting point	Mass exchange	Thermal exchange + mass exchange
Polymer mass viscosity	High	Medium	
Operating	High (100-300 bar)	Medium-low pressures up to 20 bar	
Spinnerets	Steel of proper thickness (2 mm and more) Hole diameter: 0,15- 0.5 mm	In various materials (steel, noble metals, glass) Hole diameter: 0,025-0.25 mm	
Spinning speed	High Yarn: up to 6,000-7,000 m/min Tow: up to 1000-1500 m/min	Slow Yarn: < 200 m/min Tow: 5-40 m/min	Medium Yarn: up to 1000 m/min Tow=200-600 m/min
Fibre morphology:			
Cross-section	Follows capillary profile	Usually deformed (from round to lobated)	Usually deformed (from round to lobated)
Structure	Compact structure with smooth surface	Micro-porous with rough surface	Micro-porous with compact surface
Fibres	PA, PES, PP	PAN, CV, CUD, CMD, EL	CA, CT, EL, PAN

Table 4 Comparison between different spinning systems

Melt spinning



Solution spinning

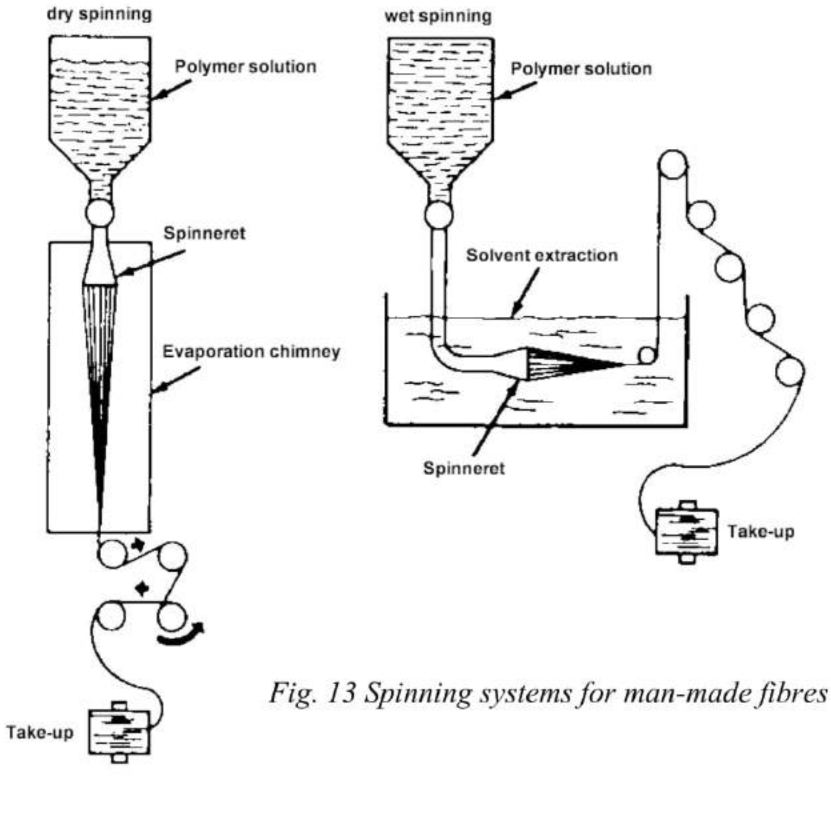
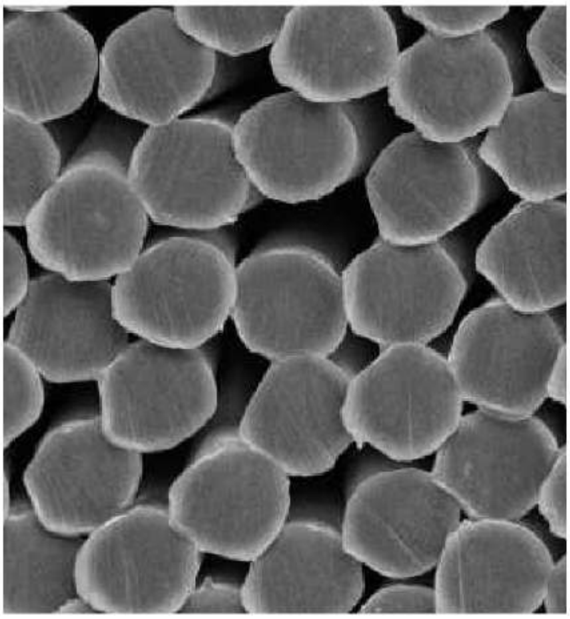
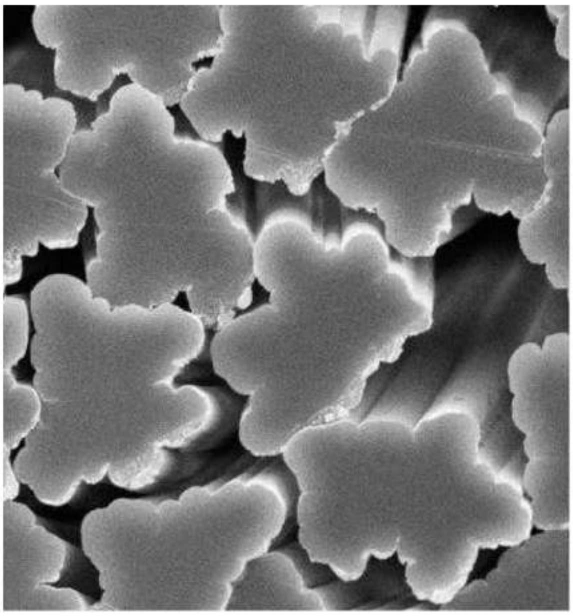


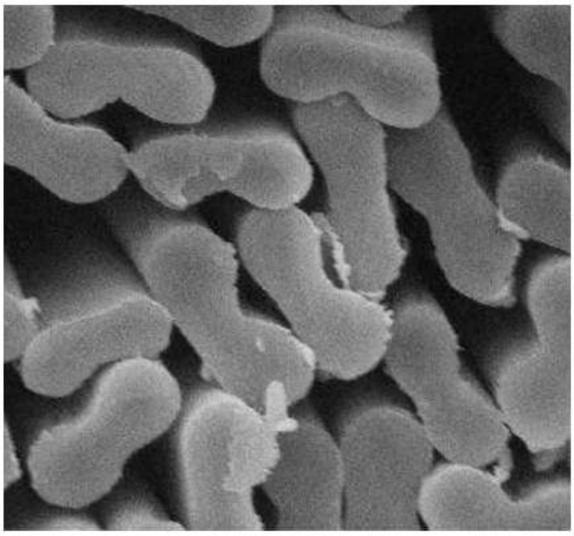
Fig. 13 Spinning systems for man-made fibres



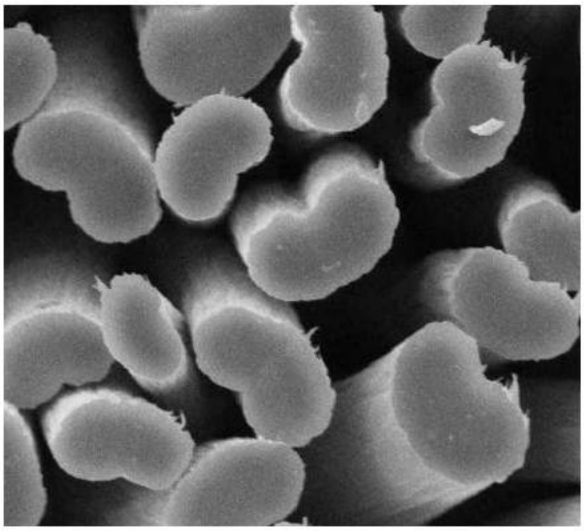
Round cross-section of melt-spu thermoplastic fibres



Multi-lobal cross-section of wet-spun viscose



Lobed (dog-bone-shaped) cross-section of dry-spun acrylic fibre

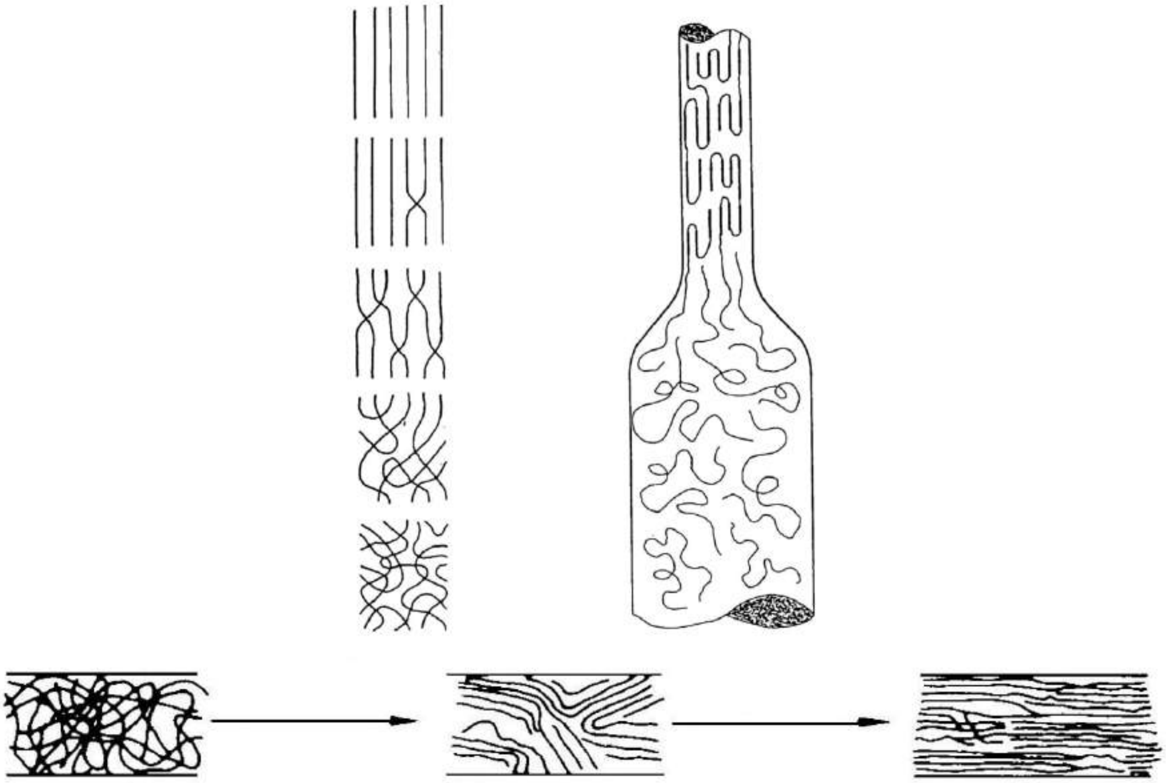


Lobed (kidney-shaped) cross-section of wet-spun acrylic fibre

Fig. 14 Typical cross-sections of fibres produced with different spinning processes.

Drawing

The polymer extruded by the spinnerets in form of filaments has not yet the properties which are typical of a textile fibre: in fact the polymer mass (solidified through cooling or solvent removal) is characterized by a mass of disorderly placed molecular chains (in amorphous state) which provides the material with poor thermal and chemical stability, low resistance to ageing, high plasticity and deformability and consequently insufficient physical/textile properties.
If we take natural fibres as models, we need to orientate the molecular chains (orientation phase) in the direction of the fibre axis and at the same time or successively activate or increase the ordered arrangement of the intermolecular structure (crystallization phase).
This process can be partly activated during spinning by increasing the ratio between the take-up speed and the extrusion speed (spinning ratio) but, excepted the case of high speed spinning of continuous filament yarns, the process needs to be completed by an additional operation of mechanical drawing.
The process entails winding the yarns on rollers or cylinders running at high speed and can be carried out continuously on filaments coming from the spinning room (single-phase process) or on filaments coming from a phase subsequent to spinning (two-phase process).
The speed ratio between the delivery or drawing rollers and the feeding rollers is the draft ratio R.
The mechanical configuration of the rotating devices and the filament path are designed in order to ensure the equivalence of fibre speed with the speed of contact organs.



Pre-orientation and partial crystallization   *Drawing*

Fig. 15 Molecule orientation during drawing

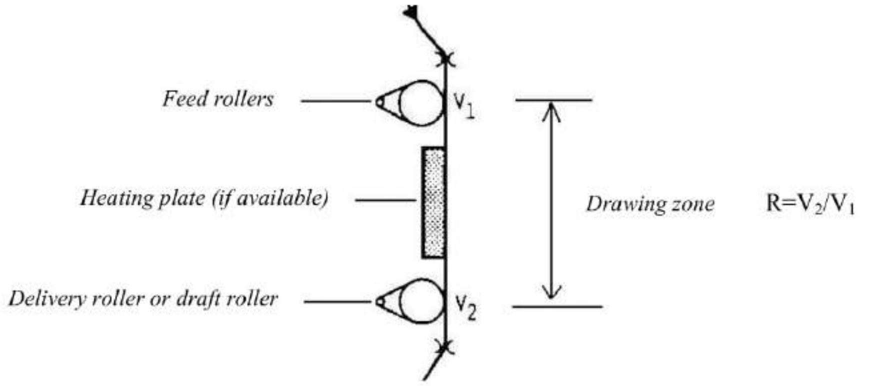
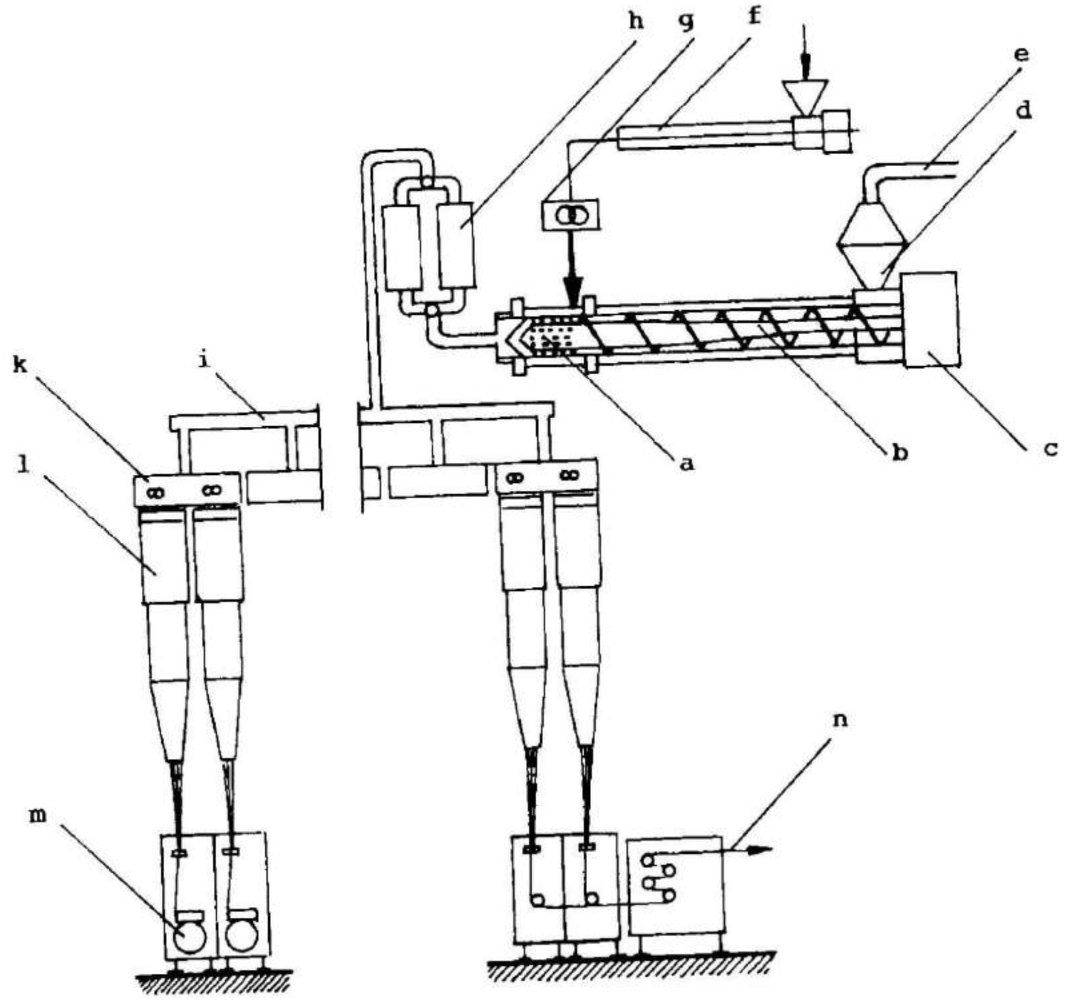


Fig. 16 Drawing principle

Draft ratio levels are variable and depend on the fibre typology, on the production process and on the end-use characteristics: they can fluctuate between values slightly higher than 1 (≈ 1,2 for traditional cellulose fibres) and max. 10 (for acrylic fibres).
Usual ratios for thermoplastic fibres are situated between 3 and 5; higher values identify fibres for technical applications.
Optimal conditions for fibre drawing are attained when the molecular chains show high mobility and creep; this result is in practice attained by increasing temperature to levels higher than glass transition and by introducing plasticizers which can make the structure more deformable and can reduce glass transition temperature (generally by acting upon the system water/humidity or using spinning solvents).
From an operational point of view, the draft zone can operate at room temperature (cold drawing) or at heated conditions (warm drawing) and consists of rollers, contact plates, heated air chambers or steam chambers and of immersion baths.
In order to provide the drawn fibres with thermal stability, usually these fibres undergo also a treatment at temperature higher than drawing temperature, under controlled tensions or in a free state, with the objective of eliminating internal tensions through readjustment of intermolecular chemical links and of the crystallization degree.

Technologies for the production of continuous filament yarns and of discontinuous fibres (staple fibres)

As already mentioned, from a morphological point of view fibres can be divided into discontinuous fibres and into continuous filaments.
This distinction applies also to natural fibres, although they have only one single case of continuous filament: silk, which is moreover available in nature only as monofilament and is available in limited quantities.
Only with the coming of man-made fibres, continuous filaments took on a great importance by giving rise to innovative transformation processes and application sectors; at present the market of man-made fibres is roughly divided equally between the two forms of fibre.
Theoretically, every fibre can originate continuous filaments or staple fibres; actually however production and application reasons have conditioned the use of one fibre form or of the other: elastane is produced exclusively as continuous filament, and nylon mostly in this form; polyester, polypropylene and viscose are produced in both forms, that is as continuous filament and as staple, whereas acrylic is produced almost exclusively in staple form.
Although the production principles are identical for continuous filament and for staple fibre, the two processes differ considerably in terms of plant engineering (Fig. 17).



A) Continuous filament yarns

B) Tow for staple fibre productio

- *a) mixer*
- *b) extruder screw*
- *c) main extruder*
- *d) hopper*
- *e) chip feeding line*
- *f) side extruder*
- *g) rotary gear pump*
- *h) continuous filter*
- *i) distribution line (manifold)*
- *k) spinning position*
- *l) cooling chamber*
- *m) take-up head*
- *n) tow for staple production*

Fig. 17 Melt spinning lines for continuous filament and staple fibre

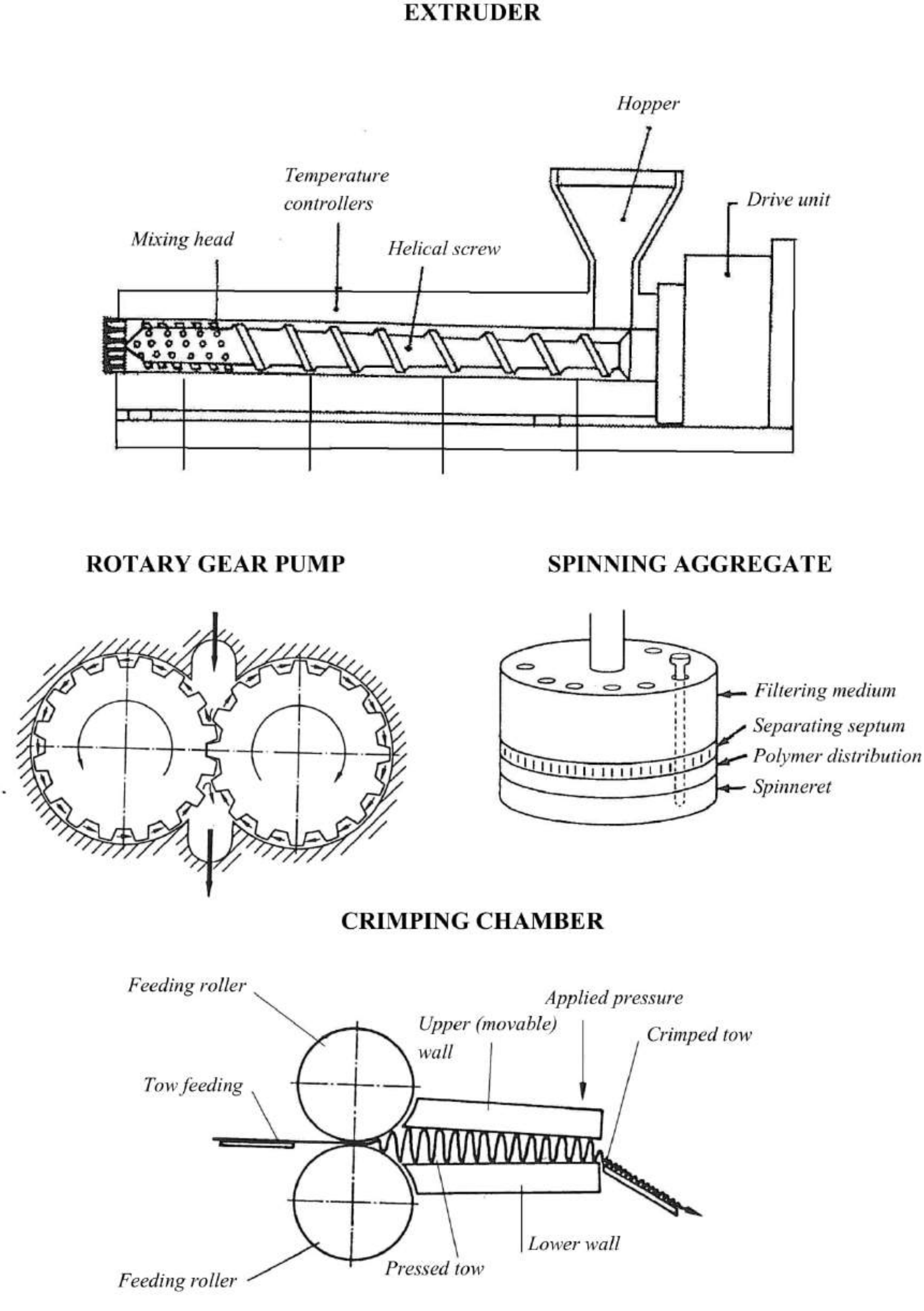


Fig. 18 Mechanical elements characterizing a production process

Continuous filament yarns

Continuous filament yarns can be composed of a single filament (monofilament yarns) or of several filaments (multifilament yarns) and are described through abbreviations, the first figure of which indicates the total linear mass (expressed in dtex or, less usually, in den), the second figure indicates the filament number and a third figure if any shows the twists per length unit (turns/m) imparted to the yarn.

Monofilaments for traditional textile uses have linear masses ranging from 10 to 50 dtex approximately; monofilaments with larger linear masses find on the contrary use in technical applications and are identified with their thickness expressed by the diameter of the round cross-section (0.06≠2 mm).

Multifilaments have variable filament number (up to 300 filaments for traditional textile uses, up to 1000-2000 for technical uses and floorcovering) and the linear mass of each filament ranges from 0.4 to 5 dtex.

A yarn can be declared as microfilament when its linear mass is lower than 1 dtex; as a rule, the number of filaments in a microfilament is higher than the linear mass of the yarn (e.g.: 200 dtex/220 filaments).

The yarn extruded by the spinneret presents smooth and parallel filaments (flat and parallel yarn).

Owing to processing and application requirements, parallel filaments are mostly tied together by means of entangling points (entangled yarns) or of twists (twisted yarns); on the other hand there are flat filaments, characterized by rigidity and poor covering power, which can be converted into curly or crimped yarns (textured yarns).

The spinnerets which produce continuous filament yarns have usually a number of holes equal to the number of filaments composing the yarn; there are however also some cases in which the spinneret produces several yarns, which are successively wound on separated bobbins (multi-bundle spinnerets), or cases in which several spinnerets produce a single yarn which is wound on a single bobbin.

The general scheme of a spinning line for thermoplastic polymers (Fig. 17A) consists of:

- one or more units, each composed of a screw extruder
- distribution system (manifold)
- spinning head or spinning position
- metering pumps
- spinnerets (up to 8 or 8x2 per position)
- spinning chimneys
- take-up units (winders for up to 8 bobbins)

In a first zone placed upright under the spinnerets, the filaments are struck crosswise by flows of cold and controlled air (cooling zone), to be cooled and solidified; then a second zone follows, where the filaments are assembled, lubricated by contact or spray devices and, if necessary, linked one another through entanglement points (produced by air nozzles) and wound on cylindrical bobbins.

The take-up speed plays a role of primary importance in establishing yarn characteristics. As far as traditional spinning is concerned, spinning speeds vary, depending on the fibre, from 1000 to 1800 m/min; under these conditions, the polymer remains substantially amorphous, scarcely oriented, with high propensity to degradation and ageing, and requires consequently to be quickly (i.e. within few days) processed.

By increasing spinning speed, the yarn is subjected to an increasing stress (due essentially to air resistance and to force of inertia) with consequent higher level of orientation and crystallization. Therefore, depending on the various speed levels, fibres with different characteristics can be produced; these are identified with English acronyms which are conventionally used to distinguish the single processes:

Type of yarn	Speed (basis PES)
LOY (Low Oriented Yarn)	1000-1800 m/min
MOY (Medium Oriented Yarn)	1800-2800 m/min
POY (Partially or Pre-oriented Yarn)	2800-4000 m/min
HOY (High Oriented Yarn)	4000-6000 m/min
FOY (Fully Oriented Yarn)	> 6000 m/min

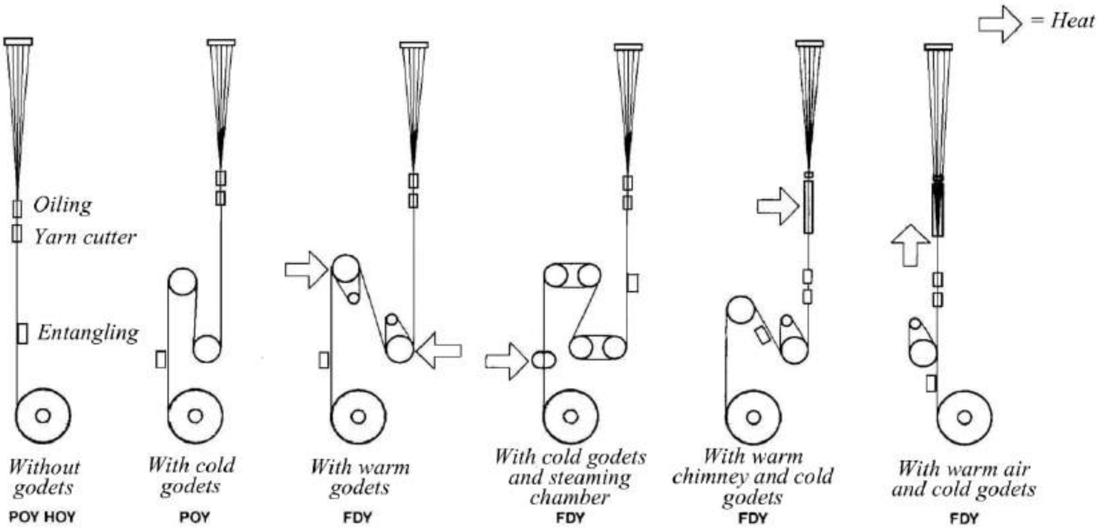


Fig. 19: Basic configurations of different spinning technologies for continuous filament yarns

Yarns produced with high speed spinning (HOY and FOY) show some qualitative and technological problems and found therefore up to now a limited diffusion at processing and application level.

An advanced form of LOY, which needs to be submitted to a drawing process in order to be usable, is POY, a yarn characterized by about 100-120% elongation at break. This yarn is widely used thanks to its good stability to ageing and, although not directly usable in the production of textile items, to its suitability to intermediate processes which combine a specific process (warping, sizing, etc.) with a complementary drawing process; in fact this yarn finds wide use in draw-texturization, but also in draw-warping and in draw-sizing.

Yarns originated by a specific drawing process performable either directly in spinning or successively in a separate phase, are named "fully drawn yarns" (FDY).

Techniques for additive feeding in the spinning process

The selection of the most suitable technology depends on the demanded flexibility level: the market offers on the one hand lines designed for the production of mass quantities with constant

properties, and on the other single units which operate in a way completely different from others (Figures 20, 21).
The flexible solution is preferred especially in the case of extremely diversified productions (as e.g. in the case of dope dyed fibres) which require a cost optimisation related to the produced fibre quantity.
The techniques for the feeding of additives (dyestuffs, dulling agents, polymer stabilizers) can be schematised as follows:

- addition of additives in solid state or in form of masterchips to the granules of the basic polymer during the feeding phase of the extruder; metering is carried out with a volumetric or gravimetric system, mixing takes place inside the extruder and usually continues in the melted state in a subsequent mixer.
- ystem for the injection of additives in melted or liquid state into the flow of melted polymer; the additive in melted state is obtained by masterchips treated in a separate (secondary) extruder, while the additive in liquid state is prepared inside a tank.
  Metering is ensured by metering pumps and the injection points are placed on the main extruder or on the main spinning line, or even right before spinning pumps.

The technique of additive feeding near the single spinning positions is increasingly widespread as, besides ensuring flexibility to the plant, it reduces the waste caused by frequent lot changing due to small productions and improves the quality of the fibre, owing to its reduced stay time in melted state (thermal stress).

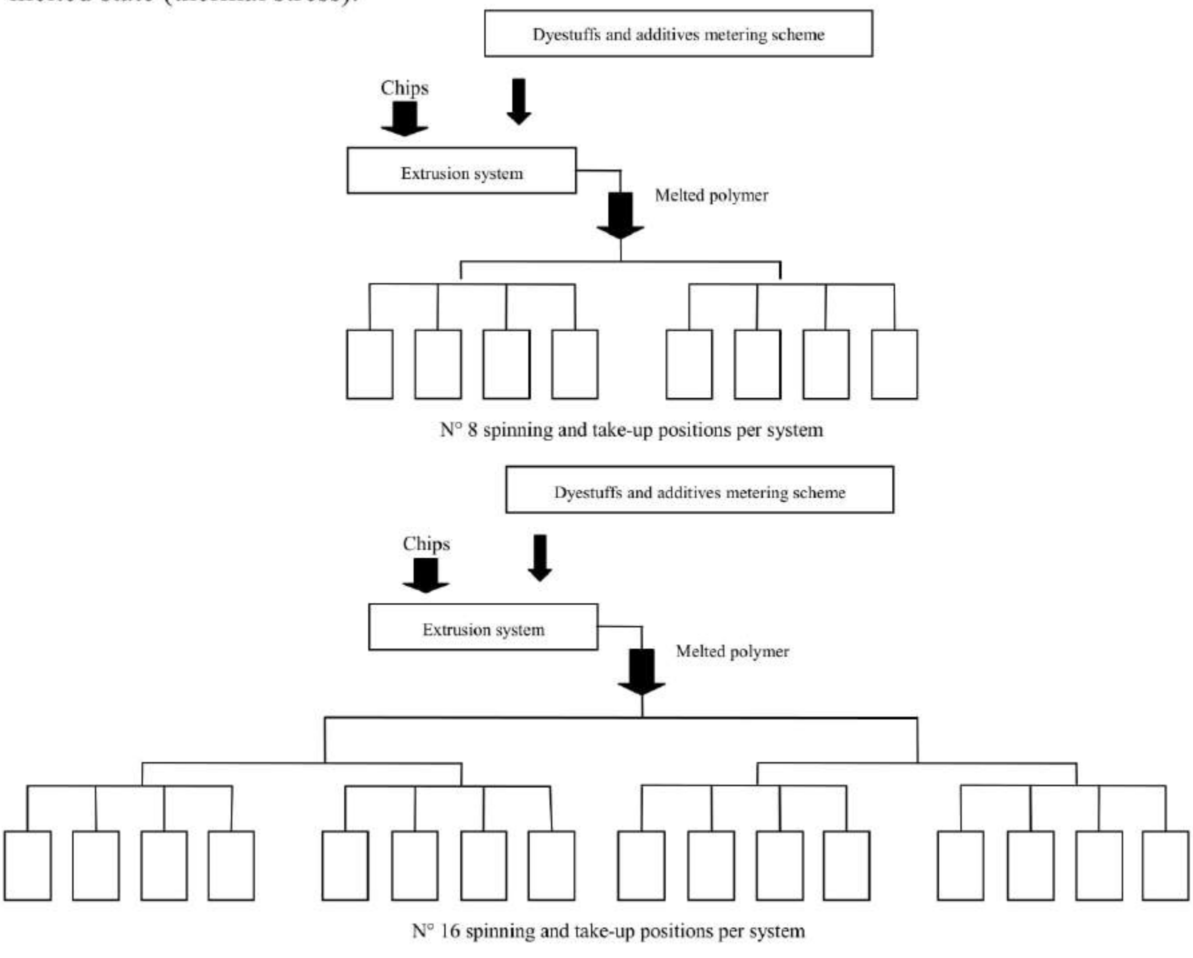


Fig. 20 Typical configuration of a traditional spinning line from chips (N° 8 and 16 positions)

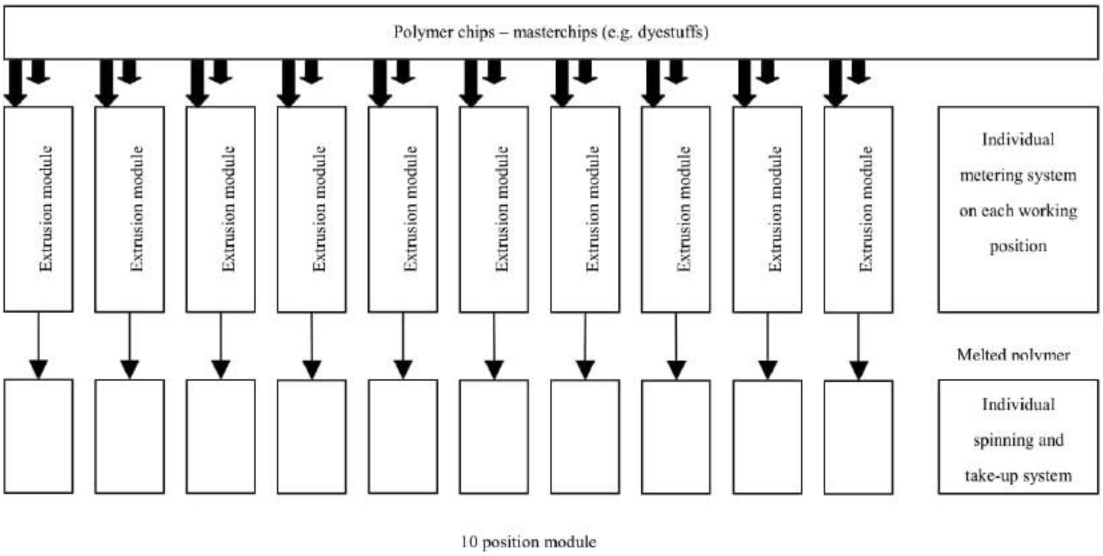


Fig. 21 Typical configuration of a spinning line with independent feeding(polymer + additives) on each working position

Drawing process

Flat yarns resulting from a drawing process are named FDY (Fully Drawn Yarns). The drawing process can be carried out with two different techniques:

Two-stage-process

This technique can be applied to yarns which are not fully drawn (LOY, MOY, POY).

With the old traditional plants, the bobbins of LOY yarns were drawn in a suitable department by machines named "draw-twisters".

On these machines the yarn runs along a vertical path composed by the feeding system (with bobbins in upper position), by the draft zone and by a winding device similar to the one of a ring twister (Fig. 22 a).

During the winding on a stiff tube, the yarn is provided with a light twist originated by the rotation of the ring around the spindle.

The speed of current machines can range between 600 and 1500 m/min depending on the yarn type, and the weight of the yarn packages (cops) can reach up to 4 kilos; in order to increase productivity and to reduce costs, the machines can be equipped with automatic doffing device.

The 1980's recorded the development of a new type of drawing frame (draw-winder), in which the winding on spindles was replaced by a take-up system on bobbins with cross-winding (Fig. 22 b).

This system permits a higher winding speed (up to 2000 m/min), the production of packages with higher weight (10-15 Kg) and, from the quality point of view, of a yarn with more uniform properties thanks to a more accurate control of the variations in the winding tensions (the winding frame with spindle winding can cause tension peaks).

Yarns wound on spindle present a twist which binds together and protects the filaments; on the contrary the filaments of yarns wound on bobbins are parallel so that, to make up for this deficiency, an intermingling device (a nozzle with intermittent flow of compressed air) placed before the winding device can be envisaged.

For some applications as technical uses, additional cylinders (some of which heated) are positioned after the main drawing zone, for the scope of stabilizing the yarn and of fixing a prearranged thermal retraction (Fig. 22 c).

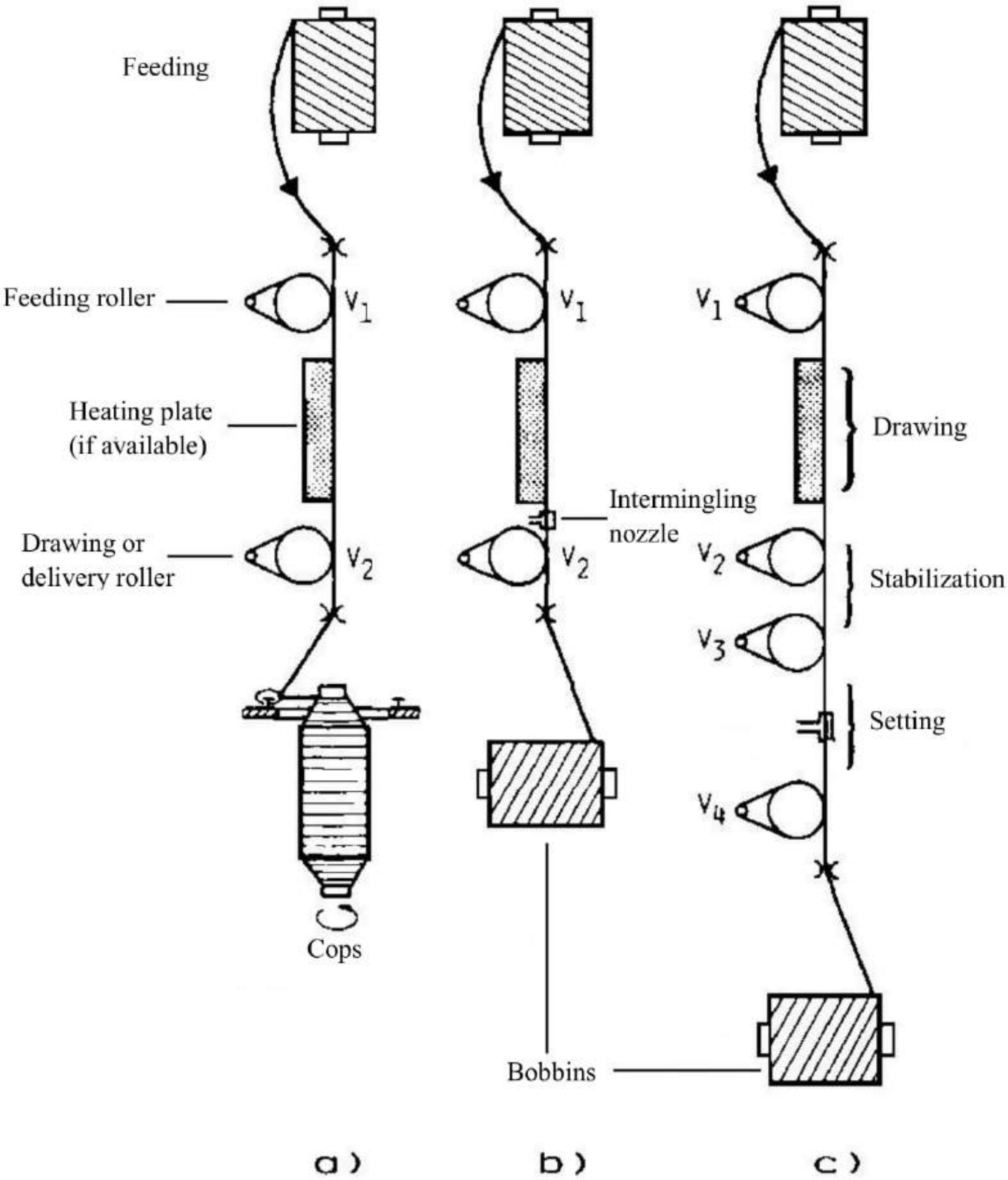


Fig. 22 Principles of two-phase drawing

Single-phase process

The increase of spinning speeds (4000-5000 m/min) set itself as additional goal, besides rising productivity, the drawing of the continuous filament yarn right during the spinning process (Fig. 19 – FDY configurations).

The spinning configuration may be modified on the basis of the various fibre typologies and technologies; in any case the yarn needs, before its take-up, to be submitted to a drawing unit

composed of one or more drawing zones placed between godets and moreover of heating sources (the heated cylinders themselves, or steam/air heated tubes, or chambers positioned before or after the cylinders).
The requested yarn characteristics (tenacity, elongation, tensile modulus, thermal retraction) can be modified to a large extent through various adjustment possibilities.
Usually yarns coming from the same spinning position are drawn by just one drawing unit, and are then again separated during winding on the various packages composing the winding unit.
A comparison between the two drawing processes highlights the fact that the single-phase process is an integrated process characterized by high productivity, low labour costs and reduced space requirements, whereas the two-phase process presents a simpler technology and higher flexibility in terms of product range extension and of productivity.

Discontinuous fibres (tow and staple fibre)
This production takes place in plants which have a conception completely different from those designed for the production of continuous filaments.
The basic concept is to obtain from spinnerets a high number of parallel filaments (spinning tow or tow) to be delivered to subsequent textile processes (Fig. 17B).
The tow must therefore be considered as an intermediate step in the production line of discontinuous fibres which are designed to feed subsequent textile processes (spinning and non-woven sectors); it is characterized by a considerable linear mass (up to 150 ktex) and is composed of filaments with the same range of counts as the standard range for staple fibres (from a 0,4 dtex micro-fibre to 17 dtex staple fibre for carpeting).

Production lines
The transformation process is, excepted variations due to the different nature and typology of the fibre, essentially made up of following processes: spinning, drawing, heat-setting, oiling, crimping, drying, cutting into staple if necessary, baling (in form of tow or of staple fibre).
The processes can be carried out by means of production lines which transform without break the fibre delivered by the spinnerets as far as the end-phases (continuous single-phase lines) or by means of lines in which the flow of the fibrous material is interrupted after spinning and is fed in a subsequent step (as from drawing) as far as the lines of final conversion (discontinuous two-phase lines).

Continuous single-phase lines
Continuous single-phase lines are used for the production of fibres, in which the flow speed of the material can be balanced through the various transformation phases; a typical application of these lines is the wet spinning process (for acrylic and viscose fibre spinning), but their use has also been recently extended to the compact spinning process for thermoplastic polymers.
The limited spinning speeds of these processes are compensated by the high flow rates of the spinnerets. The final speeds of the lines (composed of 1 or more tows) can reach 50-200 m/min.

Discontinuous two-phase lines
These lines are used when there are differences of operating speeds between the different phases. This occurs in processes in which spinning speeds are higher than in subsequent processing stages. Such is the case of processes traditionally used for thermoplastic fibres and dry spinning processes, in which spinning speeds (over 1000 m/min for thermoplastic polymers, 400-600 m/min for PAN dry spinning) are higher than speeds of downstream processes (final speeds, resulting from initial speeds and from drawing ratio of about 200-300 m/min).

One of the most specific technological differences between staple fibre spinning and filament spinning is to be found in the characteristics of their spinnerets. In fact, in the case of continuous filaments the number of holes per spinneret is relatively low and closely connected with the number of filaments in the yarn, whereas in the case of tow production the spinnerets are bigger and have a higher number of holes.
The nature of the material and the configuration of the spinnerets must anyway take into account the rheological properties (viscosity) of the polymer mass as well as the spinning typology.
Spinning parameters must ensure an even solidification of the polymer mass after extrusion, without varying textile properties and originating physical imperfections (drops, badly drawn yarn pieces, stuck together fibres, broken filaments, etc.) in the filaments.
Concerning wet spinning (PAN, CV), owing to the low extrusion speed and to the coagulation process, spinnerets with round cross-section are usually employed; these spinnerets, which can be made of different materials, show thousands of holes (even more than 100.000).
As to spinning from melted polymer, considering the high speeds and the necessity of a quick and uniform cooling of the extruded filaments, different technologies are used which, as far as traditional discontinuous processes, fall within following criteria (Fig. 23):

Rectangular spinnerets with lateral cooling flow
This structure shows holes positioned on parallel rows of rectangular plates made of special steel, designed in a way that the flow of cooled air comes only from one direction and consequently does not hit uniformly the various filament rows; this fact involves a limit in increasing the number of holes; moreover the system does not ensure an efficient removal of spinning steams (monomers).

Ring spinnerets (round spinnerets with a large central hole)
Cooling is carried out by adjusting air flow (coming from the bottom of the chimney) on the whole filament bundle by means of a flow which is addressed from the outside to the inside of the filament bundle or from its inside to its outside.
This system guarantees a more uniform solidification and a more effective removal of steams and impurities, thus enabling a higher production capacity (up to 4,5-5 kg/min).
In the case of mass productions, the holes per spinneret attain a number of 5,000-6,000 (5,250 holes for standard fibres, 6,000 holes for micro-fibres).
The bundles of cooled yarns are successively oiled (by means of spray or roller devices), conveyed in horizontal direction by diverting pulleys, combined with other yarn bundles in order to obtain a tow of larger size (or sub-tow) which, in the case of the two-stage process, is collected into cans; these are placed in a certain number on the creel to feed the drawing line.

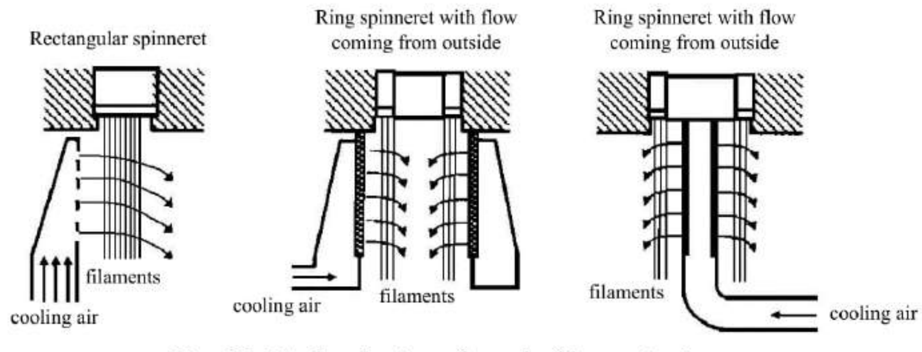


Fig. 23 Technologies of staple fibre spinning

TEXTILE PROCESSES

The introduction of man-made fibres started up the development of processing technologies, which are partly or totally innovative compared with the world of natural fibres.
Man-made fibres had initially the propensity to superimpose to natural fibres in the various application sectors, adjusting themselves to the different traditional processes; successively, especially with the discovery of synthetic fibres, their larger diffusion and the knowledge of their potentiality led to the development of original processes, which allowed to widen the application fields known at that time and to create new ones.
Some processes (texturing, tow-to-top process, twisting/warping) were connected to such an extent to fibre typology, that they were carried out, at least in the past, directly within the fibre production units as final stages of the product to be marketed.

Texturing
Texturing is probably the most typical example of innovative process tightly connected with the production of continuous filaments, the properties and uses of which it has deeply modified.
As to world consumption of man-made fibres, it is estimated that continuous filaments amount to about 18 million tons (55% of total consumption in 2002), divided among apparel (45%), upholstery (31%), industrial uses (13%), carpets and floorcovering (11%).
The yarn produced through spinning can undergo several processes before its use, as exemplified in following scheme:

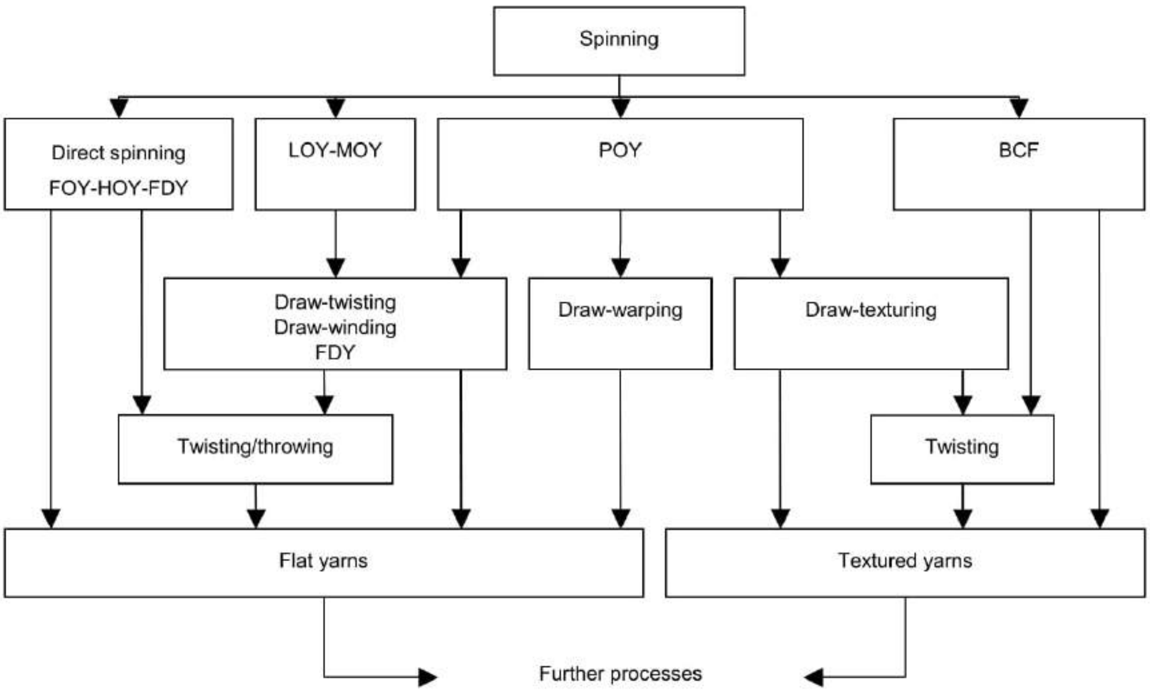


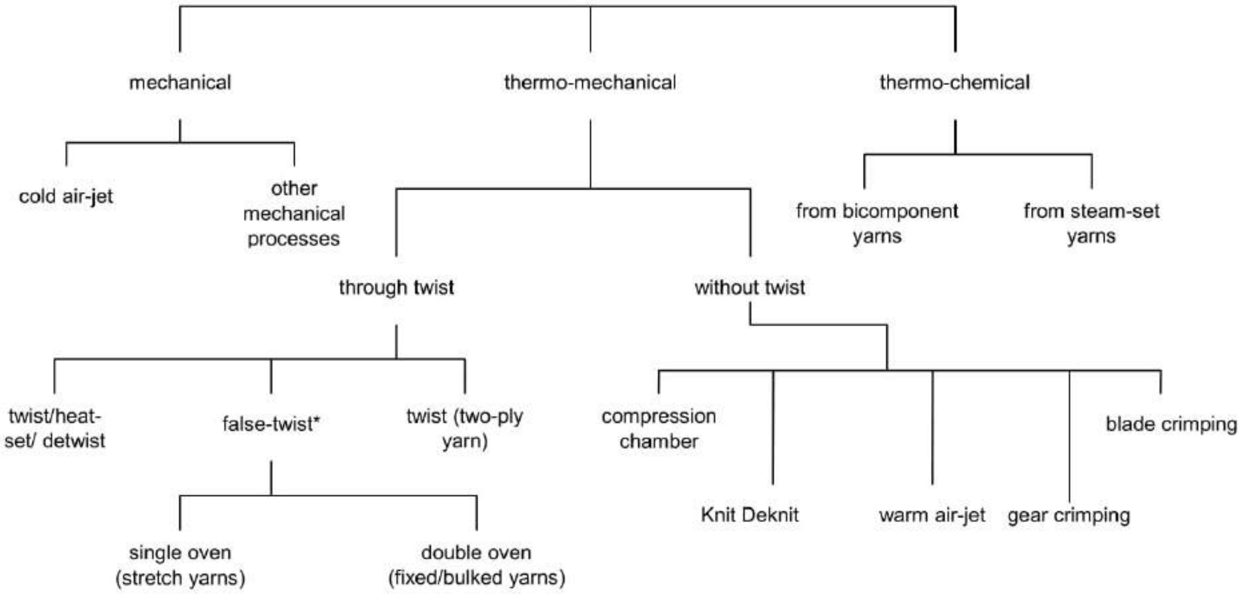
Fig. 54 Main processing stages of a continuous filament yarn

Textured yarns account for a large part of processed filament yarns. The texturing process makes up for the inherent deficiencies of a flat continuous filament yarn, both parallel and twisted, by varying its original textile character and imparting new properties as bulkiness, covering power, elasticity, soft touch, "natural" aspect, hygroscopicity and easier processing. In other words flat yarn, which structure can be compared to iron wires, gains properties which make it similar to a traditional cotton or woollen yarn.

A textured yarn can be defined as "a yarn characterized by effective or latent crimps, waves, loops of single filaments which, after suitable treatment, can originate properties as bulkiness and/or elasticity".

In the course of time several processes based on different principles were developed; only a limited number is at the moment interesting for industrial applications; the process which is by far the most important is false-twist texturing, whereas the air-jet and compression-chamber systems are aimed at more specific uses.

Following scheme shows a general classification of the various processes.



*from drawn yarn (FDY) or partially drawn yarn (draw-textured POY)

Fig. 55 Scheme of the various texturing processes

Textured yarns are in general defined according to their production process.

With the twist-texturing process following yarns can be obtained:

- Highly elastic yarns (stretch yarns), characterized by high crimp elongation (extensibility) and high crimp contraction; in the case of false-twist process, they are produced by means of an oven and are named FT (False-twist) yarns.
- Set yarns (bulked yarns), characterized by low crimp elongation and low crimp contraction; in the case of false-twist process, they are produced with two ovens and are named FTF (False-twist Fixed) yarns.

Description of the texturing systems

Thermo-mechanical processes with deformation through twist

Discontinuous method: twisting-thermosetting-de-twisting

This is the first texturing method ever used: it is based on the thermosetting of a yarn after twisting and subsequent de-twisting. When this yarn made its first appearance in the market in the 30's (in Germany and Japan), it was used for viscose texturing. However the users soon realized that this fibre, owing to its non-thermoplastic nature, was not suited to develop a sufficiently permanent crimp.

The fibre went through a period of considerable expansion in the 50's, when people realized that through such process thermoplastic fibres like nylon offered good elasticity and thermal stability: let us
remind in particular the Helanca process for hosiery yarns developed by the company Heberlein.
The classical method consisted of three discontinuous processes:

- Twisting on a twisting machine in 1 or 2 stages with a high number of turns (twists between 2,500 and 4,500 t/m, i.e. inversely proportional to the linear mass of the yarn).
- Twist setting on bobbin by thermal treatment, usually in autoclave with saturated steam and vacuum-steam cycles (130°C temp. for nylon).
- De-twisting on a twisting machine, in a first stage zeroing the existing twist and successively applying a further slight twist in order to improve yarn stability and regularity.

As a result of the thermoplastic deformation caused by twisting, the single filaments composing the processed yarn show in the relaxed state a special/helicoidal waviness which has same direction as the imparted twist (the applied slight final twists are in fact aimed at reducing the yarn trend to rotate on its own axis). This process resulted into yarns with excellent elasticity (for use in hosiery), but some end-uses, in particular polyester for knitwear, a stabilization of elasticity was necessary; to this purpose a further thermosetting stage was applied on the yarn, which was wound on bobbins with a preset tension (stabilized yarns or "set" yarns).
A variant of the classical method included:

- Separate twisting of 2 yarns with equal number of twists, but opposite twist direction (S and Z).
- Yarn setting on cones, by means of steam autoclave
- De-twisting of the single yarns, as far as a twist slightly over zero.
- Twisting together of the 2 yarns with low twist (e.g. 150/S).

In this way more balanced textured yarns were obtained.

False-twist method

The previously described process fell into disuse owing to the numerous operations involved , to its low productivity and to consequently high production costs.
Around mid 50's, a new process proved suited to carry out in a single stage (in continuous) the various operations previously performed separately.
The process is based on the principle of providing the yarn with a false-twist.
If we imagine to take a piece of yarn, block its two ends and rotate it in one direction by sliding it at an intermediate point between thumb and index of our hand, the yarn segments placed respectively upstream and downstream that point will receive a twist characterized by equal number of turns, but with opposite direction.

If we remove the twisting action by releasing our hold on the yarn, the twist will be set to zero and the original parallel state of the yarn will be reinstated; in practice this operation has not produced a real twist, but only a "false-twist".
Let us now consider same situation, but with a yarn in motion: the yarn coming out of the twisting element will have same configuration as the fed yarn. In fact the twist produced in the zone placed before the twisting element is cancelled by the twist in opposite direction produced in the subsequent zone.

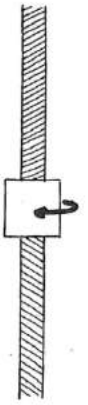


Fig. 56a False-twist insertion into a stationary yarn

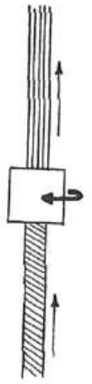


Fig. 56b False-twist insertion into a yarn in motion

Now, if in the first zone the twisted yarn is brought into contact with a heating medium (oven) and is successively cooled (cooling zone), the filaments composing the yarn undergo a thermoplastic deformation of twisting and permanent nature, which is absolutely similar to that of previously described discontinuous process.
If we wish to stabilize yarn elasticity, we shall need to place a second oven after the twisting element.

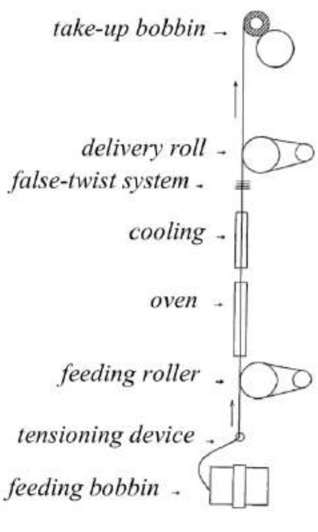


Fig. 57a Machine with 1 heating oven

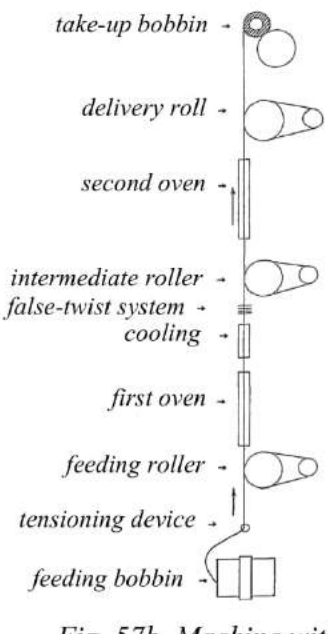


Fig. 57b Machine with 2 heating ovens

False-twist technology, which is by far the most important technology among the various processes, enjoyed an extraordinary development since its invention: from an initial processing speed of about 10 m/min, a speed of 1000-1200 m/min was attained (at present the mechanical speed can reach even 1500 m/min).

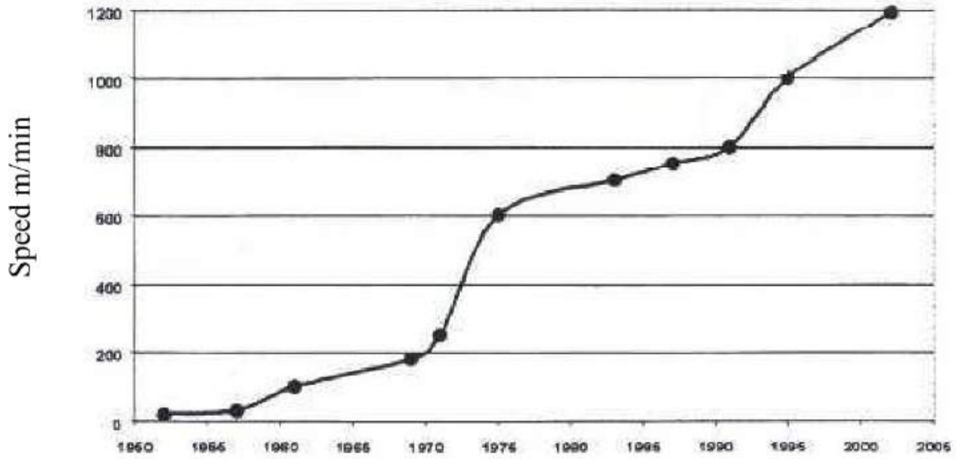


Fig. 58 Development of false-twist texturization speed

This goal was made possible by improvements brought to all machine elements, but in particular to the twisting element.

<u>False-twist with hollow spindle</u>

The machines which use such system are the so-called 1st generation machines.

The twisting device is formed by a hollow tube, inside which a pin is fixed crosswise; the yarn is wound around this pin with a full rotati on of 360°.

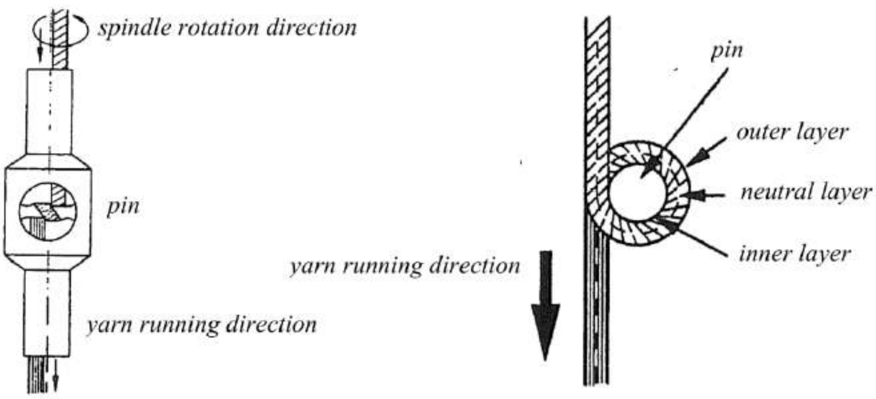


Fig. 59 Twisting with hollow spindle

Each rotation of the spindle around its own axis entails the insertion into the yarn of a false-twist which moves in length direction along the yarn.

Originally spindles got rotated on ball bearings by friction belts: in this way speeds of 40.000-80.000 t/min. could be obtained, wear characteristics of the bearings permitting. Later on mechanical bearings were replaced by magnetic bearings, which permitted to attain spindle speeds up to 900.000 t/min (yarn speed max. 200 m/min). Such high speeds constitute a limit both from the mechanical point of view (there are nowadays no mechanical components working at higher industrial speeds) and from the processing/technological aspect; in fact higher speeds would heavily damage the yarn in consequence of the tensions occurring during the yarn winding around the spindle pin.

False-twist with friction disks

The limits of the twisting spindle have been overcome with a transmission system in which the rotating motion is produced by a disk which is mostly in contact with the running yarn (Scragg patent, 1972). In such way the twist is inserted into the yarn according to a peripheral speed process and the quantity of theoretical twists applied to the yarn is proportional to the number of disk rotations and to the disk diameter/yarn diameter ratio.

The system consists of a series of disks mounted on three spindles, which have their axes spaced out in such a way, that the disks result partially superimposed; the running yarn gets twisted by its contact with the disks, as it performs a helicoidal evolution around an imaginary cylinder generated by the superimposition of the disks.

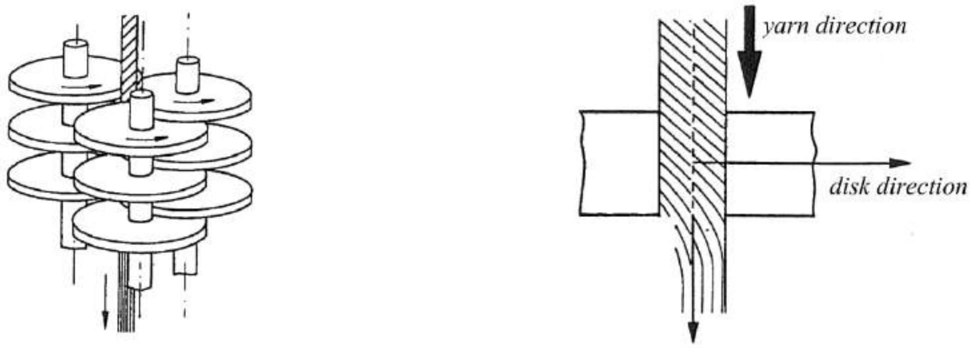


Fig. 60 Twisting with friction disks

The false-twist aggregate is composed of a disk package placed on a three-axial system, in which the first package at yarn entrance and the last one at yarn delivery simply have the function of positioning the yarn (guiding disks) without originating any friction, while the inside disks exert a torsional friction force on the yarn (working disks). The effectiveness of the system depends on aggregate configuration, on geometry and material composing the disks, on spindle gauge and on number of twists applied. Particularly important is the type of material used for the disks: it must ensure on one hand a good grip and on the other a good abrasion resistance.

Basically we can divide the materials into 3 groups: polyurethane and its mixtures (soft and light material), covered ceramic (with intermediate characteristics) and pure ceramic (more resistant to abrasion). Disks with soft surface are generally used for PES, especially for fine counts, while ceramic and covered ceramic disks, which are more widely used, are intended mainly for PA.

A formula which permits to calculate the twists to be applied on the yarn is the following:

$$\mathbf{t} = \left(\frac{250.000}{\text{Tdtex} + 40} + 970 \right) \cdot f$$

where

t = twist number/m yarn

Tdtex = linear mass of drawn yarn (dtex)

f = 1 for traditional process (type FDY)

f = 1,1-1,2 for simultaneous draw-texturization process (POY yarn)

The twist adjustment on the machine depends on the ratio between the peripheral speed of the friction disks and the yarn speed; this ratio, which is named D/Y, has typically values around 2,0.
The false-twist system with friction disks is at present the dominant process in the texturization scenario: it ensures the insertion of 2,000.000 t/min in a PES yarn dtex 167 and of up 8,000.000 t/min in PA yarns.

There are however also other interesting industrial processes which apply the friction principle for linear speed transmission. In particular a system in wide use, developed in Japan, makes use of a device with crossed belts; the yarn, when coming into contact with these belts, is submitted to a twisting action.

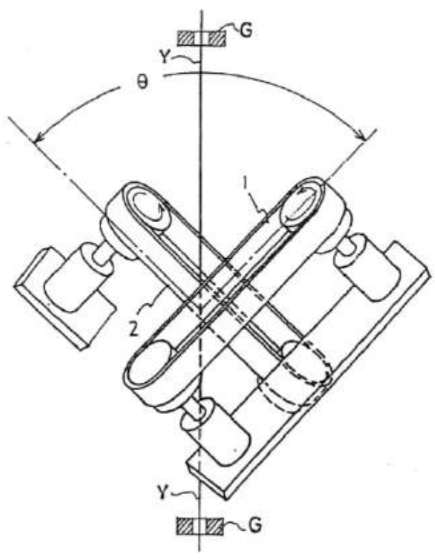


Fig. 61 Twisting with crossed belts

<u>Heating and cooling zones</u>
These zones are an integral part of the false-twist texturization process.
In fact, as already pointed out, the twisting action which the yarn went through in the false-twist group is transmitted to the preceding yarn path; the oven which is positioned in that zone makes filaments thermoplastic and is followed by a cooling track which blocks the twisting deformation.
With the increase of machine speeds, also these elements experienced substantial improvements. The primary oven is composed of a series of grooves or tubes which are arranged in blocks, through which run the single yarns and which have a variable length from 1 to 2,5 m about; these blocks are heated by resistors with heat exchange (Dowtherm) fluids, with higher temperature ranges, the shorter the permanence times of the yarn in the oven (times are function of processing speed and of oven length).
In traditional ovens, temperature may range between 160 and 250º for 2000 mm oven length and between 200 and 320º for 1400 mm oven length; in all cases, tolerances must be narrow and strictly controlled (±1°C inside the oven).
Recently high temperature ovens (through HT resistors) have been developed; these allow temperatures up to 500-600ºC with convection heating, which offers the advantage of reducing further oven lengths and of favouring the removal (by combustion) of deposits (finishes, polymeric remnants) originated inside the oven.

In any case, it is necessary to ensure to the delivered yarn, in the polymer softening zone, temperatures of 190-210ºC for PES, 190-205ºC for PA 6.6 and 165-175º for PA 6.
When leaving the oven, the yarn is cooled down along a path of variable length (1-1,5 m about) composed of tracks or of metallic plates; cooling takes place through natural circulation of room air or by active systems, like forced circulation of air, cold air or water. Yarn temperatures at the exit of the cooling zone (or at the feeding into the twisting aggregate) range between 70 and 100ºC, depending on the type and on the linear mass of the yarn and on the cooling system.
If a second oven is envisaged, this shall be shorter and have lower operating temperatures.

Draw-texturization
Until the 70's, the texturization required the use of fully drawn yarns (FDY) obtained from spinning-drawing carried out in two stages.
As soon as the spinning speeds increased (to 4000-5000 m/min), a partially drawn yarn (POY) became available, giving a substantial contribution to the expansion of the false-twist texturization technology.
In fact this yarn has excellent extensibility during texturization, thus permitting to complete the drawing on the texturing machine (drawing-texturization). The drawing operation (R= 1.2-1.7) can be carried out by means of rollers or drawing shafts during the first stage before texturization (sequential process) or directly in the texturing zone itself (simultaneous process).
This last system is at present the only one used both for PES and for PA.

Texturing machines
The machine manufacturer has as his primary target the construction of a machine which can assure a stable yarn path (without fluctuations) as well as low and controlled tensions in the zone included between the draft points situated before the first oven and those after the drawing unit, in order to attain high production speeds as well as a yarn with good characteristics in terms of elongation, tenacity, crimp and absence of broken filaments.
Owing to the considerable dimensions of the machine and to the necessity of assembling various cumbersome parts, very important are also the ergonomic characteristics of the machine in terms of compactness, accessibility, user-friendliness and maintenance.
Moreover it should be pointed out that, whereas guaranteed mechanical speeds reach 1500 m/min, technological speeds (processing speeds) are until now about two thirds of that figure (higher speeds than on PES can be obtained on PA).
Best performances as to productivity and quality require solutions which optimise yarn path, oven parameters (length, temperature), cooling system (active cooling means), effectiveness in false-twist insertion (twisting force, tensions, friction heat dispersion), take-up system, process continuous monitoring.
These machines are characterised by the presence of only one oven to produce false-twist (FT) yarns mainly in PA fibre, or by the presence of 2 ovens for the production of false-twist set (FTF) yarns, mostly in PES fibre and to a lesser extent in PA fibre.
Two-oven machines are in more common use and can of course work with FT process, excluding the setting in the second oven.
From the structural point of view, the machines can moreover differentiate on the basis of their profile which, in their usual configurations, recall the form of the letters H, M and V.
In the H configuration, the yarn path is almost straight (in the course from feeding device through oven and cooling, till twisting unit) with consequent low tension levels and less yarn damage, whereas in the M and V configurations the yarn meets angled points which increase tensions, but on the other hand can improve path stability.

A two-oven draw-texturing machine for several uses is composed of following parts:

- Multilevel creel for bobbins (up to 20 kg each)
- Thread cutter with sensor to detect and stop possible broken threads
- Feed shafts; in variable number (generally 3 or 4), they fix draft ratios through a yarn holding system (aprons)
- First oven: Dowtherm type (or HT type)
- Cooling zone: natural or forced systems
- Spindle group: centralized control or control on single positions
- Disk combination: variable (1-4-1 to 1-8-1) with polyurethane or ceramic disks (diam. 45 mm, H = 6 mm)
- Second oven
- Contact oiling device with rotating rollers dipping in cups containing the batching oil (quantity: 1-3%)
- Take-up: placed on several levels (3 levels) with bobbin formation (4-5 kg)
- Computerized machine control system: setting and control of the various process parameters

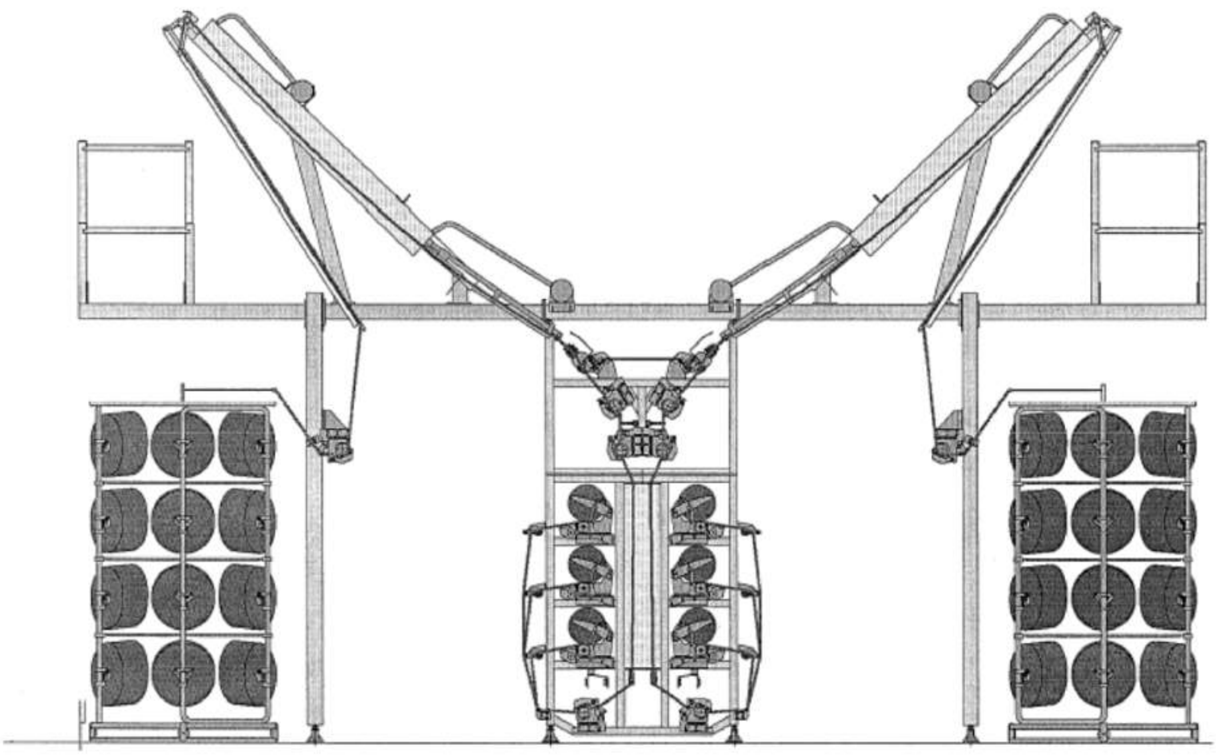


Fig. 62 Two-oven draw-texturing machine with "V" configuration and two independent sides. For FTF or FT processing of PA yarns dtex 11-110 and of PES yarns dtex 33-330

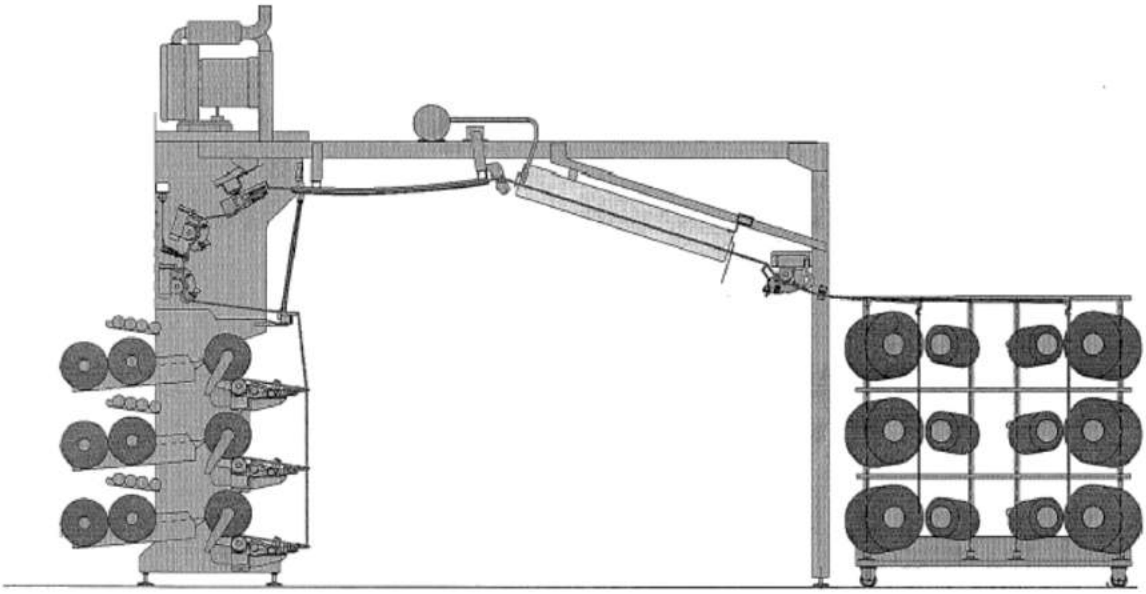


Fig. 63 One-oven draw-texturing machine with "H" configuration and two independent sides. For FT processing of PA yarns dtex 11-110

<u>Two-yarns twisting method (duo-twist method)</u>

This method falls within the systems based on thermoplastic deformation through twisting.

It is based on the principle of twisting a piece of 2 yarns coming from 2 feeding units, thermosetting the twisted yarn and then de-twisting it on a separating unit or winding them separately.

It is a process of scarce interest, suitable particularly for processing fine counts (also monofilaments) with a production speed of 600 m/min.

Thermo-mechanical processes with deformation obtained without twisting

These processes are not based on a principle of twist deformation, but on bending, curving, waving systems which produce yarns with different bulkiness/elasticity properties, but without any tendency to rotate on their own axis.

<u>Method with mechanical compression chamber</u>

In this method the yarn is forced, by 2 feeding rollers, into a heated crimping box and is submitted to a compression which generates planar bending points (saw-teeth type) on the yarn. The pressure inside the chamber is regulated by a device which permits the delivery of the yarn at a constant pressure.

The textured yarn which used such technology was marketed with the trademark Banlon (manufacturer: Bancroft); at present the process is no longer in use for textile yarns and has lost ground also for carpet yarns.

This principle found on the contrary wide application in the production of crimping boxes for tow and staple fibre (Fig. 18).

Air-jet compression chamber method

This method can be considered a development of previously described method: yarn compression is not exerted mechanically by feeding rollers, but is generated by an aerodynamic system with jets of compressed heated air or steam.

The warm gaseous stream under pressure enters into a lateral opening of the box, flows into the yarn guiding channel, pushes the yarn into the expansion box where it is brought to a softening temperature (plasticization) and is compressed; the result on the yarn is a three-dimensionally shaped bending.

The exhausted air gets out of leaks placed at the extremity of the box and the yarn is pushed out of the box.

In order to maintain the properties gained through texturization, the yarn has to be quickly cooled on perforated drums with air suction to a temperature lower than the glass transition temperature of the fibre. The yarn reaches the drum through rollers extracting the yarn which accumulated in the final part of the box, or which accumulates in a contact zone between box and drum (Fig. 64). The process is widely used for the production of carpet yarns in PA or PP according to BCF technology (Fig. 35).

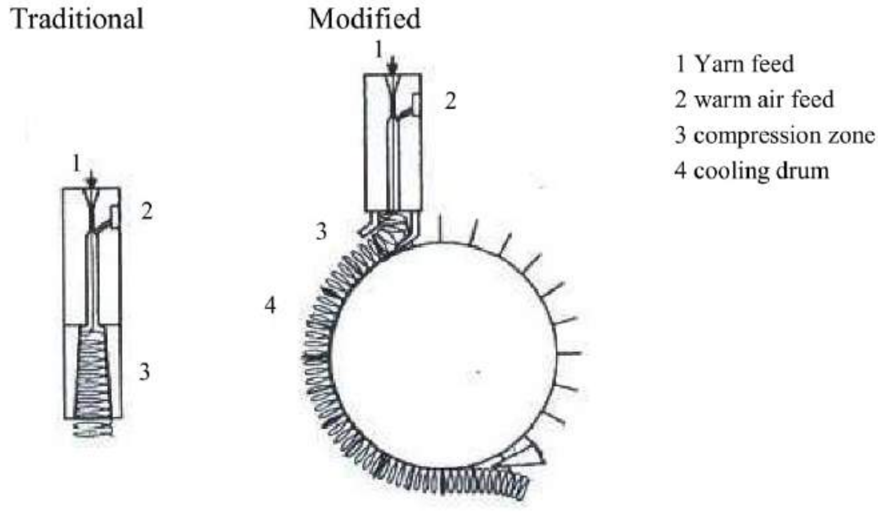


Fig. 64 Texturization principle by air-jet compression chamber

Knit-de-knit method

This is a discontinuous method which uses a knitting process on single-feed small diameter circular machine; the tubular produced is wound on a support and thermo-set by steam or straight during dyeing operation. The yarn is successively unravelled and wound on cones (speed: abt. 500 m/min). It shows a typical crimp, with wide planar waves of same length as the stitch.

Owing to its elasticity, this method finds specific uses, in particular in the case of nylon; the process is less suitable to polyester, owing to its poor crimp stability.

Blade method

The textured yarn produced with this process bore originally the mark Agilon (producer: Milliken), but at present the process is no longer in use, owing to the poor properties (low crimp stability) of the yarn.

After being submitted to direct heating on feeding rollers, the yarn is let to glide under tension on the rounded edge of a metallic blade with a certain bending angle and successively cooled on delivery rollers.
The filaments undergo a structural change due to a compression force exerted from the blade on their contact side and to the contemporaneous drawing force exerted on the yarn side situated on the outside of the blade.
The physical strains generate structural deformations in form of irregular three-dimensional waves.

Gear method
The yarn obtained with this process was known under the trade name Pinlon; nowadays this technology has negligible importance.
The pre-heated yarn gets through two heated toothed wheels (speed: up to 600 m/min), between which it is deformed and gets a flat waviness, assuming a geometry which is set by the profile of the wheel teeth.

Mechanical process
Air-jet method
The development of this process was promoted by studies carried out on the effects of compressed air on yarns (DuPont, 1952); this technology led on one hand to the development of intermingling systems (with intermittent binding points) for multifilament parallel yarns and on the other to the production of yarns with modified structural characteristics, which were originally marketed with the trademark Taslan (which originated the name "taslanized" given to these textured yarns). The principle is based on a jet of a pressurized air directed through a nozzle with a certain angle and turbulence level against a yarn going through the nozzle; the yarn is overfed in order to create a compression which has an intensity defined by the ratio between feed and delivery speeds and which affects the typology of the loops generated in the yarn.
The air-jet action operates in various phases:

- Filament opening at the beginning of yarn feeding into the nozzle.
- Creation of a whirl on the open filaments.
- Bending of the overfed filaments, with consequent generation of typical filament loops which tend to come out of the yarn core.
- entangling and setting of the crimped and wavy filaments into a bulky and soft yarn.

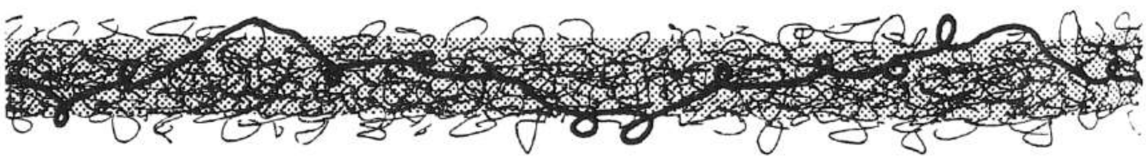


Fig. 65a Schematic illustration of the path and of the aspect of a filament within a taslanized yarn (path: see marked line)

The process can be considered as mechanical if the air jet is cold; the textured yarn obtained through a simple aerodynamic stress presents structural characteristics which are considerably different from those of a false-twist yarn (higher bulkiness, lower elasticity, similarity to traditional yarns).

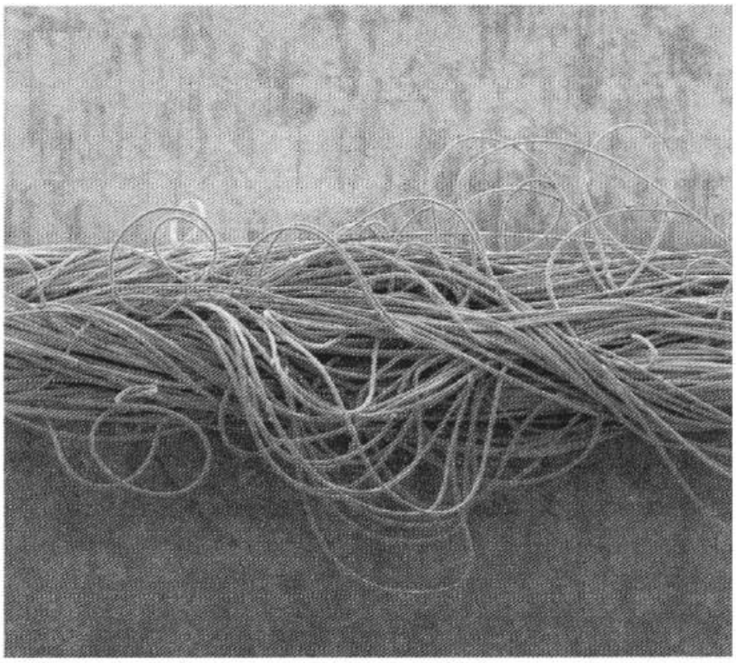


Fig. 65b PES 330 dtex taslanized yarn

The development of this technology is closely connected to the design of the air-jet nozzle.
Since its launch, several generations of nozzle have been developed, showing each time technological and qualitative improvements; process speed depends essentially only on air flow speed: the higher is the speed, the quicker is the process.
Initially process speeds of 50 m/min required 20 m^3/h of compressed air (which involves high energy consumption), while nowadays speeds of 500-600 m/min are attained with consumptions of compressed air (8-12 bar) limited to 5-6 m^3/h.

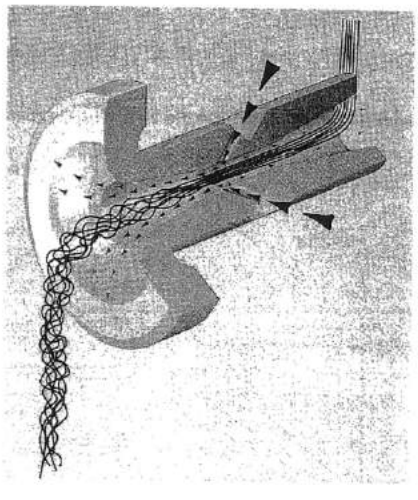


Fig. 66 Nozzle of the air-jet texturization system

As the texturization principle is not based on a thermoplastic deformation, but is purely aerodynamic, the process is not limited only to thermoplastic fibres, but can be extended also to other fibres as cellulose fibres and glass fibres.
Air-jet texturization ranks at present the second place and holds a 5% quote in the market of false-twist textured yarns.
Its application fields are extremely wide and cover following sectors:

- Upholstery and home textiles
- Car interior
- Sportswear and casual wear
- Sewing threads
- Items for technical and industrial uses

Air-jet texturization is at present less productive than false-twist texturization, which fact hampers economically its application for end-uses which require fine count yarns (that is, finer than 100 dtex).
Air-jet machines are mechanically derived from false-twist machines; besides the air-jet device, they are equipped with preliminary drawing zones (for POY yarns), ovens for loop setting after texturization, and humidifiers of the yarn at its introduction into the nozzle, to improve the efficiency of the texturing process.
A machine for universal use is composed of following parts:

- Multilevel creel for up to 20 kg bobbins
- Thread cutter with sensor to detect and stop possible broken ends
- Feed shafts in variable number, which fix draft ratios through a yarn holding system
- Fixed heated pins or heated godets, positioned in the drawing zone to heat the yarn
- Nozzles (air-jets), placed along with yarn humidifiers at the feed side
- Oven: Dowtherm heated oven (length: 100-1500 mm, operating range: 140-240ºC)
- Oiling device
- Take-up: through centralized system or with single take-up positions
- Computerized machine control system: setting and control of the various process parameters.

Thermo-chemical processes
These processes are intended for two yarn typologies:

- Bicomponent yarns, in which the single filaments are made up by two polymeric components with different thermal retraction levels. Further to a thermal treatment, they develop a three-dimensional spiral crimp.
  The two components must have a side-by-side (S/S) configuration or a skin-care (S/C) asymmetrical configuration.
- Bi-retractable yarns, composed of 2 groups of filaments with different thermal properties. This is not a process of effective texturization, as no deformations inherent to the single filaments are activated, but an effect of bulkiness is generated on the yarn as a result of different retraction levels among the various filaments.
  This principle finds anyway a remarkable application in the production of high-bulk (HB) acrylic yarns.

Properties of textured yarns
As already pointed out, textured yarns are characterized by higher extensibility, elasticity and bulkiness than flat yarns (fig. 67).

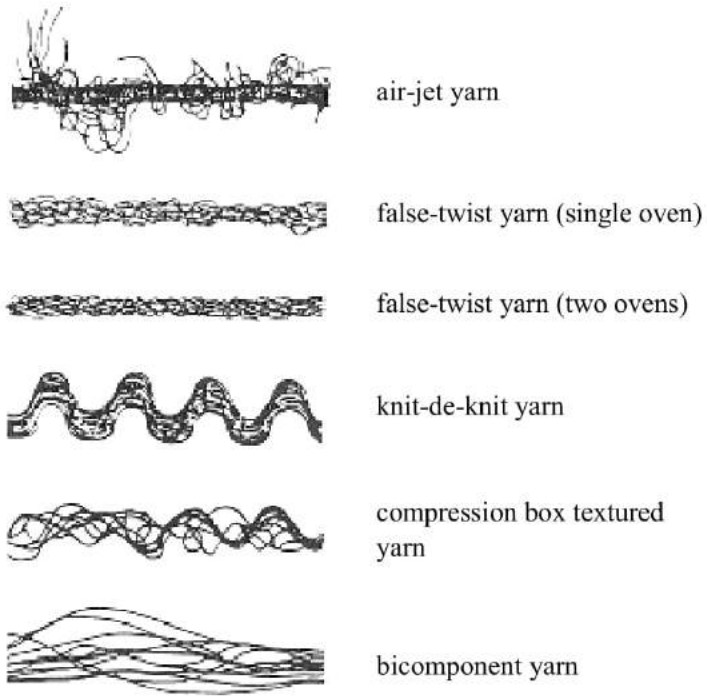


Fig. 67 Schematic longitudinal view of textured yarns

Among the various properties, generally assessed with methods similar to those used for other types of yarn, there is a method of particular importance and for specific use, termed <u>crimp contraction (or crimp elasticity).</u>

This property is essentially assessed on false-twist yarns and is defined as "the contraction of a textured yarn due to crimp development, expressed as percentage rate of the stretched out (not crimped) yarn length".

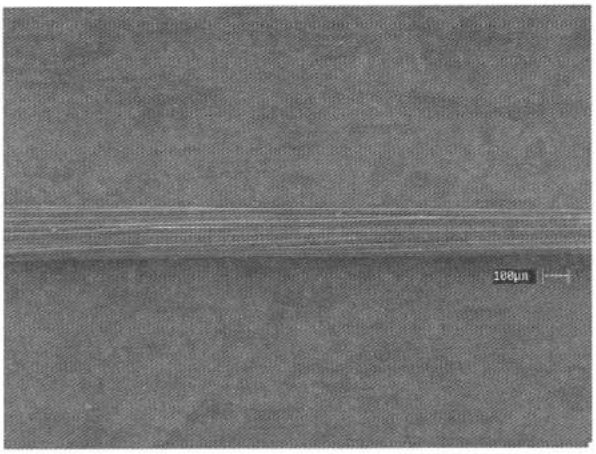
There are several procedure variations, but all of them involve following operational phases:

- preparation of hanks composed of a certain number of windings.
- Latent crimp development in thermal means (water, air).
- 1st measurement: length of stretched out hank L_0 (stretching pre-tension).
- 2nd measurement: length of the crimped hank L_1 (contraction pre-tension)
- expression of crimp contraction as $(L_0 - L_1)/L_0 \cdot 100$

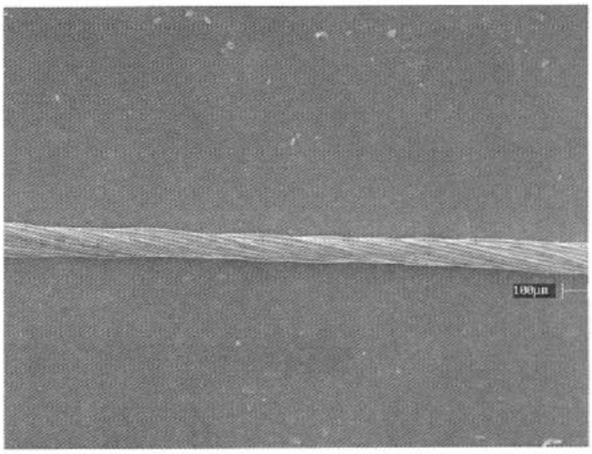
Let us mention some of the most used methods:

<u>Heberlein method</u>

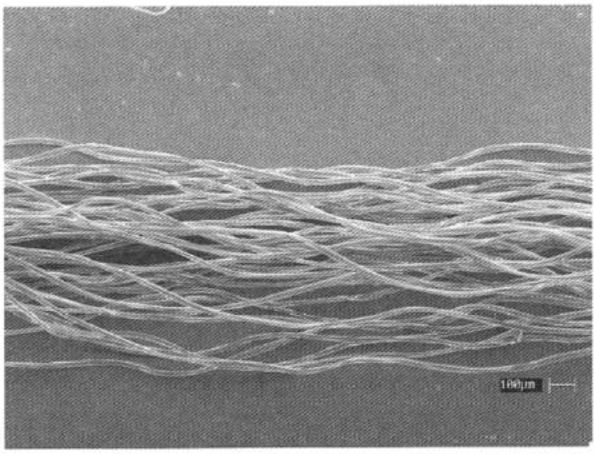
- 10 m hanks (10 windings) with 1 cN/tex winding tension
- crimp development in water at 60-70ºC for 10 min in the case of PA and in boiling water for 15 min in the case of PES, with subsequent drying
- 1st measurement on wet hank (at 60ºC) under 1,8 cN/tex preliminary tension for 1 min (L_0)
- 2nd measurement on dried (60ºC x 60 min) and cooled (60 min) hank under 0,018 cN/tex preliminary tension for 1 min (L_1)
- $KK = (L_0 - L_1)/ L_0 \cdot 100$



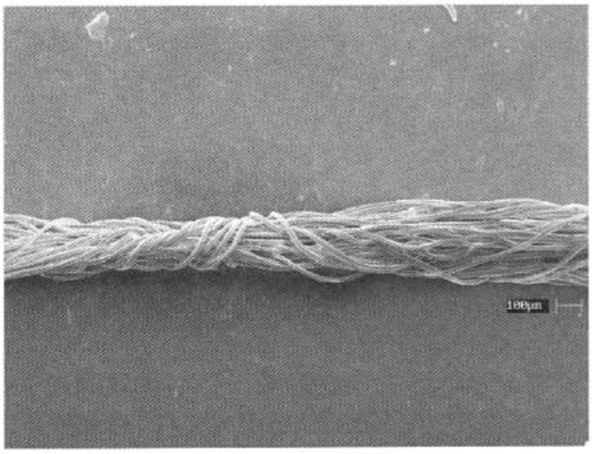
1) Untwisted flat yarn dtex 78/24



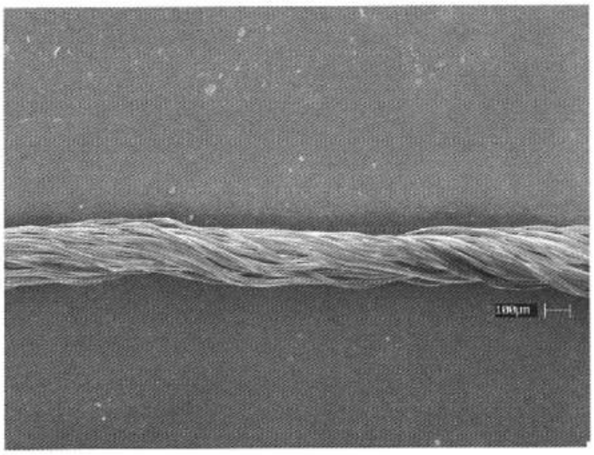
2) Twisted flat yarn dtex 78/24/800Z



3) FTF textured yarn dtex 167/48

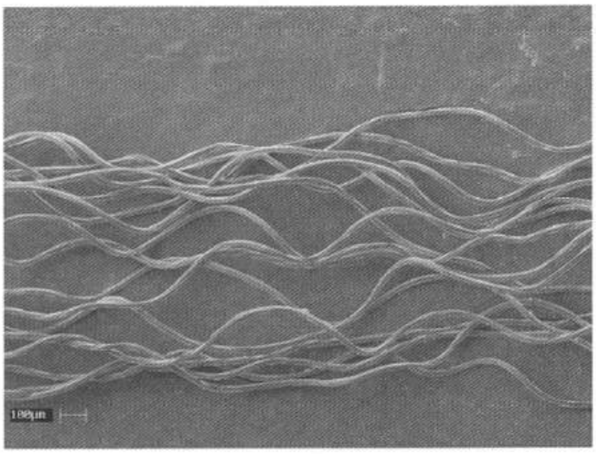


4) Intermingled textured yarn dtex 167/48

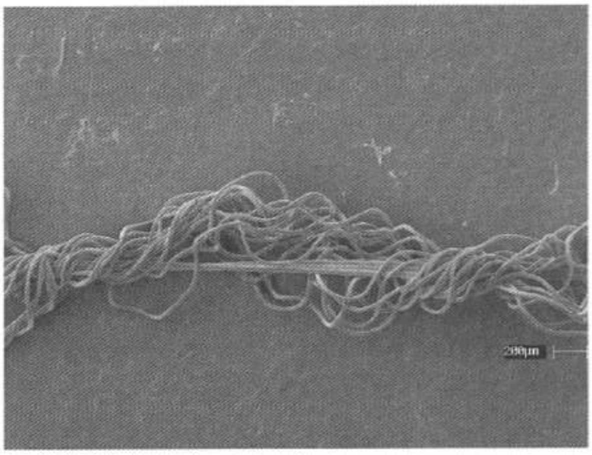


5) Textured twisted yarn dtex 167/48/480Z

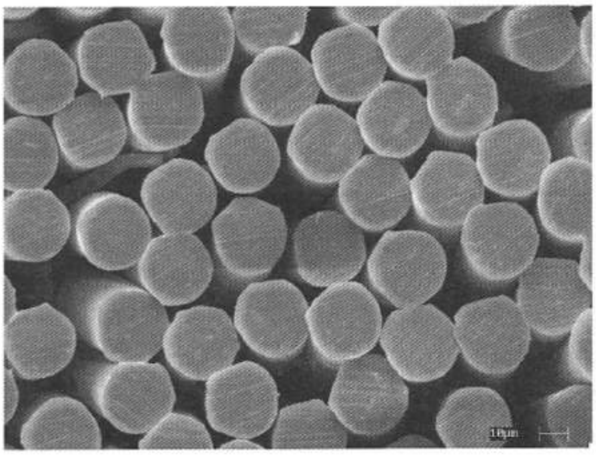
Fig. 68 Various typologies of multifilament polyester yarn (SEM microphotographs)



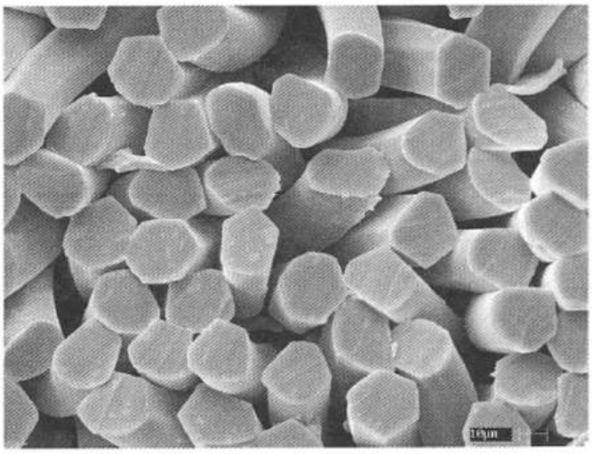
1) FT textured yarn dtex 78/17



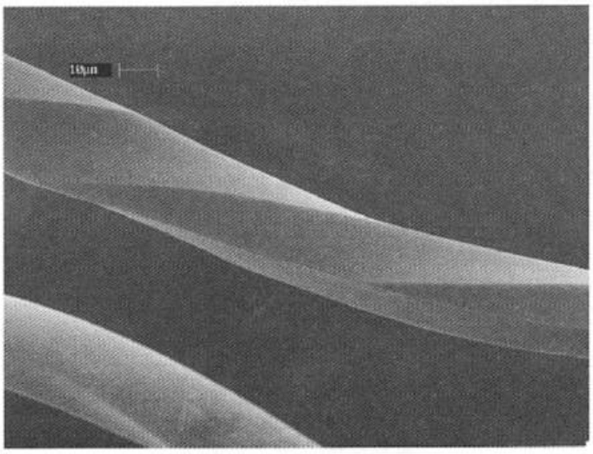
2) FT covered yarn PA dtex 78/17 + EL dtex 44



3) Cross-section of flat yarn



4) Cross-section of FT textured yarn



5) Longitudinal section of FT textured yarn

Fig. 69 Multifilament polyamide yarn (SEM microphotographs)

BISFA method

- Hanks with 2500 dtex global linear mass (fil.count ≤ 200 dtex) with 2 cN/tex winding tensions
- Crimp development in oven-heated air at 120°C for 30 min (PA, PES) and cooling in standard room conditions for 12 hours
- 1st measurement under 2,0 cN/tex preliminary tension for 10 min (L_0)
- 2nd measurement under 0,01 cN/tex preliminary tension for 10 min (L_1)
- Calculation: $E = (L_0 - L_1)/ L_0 . 100$

On the basis of the crimp contraction values, the yarns can be divided into:

- Yarns with high elasticity: E = 35-50%
- Yarns with medium elasticity: E = 25-35%
- Yarns with low elasticity: E ≤ 25%

Another parameter related to crimp contraction is crimp stability S, which defines the percentage crimp ratio between the yarn after mechanical stress and same yarn before stress:

S = (Crimp contraction after stress / crimp contraction before stress) • 100

Twisting

The scope of this operation is the insertion of twists into already formed yarns.
In the case of mono- and multifilament yarns, twisting is applied both on the single components (ends) and on several components doubled together; in the case of yarns, it is referred only to yarns with 2 or more components (throwing), as twist insertion into single yarns is an operation automatically involved in yarn formation (spinning).
The term twist defines the helicoidal or spiral configuration originated by the rotation of a yarn or of a fibre bundle around its longitudinal axis.
The properties related to twist are:

- Twist intensity or twist level, which is the twist number per length unit and is usually expressed in turns/meter (t/m)
- Twist direction, which indicates the inclination of the filaments in respect to the longitudinal axis and is expressed as follows:
  - type S twist: filament inclination from top left to bottom right
  - type Z twist: filament inclination from top right to bottom left

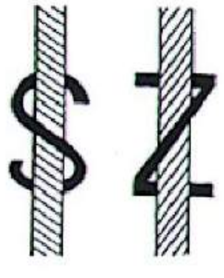


Fig.70: Twist direction

Twist coefficient α, which is connected with twist intensity and linear mass and, in the case of tex system, takes the form:

$$\alpha_{Ttex} = \frac{t}{100} \sqrt{Ttex}$$

where:
t = t/m
Ttex = linear mass in tex

The twist inclination angle towards the longitudinal axis depends on twist and on yarn diameter as per following relation:

$$t = \frac{\tan\theta \, 1000}{D\pi}$$

Where:
θ = inclination angle
D = yarn diameter in mm
t = turns/m

Yarn twisting may have several purposes:

- to improve dynamometric properties (tenacity, elongation, modulus of elasticity) and regularity
- to reduce the tendency of textured yarns to rotate on their own axis and to form loops
- to improve abrasion and wear resistance
- to modify structural properties affecting tactile characteristics (touch) and appearance (crêpe effect, covering power, lustre)
- to improve processing yields by replacing in some cases operations like sizing

The function of twist as simple filament protection is largely replaced by the intermingling operation in which compressed air is blown through nozzles against the yarn, thus producing entanglements in the filaments and formation of cohesion points (false knots); this operation is applied on flat untwisted yarns, both drawn (FDY) and not drawn (POY) and on textured yarns.

Typical twist values which can be found on single yarns of continuous filament are:

- 10-20 turns/m on draw-twisted yarns (cops)
- 160-800 turns/m for weaving and knitting use
- 300-500 turns/m for technical/industrial uses (cord)
- 2000-3000 turns/m for crêpe yarns.

DENOMINATIONS AND REPRESENTATIONS OF SOME YARN STRUCTURES
(according to UNI standard No. 6699-70)

- Twisted single yarn: continuous filament yarn with only one component (yarn end), on which a twist is applied

Example:

Representation — conventional definition

in figurative form — in schematic form

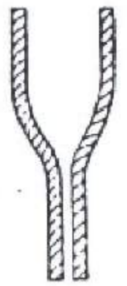
150 dtex f30 Z 300

- Doubled or plied yarn: yarn in which two or more components with same or different characteristics are doubled together without any twist

Example:

Representation — conventional definition

in figurative form — in schematic form



200 dtex f50 Z 400 x $2t_o$

- Simple-twisted yarn: yarn in which two or more components with same or different characteristics are joined together through only one twisting operation

Example:

Representation — conventional definition

in figurative form — in schematic form

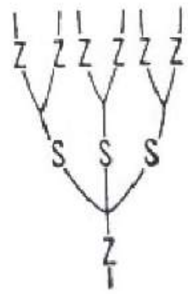
200 dtex f50 Z 400 x 2 S 300

- Composite-twisted yarn: yarn in which two or more components with same or different characteristics are joined together through two or more twisting operations

Example:

Representation — conventional definition

in figurative form — in schematic form



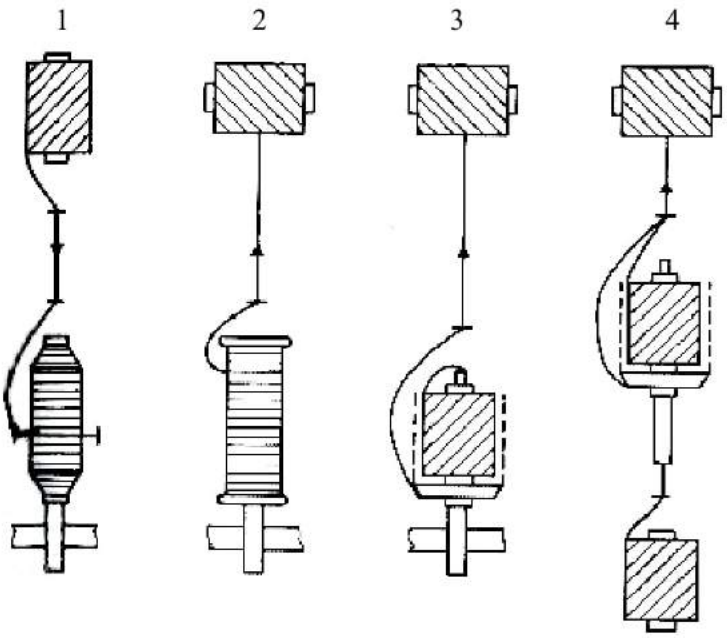
200 dtex f50 Z 400 x 2 S 300 x 3 Z 250

In the commercial practice, yarns may anyway be identified with particular denominations based on typology, composition, structure and application sector.

Twisting technologies

Twisting technologies are based on several working principles.

According to the two classic traditional technologies, twist insertion requires the rotation of the yarn package around its own axis: if the rotation concerns the package in feed position, the twist is applied in upwards direction (up-twisting), whereas if the rotation concerns the delivery package, the twist is applied downwards (down-twisting).



1 ring twisting
2 twisting with rotating feed package
3 double twisting
4 direct twisting

Fig. 71 Twisting principles

Ring twisting

This is a classical "down twist" process, which uses the same principle used in ring spinning, i.e. a ring.

The yarn coming from a fixed feed unit in upper position runs downwards and is taken up by rotating spindles through a ring/traveller system.

The feeding bobbin remains stationary, while the receiving bobbin rotates and imparts twist to the yarn.

Yarn twists are correlated to the angular velocity of the traveller, which runs slightly late in respect to the angular velocity of the spindle, in order to permit winding the fed yarn on the package (bobbin) under formation.

The relation between the various parameters is the following:

$$n = n_o - \frac{V}{2\pi R}$$

where:

n = traveller t/min.

n_o = spindle t/min.

V = yarn feeding speed (m/min)

T = radius of bobbin under formation (m)

Consequently:

$$T = \frac{n_o}{V} - \frac{1}{2\pi R}$$

Where:

T = yarn t/m

The differences between n and n_0 are negligible (that is the term $V/2\pi R$ is negligible) and anyway by unwinding the yarn from the bobbin in axial direction (overhead unwinding) this difference is compensated, so that twists are the result of following equation:

$T\ (t/m) = n_o/V$

Twisting tensions depend on traveller type (geometry, material) and weight, besides from spindle rotation speed and from ring diameter/ bobbin diameter ratio; anyhow ring twisting is considered to generate a "stiff" torsion, which is particularly suited for technical uses.

Twisting with rotating feeding device

This "up-twist" process is based on the rotation of the feeding package and on the take-up on stationary bobbin (the rotation of the take-up device has only the function of winding the yarn on the package).

The yarn is drawn out tangentially from the balloon of the rotating bobbin and assumes twist in axial direction along a path which, through a thread-guide, winds it on the take-up bobbin.

Process tensions are essentially controlled by the balloon and the resulting yarn presents a "soft twist; inserted twists are the result of following equation:

T(turns/m) = spindle speed (turns/min)/ yarn take-up speed (m/min)

Double-twisting

This technique permits to overcome the limit of the two before mentioned twisting principles, imposed by the necessity of rotating at least one yarn package in order to impart the twists: in fact in this case both the feeding package and the take-up bobbin remain stationary, while the only moving element is the balloon of the yarn wound on the feeding package.

The double-twist principle (two-for-one-twist) is based on the principle that a piece of yarn, after U-bending and rotating around one of the two straight strokes constituting such letter, gets a first torsion in the descending segment and a second torsion with same direction in the ascendant segment. Practically, in the twisting machine the yarn, while unwinding from the stationary package, passes through the spindle axis from its top, comes out of a hole placed at the bottom of the spindle and re-ascends outside the package until it passes through a pig tail guide and then continues its path till reaching the take-up head.

The double-twist process, which was launched in the 30's for some specific applications in the industrial sectors (tyre cords), became in these last decades widespread in various textile applications, largely surpassing above mentioned traditional methods.

In fact this process offers two remarkable advantages:

The insertion of a double twist related to spindle speed according to the formula:

T (turns/m) = spindle speed (turns/min)/take-up speed (m/min).2

The possibility of using feeding packages having considerable mass, as they are static masses not subject to rotating actions; this permits to increase further spindle speeds by lower energy consumption.

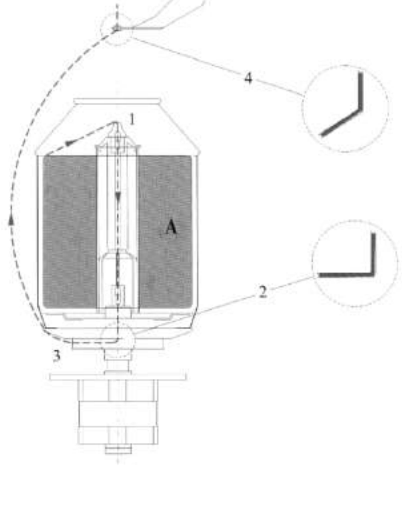
From a mechanical point of view, very important is the study of the balloon of the yarn winding the package, which through a magnetic field is maintained static on a moving system.

A multipurpose double-twister for continuous filament yarns (both flat and textured) has generally a double-deck structure with two faces and offers the possibility of mounting different spindle types with different gauges both for cops and for bobbins.

The yarn is guided by an overfeeding roller to the take-up aggregate, which consists of traverse motion box (thread guide), transmission roller, take-up stand (usually on bicone bobbins).

Furthermore the machine is equipped with monitoring system for the working parameters.

Indicatively, machine speeds can reach 16.000 t/min with take-up speeds up to 200 m/min and processing yarn range from 33 to 560 dtex and twists from 30 to 2800 t/min.



A package
1-2 first twist
3-4 second twist

Fig. 72 Principle of double-twisting process

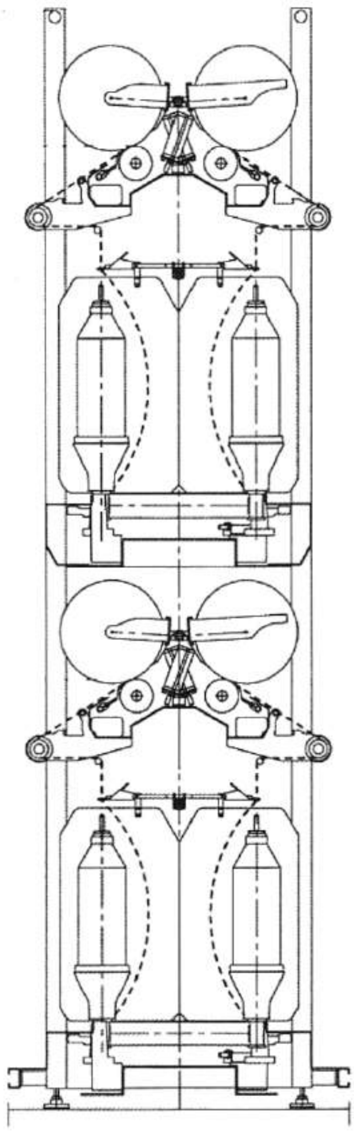


Fig. 73 Two-tier double-twister

Direct twisting
This is an innovative process, also called direct cabling, which permits to obtain two-component twisted yarns starting directly from parallel continuous filaments wound on two stationary packages.
The mechanical configuration is somehow derived from the double-twister and the process develops as follows:
A yarn (outer yarn or balloon forming yarn) coming from an outer bobbin is conveyed to the lower part of the axis of the hollow spindle; a second yarn (feeding yarn) comes directly from the bobbin housed in the static spindle basket, from which it is unwound in axial direction.
Through spindle rotation the outer yarn, while coming out of spindle basis, creates a balloon which closes on the adjustment device ((throttle) in the combination point with the feeding yarn, where twist is generated.

To obtain a perfectly symmetric twisted yarn, it is essential that the two starting yarns join together in the twisting point with equal tension and feed levels, in order to avoid structural unbalances which are termed, owing to their aspect, as "corkscrew" effect.
In the course of the process, the feeding yarn does not get any twist(excluding twists due to axial unwinding), while the outer yarn is subjected to false-twist action resulting from spindle rotation (which generates a twist in one direction) and from the twist produced on the twisted yarn (twist with equal intensity, but in opposite direction).
The consequence is that the yarn obtained with such process presents a very particular structure: the two ends are twisted one around the other but not on their own axis, with the filaments of each yarn end in parallel position and perfectly oriented along the yarn axis.
Under this point of view, direct twisting can be defined as the operation which maintains unchanged in the assembled yarn the morphology of the single components.
Direct twisting, owing to quality and productivity reasons, tends to replace, in the production of tyre cord and of industrial twines, the traditional two-stage technique made up by the twisting of parallel single yarns and by a subsequent throwing (of 2 or more doubled yarns) with same number of turns in opposite direction.
The twists imparted to the yarn are the result of the ratio between spindle speeds (t/min) and take-up speed (m/min): the machines can work at 10,000 t/min with feed/take-up bobbins weighing up to 10-15 kg; the yarn counts used for technical uses range from 940 to 2100 dtex, the inserted twists from 150 to 600 t/m.

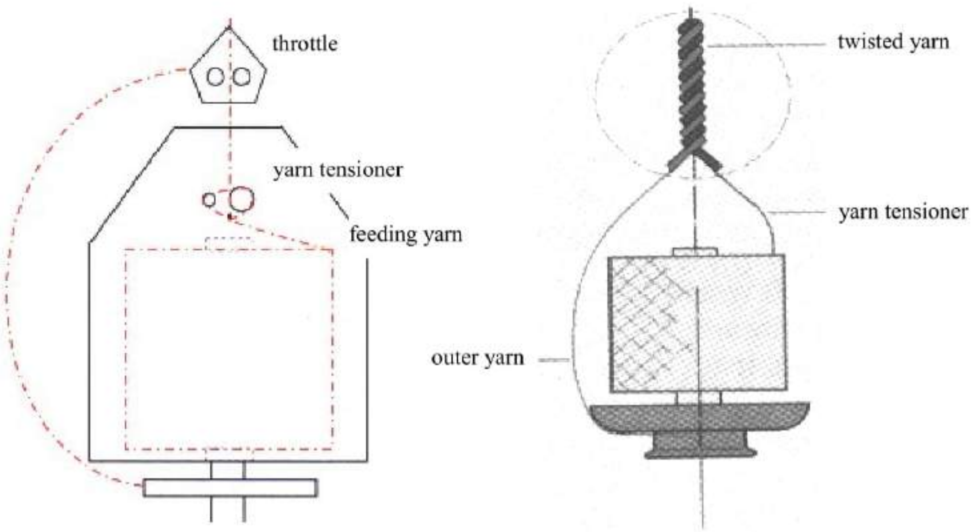
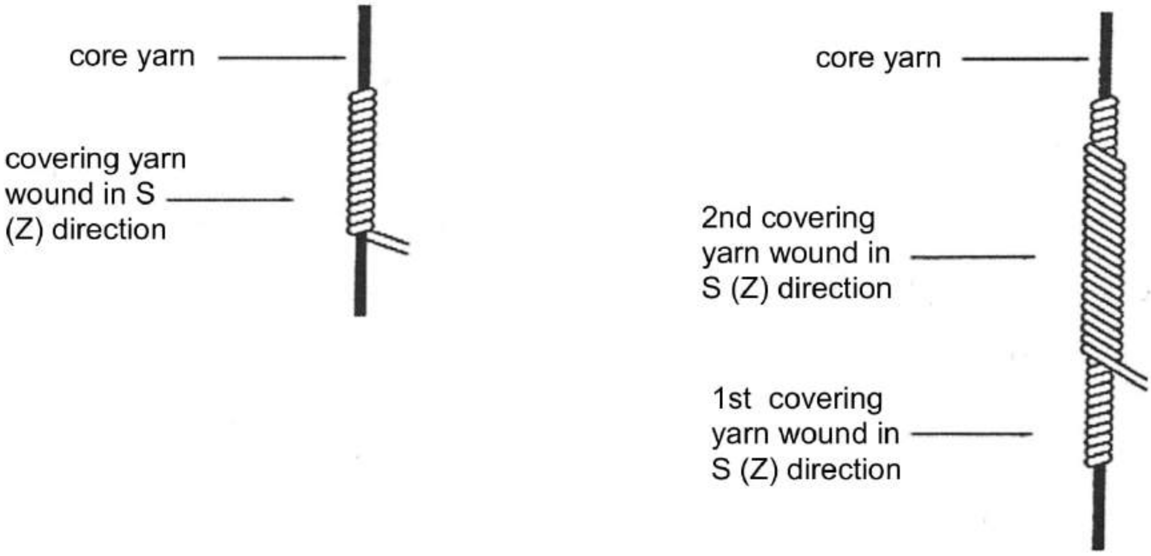


Fig. 74 Principle of direct twisting

Yarn covering

Yarn covering or wrapping is a process which winds one or more yarns (sheath) around another yarn (core) without imparting any twisting effect.
It can be of two types: single-covered (core + textile yarn) wound in S or Z direction (Fig. 75a) or, to ensure a perfect twist balancing, double-covered (core + two textile yarns wound in opposing directions (Fig. 75b)).



a) Single covered yarn *b) Double covered yarn*

Fig. 75 Yarn covering

This operation can have different purposes:

- Protection and improvement of the mechanical characteristics of the core yarn (resistance to abrasion and to tensile stress)
- Modification of the structural properties in relation to tactile (touch, softness, bulkiness) and optical (colour effects) needs, for instance in case of production of fancy yarns
- Control of core elasticity, in the case of elastane yarns.

Covered yarns belong to a more generic yarn class of corespun yarns, generally composed by an elastane core and by sheath yarns of different nature wound with various techniques (see: "Elastane" chapter). Out of these techniques, only hollow spindle throwing (used for doubled cotton yarns) makes use of same principle of covering machines.

The operation principle is the following:

The core yarn coming from a feeding bobbin is made pass, under a precisely set tension, through the perforated axis of the spindle and wound on tubes. At the same time the spindle is rotated with a package of covering yarn, which winds like a spiral the passing core yarn.

Machine configuration may envisage only one operating spindle, in which case a single covering (S.C.) is carried out, or two spindles in series and with axial ranging, in which case we have a double covering (D.C.).

Some sectors which find important applications (ladies' stockings and panty-hoses, welts of men's socks, elastic fabrics, bandages, laces) use covered yarns composed of elastane core yarn and textured covering yarn; another sector of great interest is that of fancy yarns, where the core can be composed of rigid yarns.

A typical process for the production of elastane-covered yarns is divided into following phases:

- Positive system (roller device) for the unwinding of the elastomer yarn from the package.
- Preliminary drawing zone controlled by a feeding unit with grooved disks. Preliminary drawing is usually envisaged for yarns with a linear mass over 156 dtex (ratio 1,3 approx.).
- Lower spindle or 1st spindle /S or Z twist) with variable speeds (27,000-12,000 t/min) depending on the weight of the flanged bobbin (300-1000 g related to linear mass). The S.C. yarn results unstable and has tendency to become curly.

- Upper spindle or 2nd spindle (in the case of D.C. yarn, twist direction is the opposite of the one of 1st spindle). In order to obtain a balanced yarn, it is necessary that twists (speeds) of 2nd covering are lower (20-30%) than those of 1st covering; in fact 2nd covering takes place on a yarn of larger diameter and the balancing is obtained only when same yarn quantity has been wounded.
- Drawing or tensioning: this operation produces the main draft of the elastane yarn. It is carried out by feeding units with grooved disks or by rubber rollers as balance weight. Depending on linear masses, the total draft ratio (preliminary draft + main draft) may vary from 3 (with fine yarns 10 dtex) to 5,8 (with coarse yarns 300 dtex).
  The number of windings per linear meter of core yarn depends on the rotation speed of the spindles (t/min) and on the transition speed of the core yarn (meters/min)
- Take-up on bobbins (max. speed 60 m/min) with cylindrical or also conical tubes. A decisive role for the subsequent processes is played by the perfect winding conformation of the winding, which has to show long and crossed pitch and tapered borders.

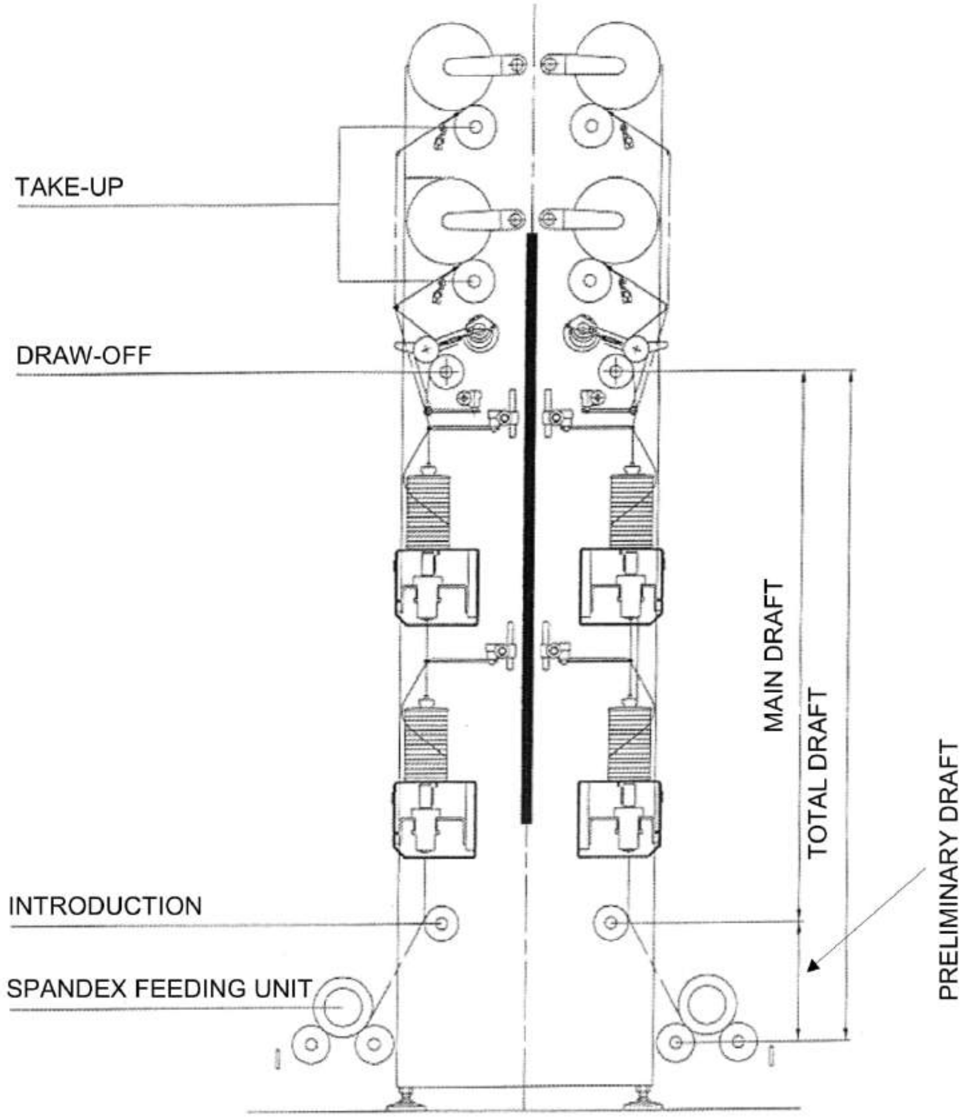


Fig. 76 Scheme of a covering machine with double or single covering working on both sides.

The linear masses of the covering yarns (PA, PES) for the production of ladies' hosiery, support hoses and welts of men's socks, range between 8 and 110 dtex, while linear masses of elastane yarns range from 10 to 450 dtex; twists applied (in case of ladies' stockings) range from 600 to 1800 t/m for S.C. yarns, while total twists for D.C. yarns range between 1800 and 2500 t/m (S + Z).

Twisting + texturing in a single phase

Among the various types of twisted yarns, particular significance have those characterized by a high number of twists (2000-3000 t/m).

These yarns, which are known as crêpe yarns and were originally developed for the silk industry, are distinguished by characteristics which provide the fabrics with peculiar properties, both tactile (springy and stiff touch, crease resistance) and aesthetical (lustre and silky appearance).

The polyester yarn (linear masses 44 to 78 dtex with medium fine filaments) is notoriously one of the most popular man-made fibres, therefore we deemed it opportune to describe hereunder as an example a process related to this fibre.

The traditional process consists of two phases:

- Twisting with double-twister under operating conditions like size of feeding/take-up packages and machine regulations suited to produce a yarn with good crêpe effect, free from irregularities and wound on bobbins of uniform form and density.
- Twist setting: this operation, which is aimed at thermosetting yarn twists, is absolutely necessary in the case of twisted yarns with unbalanced structure. It is a delicate process which is carried out by submitting bobbins in an autoclave to vacuum-steam cycles (at 120°C); it is of primary importance that the thermal action develops uniformly on the whole yarn package, in order to avoid dyeing unevenness caused by affinity irregularities and by residual thermal retraction of the fibre.

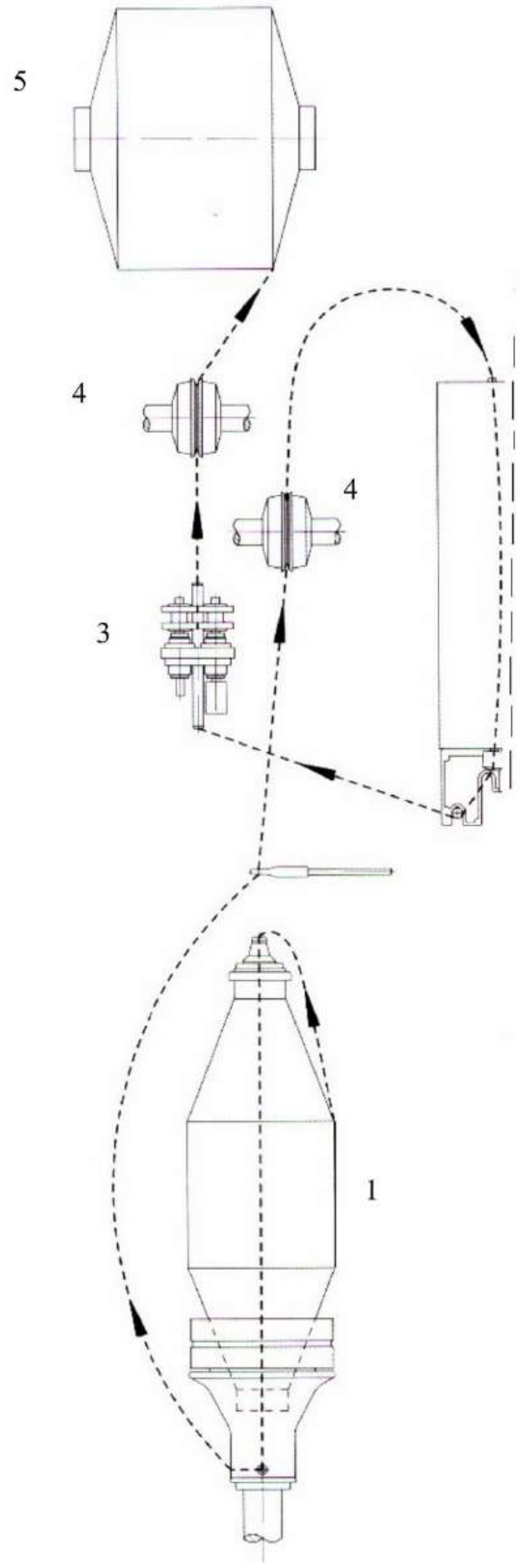
A recently introduced alternative method permits to produce yarns with characteristics similar to those obtained with the traditional method (the objective is imitating silk crêpe items) and consists in submitting the yarn to a continuous process including following phases: twisting, thermosetting, texturization.

The machine is composed essentially by following aggregates/working phases:

- Twisting on a double-twister on cops.

  The twist to be applied on the yarn is lower (600-1500 t/m related to linear mass) than the typical twist of traditional crêpe yarns.
- Ceramic disk feeders with tension control, placed on two shafts, one of which for texturization machine feeding and the other for the take-up.
- Heating oven with diathermic oil (200-220°C).
- Texturization units with false-twist spindles on magnetic bearings (speed 200,000-250,000 t/min, twists 2700-3900 t/m). It is noteworthy that in this case an outdated false-twist system is used; this is due to the fact, that the friction system is not suited to above said operation.
- Oiling system
- Take-up aggregate with up to 3 kg bobbins.

Besides running the whole process, the machine can operate also as simple twisting machine (bypassing oven and spindle), or as twisting and thermosetting machine (bypassing only the spindle).



1 – Twisting
2 – Oven
3 – False-twist spindle
4 - Feeders
5 – Take-up on bobbins

Fig. 77 Scheme of yarn path in the twisting-texturing machine

Production of discontinuous fibres

The processing of man-made fibres on traditional spinning systems requires the production of fibres of definite length which are also named, depending on their length, "short staple" fibres in the case of fibres for cotton spinning system and "long staple" fibres in the case of fibres for worsted or woollen spinning.
Staple fibres are obtained from the semi-finished product (tow) through processes which obviously have no precedent in the processing chain of natural fibres.

Tow conversion into staple fibre
This process, which is by far the most used and is generally placed in the final stage of the fibre production lines, employs mechanical cutting devices, named "staple cutters".
With the time, various fibre cutting systems have been developed, but only few are now still operative, at least for the production of standard staple fibre for textile use.

"Lummus" staple cutting machine
The operating system of this machine, although based on a simple principle, is in a position to ensure cost-effective performance and good product quality, which led this technology to a widespread application.
Cutting takes place by compressing the filaments against blades placed perpendicularly to the longitudinal axis of the fibres.
The tow, which is properly stretched in order to line up the filaments and to remove crimp, is fed to a wheel, on which outer border knife blades are radially fixed. While rotating, the tow winds up around the wheel blade and comes into contact with a pressure roller placed outside the tow. With the increase of the windings number and consequently of tow thickness, the sliver is pressed by the pressure roller until the internal filament layers are cut by the blades which face them and are discharged downwards in form of staple fibre.
The cutting process continues in a way as to maintain constant the thickness of the tow wound on the wheel. The fibre length is brought about by the distance between the knives; the cut is uniform, unless problems of excessive wear or blade damages arise (Fig. 78).

a) Tow
b) Tow tensioning device
c) Cutting wheel
d) Knives
e) Pressure roller
f) Staple fibre

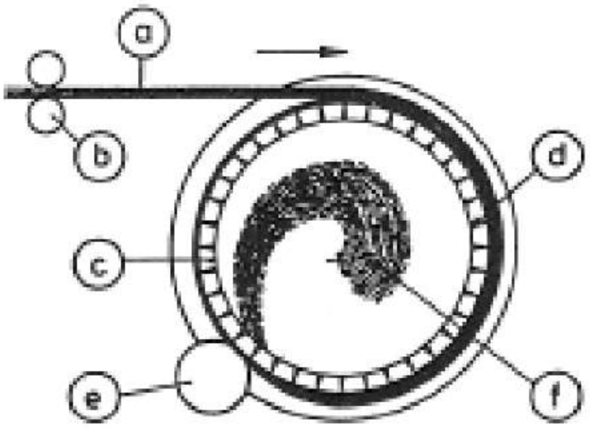


Fig. 78 Cutting principle of "Lummus" staple cutter

"Gru-gru" staple cutting machine

„Gru-gru" is the name of a cutting system composed of rotating blades, which cut the fibre cable gliding perpendicularly to them and retained by some clamping points.

The device consists of two adjacent wheels, placed on horizontal parallel axis and provided with gummed teeth separated by empty spaces.

Between the wheels, which rotate in opposite direction, the strained tow is fed from the upside and is clamped by the holding points constituted by the wheel teeth; at the same time a wheel with rotating blades moves transversely to the tow flow and, while passing through the interstices, cuts the filament bundle clamped between the wheel teeth.

The fibre length (staple length) corresponds to the distance between the interstices,(that is to the distance between the teeth).

This process, which finds limited application, presents some limits due to the quick wearing out of the knives (with consequent frequent need of replacement) and to an irregular cut deriving from a not perfect hold of the fibres between the clamping points.

The cutting machines must be capable of operating in line with speeds (up to 200-300 m/min) and linear masses (up to $3\text{-}4.10^6$ dtex) envisaged by tow production lines.

The length of the produced fibre tufts must cover the requirements of the various fibre processing sectors; in fact in the case of traditional spinning systems it ranges between following values:

- 28-40 mm for traditional cotton spinning system
- 40-60 mm for modified cotton spinning system
- 60-80 mm for carded (woollen) spinning system
- 80-120 mm for worsted (woollen) spinning system
- 120-200 mm for semi-worsted (woollen) spinning system

The quality characteristics of a staple length must meet strict tolerances in terms of deviation from the nominal cut length (both as average value and as variation coefficient), of absence of long staple fibres (e.g. >20% against the normal level) and of double or multiple cuts.

The presence, even if in minimal percentage, of fibres with anomalous length in the bales to be processed on cotton spinning system can seriously jeopardise spinning behaviour and limit the quality of the production.

These anomalous fibres originate in the cutting stage from an irregular tow conformation (filament bundles protruding from tow core) or from defects of the cutting machine (damaged or lacking blades).

Fibre tufts are usually characterized by fibres of same length (square cut); should it be needed by subsequent processes, staple tufts of different square cuts may be suitably blended together in order to get a staple with variable cut length.

Tow-to-top conversion

This term defines the direct transforming of a cable of continuous filaments (tow) into a sliver of discontinuous fibres (top).

During this operation, fibre alignment does not get lost, on the contrary of machine cutting in which tow filaments are cut and placed in bulk into the bale (staple fibre). This technology is de facto limited to the woollen spinning system, which requires the use of fibres with variable fibre diagrams (similar to wool).

Tow-to-top stretch breaking technology

This technology is based on a simple principle, which consists in drawing gradually the tow in a controlled way until the breaking point of the fibres is reached; this breakage takes place within operating zones (drafting zones) composed of a series of drafting assemblies which originate a sliver with triangular-shaped fibre diagram, also called "shoe" diagram owing to its typical form.

This process finds its optimal application in the processing of acrylic fibre, in view of its inherent characteristics which make this fibre ideally suited to its application for particular end-uses. The acrylic fibre is in fact characterized by a relatively low breaking strength compared to other fibres (as PES and PA), which fact permits the use of a tow with very high linear mass; moreover it has propensity to deform under stress (particularly in warm conditions), maintaining this deformation in a metastable (retractable) state till a subsequent thermal treatment, which restores the original state of the fibre (i.e. set or retracted).

Thanks to this peculiarity, the fibre finds an important application in the production of yarns composed by shrinkable and set fibres(HB or High Bulk yarns) which, owing to the differentiated retractions, are in the position to develop a high bulk after a thermal treatment.

The production lines are generally composed of 2 passages: a stretch breaking machine and an integrated drawing frame.

For some types of production (big lots, mixtures of several fibres, dyed fibres), the line may considered a third passage made up by a simple pin drafter.

The line with two passages includes following machines:

Tow-to-top stretch breaking machine

This machine operates only on one side and the tow path is of linear type (on a single level – see Fig. 79) or develops on two levels. It is composed by following units:

- Feeding creel:
  The tow (1 or 2 tows) reaching the machine
  must be regular, centred, open and stretched,
  without entanglements and distortions.
  This result is ensured by opening and guide devices and requires a sufficiently long tow path so that the material coming from the bales (placed before or after the machine body) arrives from above at the feeding point after passing through a series of bars mounted above the machine.
- Modules for preliminary drawing, drawing and stretch breaking

The considerable linear mass of the tow requires drawing heads of adequate strength and hold, composed of cylinder aggregates with different conformation and coupled with pressure rollers.

The first draft zone (length 1,5 m approx.) is characterized by the presence of 2 plates with adjustable heating temperature, which heat the fibres running through, thus favouring their capability of being drawn. The applied draft must only extend the filaments, without causing their break.

The temperature attained by the fibre (normally higher than glass transition temperature) and the draft ratio originate the final retraction of the fibre.

The second draft zone (long draft zone), which has a length similar to preceding zone, carries out a preliminary stretch breaking to produce fibres of a length between 1 and 4 m.

The second draft zone is followed by the end draft zones, composed by 3 drawing heads, the second and the third of which are mobile in order to enable modifying the gauges and the setting of the characteristics of the fibre diagram.

Other machines are equipped also with a cooling system for rollers and pressure rollers by means of internally circulating cooled water.
While leaving the last breaking zone, the sliver is consolidated by an air-jet nozzle and then conveyed to the crimping box, which is composed of 2 calenders and of a crimping box.
A device for continuous and linear steaming follows; this device permits, if necessary, a total retraction of the fibres (110-115°); the sliver or top is then collected in cans, through automatic can-changing.

Technical data of a modern tow-to-top stretch breaking machine

Linear lay-out (on 1 level) with only one operating side	
Heads of preliminary drawing, drawing and stretch breaking:	No.6
Total linear mass of fed tow (1 or 2 tows): (on basis acrylic fibre 3,3 dtex)	max. 240 ktex
Linear mass of filaments	0,8-17 dtex
Average staple length of stretch broken fibres	80-130 mm
Delivery speed	max. 350 m/min
Linear mass of delivered sliver	20-60 ktex
Effective output per hour	350-500 kg/h
Machine overall dimensions (length)	11,5-12 m

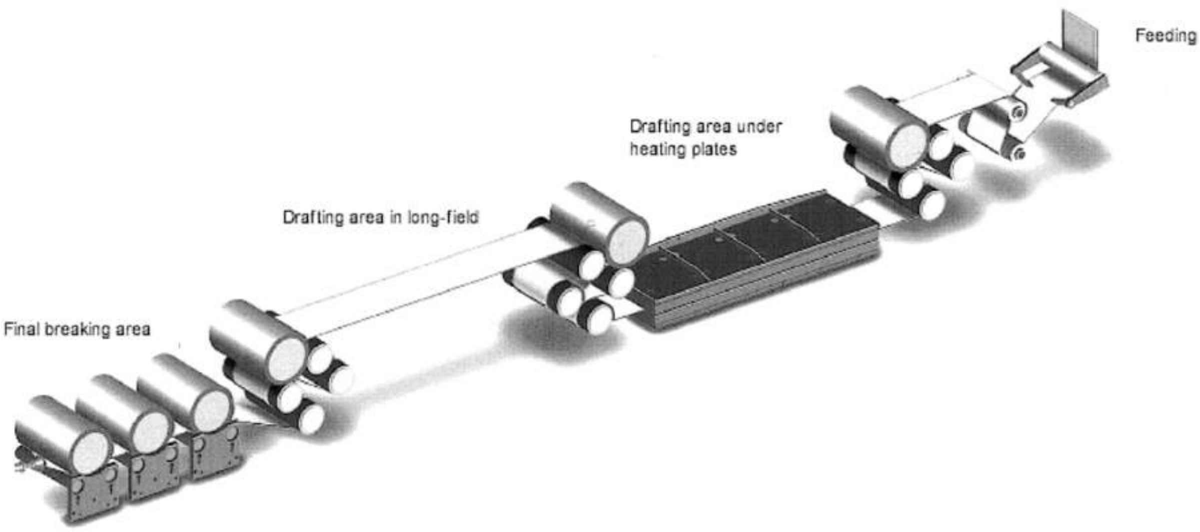


Fig. 79 Stretch breaking machine

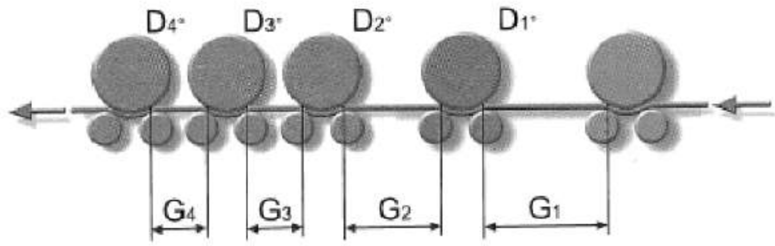
Integrated drawing frame
This machine completes the process and has the task of plucking, mixing and regularizing the slivers through an effective doubling and drawing action.
This passage performs the mixing of steam-set slivers with shrinkable slivers in order to obtain an HB (High-Bulk) top; as the two kind of slivers are usually doubled in same number, the delivered sliver weight (assuming a 20% retraction of the steamed component) is composed by about 55% steam-set fibres/45% shrinkable fibres.
The machine is constituted of two parts placed in sequence (Fig.80):

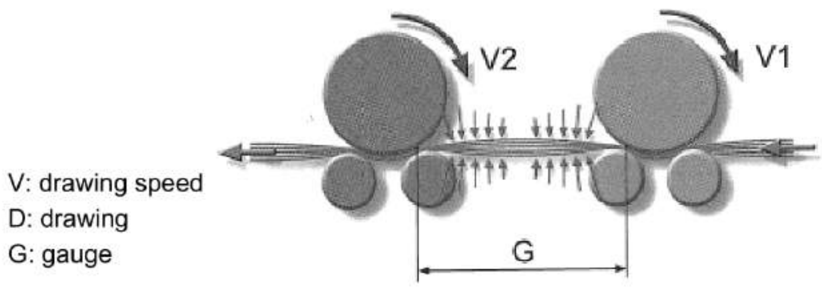
- Preliminary drawing module, which has several drawing aggregates (each of them showing a couple of rollers and a pressure roller) with independently adjustable draft ratios and gauges.
- Drawing frame with rotating flanges or chain operated combing head (intersecting).

The combined drawing action of the two modules permits to obtain a multiplying effect which increases the total drawing capacity by 24-30 times, with consequent higher doubling number and improved mixing level.

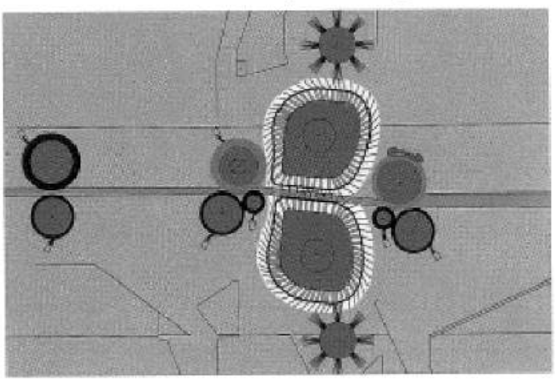
<u>Technical data of a modern integrated drawing frame</u>

Feeding batch max.	1000 ktex
Total draft (preliminary draft Of 1st, 2nd, 3rd, 4th zone)	2,5 ÷ 3,5
Feeding speed max.	80 m/min
Delivery speed max.	500 m/min(cans) 400 m/min (bobbins)
Doubling number (creels with cans or bobbins):	24-32-36
Can, bump or bobbin delivery	
Electronic autoleveller	





A – Preliminary drawing zone



B – Sliver path in the drawing zone of an intersecting

Fig. 80 Integrated drawing frame

Tow –to-top cutting technology

This technology, although based on a long known principle, finds even today very limited application. The tow, which should be regularly shaped and uniformly thick, runs between a rotating upper roller equipped with helical blade (cutting roller) and a pressure roller (called anvil) situated below.

The exerted pressure crushes the fibres level with the blade, until their cut: cutting length and variability are given by the blade pitch (Fig. 81).This process finds specific uses (sewing threads, technical yarns) for filament cables characterized by high tenacity properties (PES, PA, PP). In fact the cutting technique preserves fibre properties, in particular dyeing evenness and dynamometric characteristics.

The basic element of the process is obviously the cutting roller, the blades of which must ensure a sufficiently clear cut of fibre ends (absence of burrs and agglomerations) along with good resistance to wear and stress.

The typology of the fibre diagram can be adjusted by varying the roller pitch or the angle of the feeding tow in respect to the roller (Fig. 82); in any case a fibre diagram is obtained which shows lower inclination than the typical diagram of wool or broken top (Fig. 83).

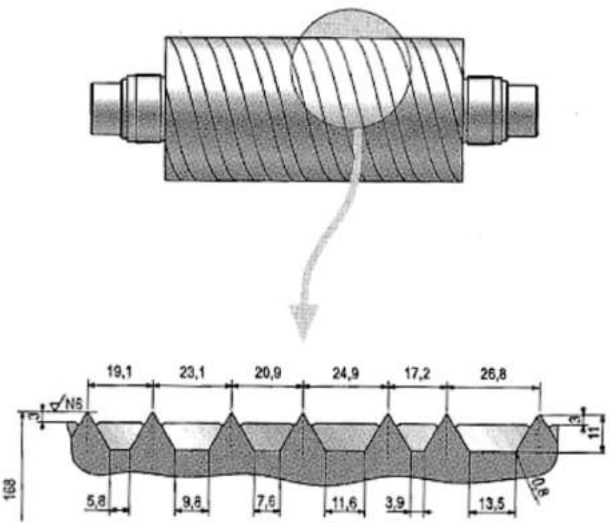


Fig. 81 Detail of the cutting line of a roller

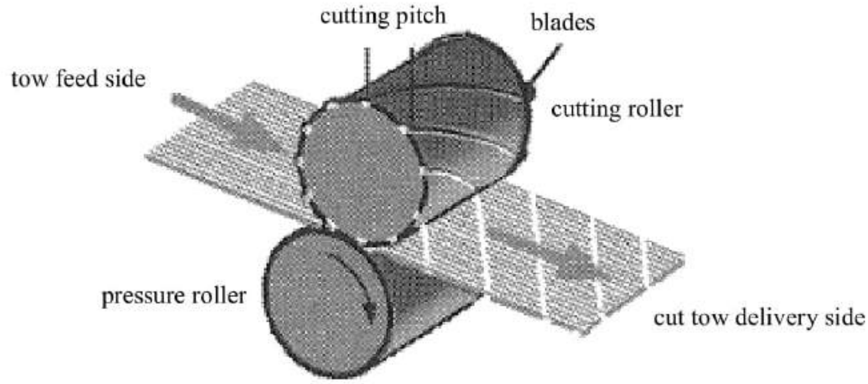


Fig. 82 Tow cutting

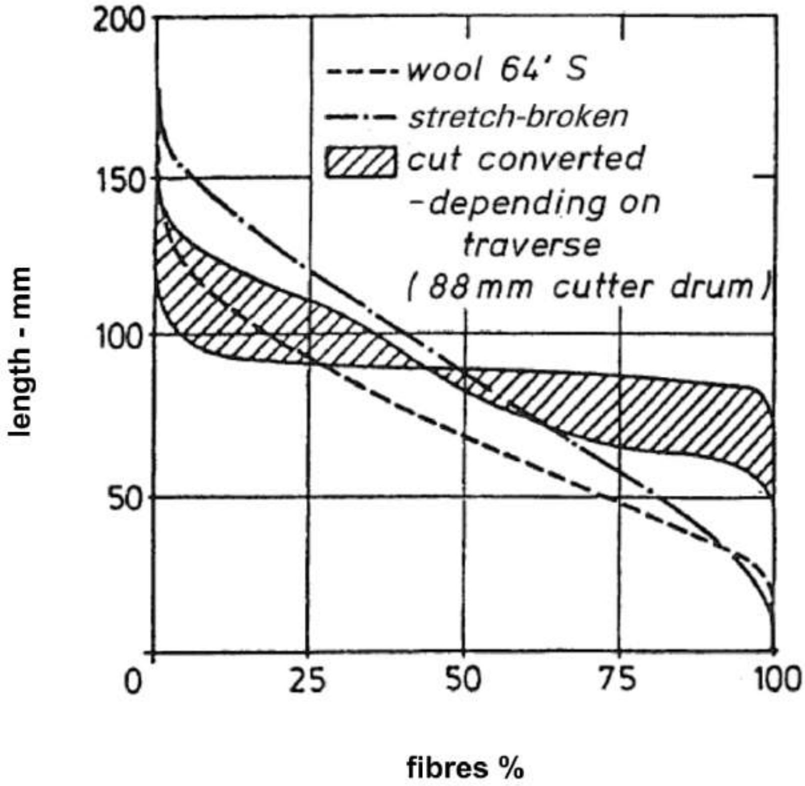


Fig. 83 Fibre length distribution in wool and PES tops

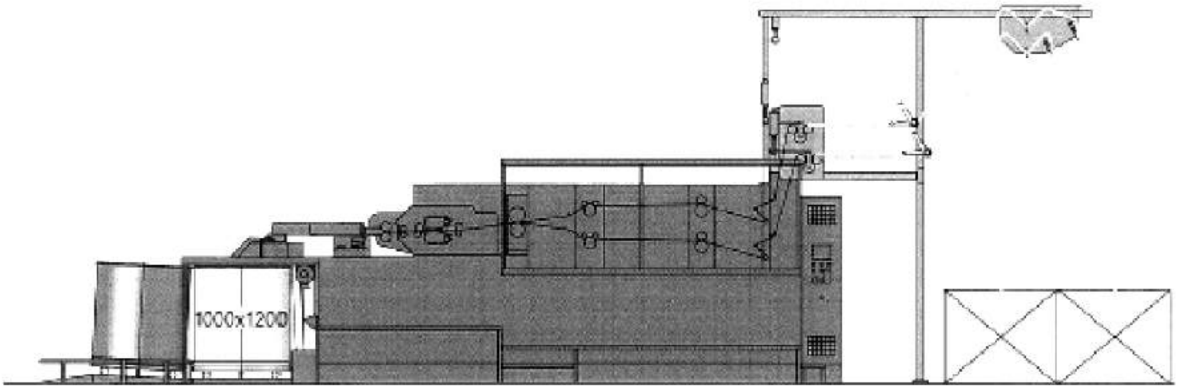


Fig. 84 Cut converter

Scheme of a modern tow-to-top cutting machine (Cut Converter)

The feeding batch is generally formed by two tows which are placed behind the machine and are conveyed, by means of guide bars and tension rollers, to the cutting aggregate. Attention has to be paid that the material reaches the cutting roller in form of a regular sliver with parallel, stretched and well opened filaments.

An intersecting head opens the fibres and distributes them uniformly, thinning the sliver; successively a crimping device consolidates the sliver, which is finally collected within cans.

Technical data

Total linear mass (1 or 2 tows)	max. 240 ktex
Linear mass of single filament	1,3-17 dtex
Average fibre length	75-88-105 mm
Delivered sliver	15-30 ktex
Mechanical feeding speed	280 m/min
Effective output	250-350 kg/h
Overall dimensions	4,5 x 14,5 m