The Rieter Manual of Spinning
Volume 6

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Volume 6 – Alternative Spinning Systems

Dr. Herbert Stalder

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J 20 air-jet spinning machine

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Volume 6 – Alternative Spinning Systems

Dr. Herbert Stalder

THE RIETER MANUAL OF SPINNING

Volume 1 – Technology of Short-staple Spinning

This deals with basic, generally valid, technological relationships in short-staple spinning. Subsequent volumes are organised according to machines or machine groups. This separates generally valid basic principles from ongoing developments in machine design and construction.

Volume 2 – Blowroom & Carding

In-depth information is provided on opening, cleaning, blending and carding and additional aspects are covered such as acclimatisation of raw materials, anticipated waste from various grades of fibre, selection and setting of cleaning and blending machinery, waste recycling, transport and the functions of the various card components as well as selection and maintenance of card clothing and autolevelling systems.

Volume 3 – Spinning Preparation

Here the technical and technological aspects of the yarn production process between carding and ring spinning are covered, that means draw frame, combing section (including combing preparation) and roving frame. This is an important process stage, because the yarn quality largely depends on the quality of the intermediate products from which it is made.

Volume 4 – Ring Spinning

Technical and technological aspects of ring spinning are covered. This is the final process in yarn production. The ring spinning machine greatly influences the yarn and its quality. Ring-spun yarns still represent the standard for comparison when evaluating yarns produced by other spinning processes.

Volume 5 – Rotor Spinning

This process resulted from research into alternative spinning systems. This volume contains in-depth information on the rotor spinning process and its properties. Continual improvements in spinning elements and conditions make it now possible to spin a rotor yarn optically similar to a ring-spun yarn.

Volume 6 – Alternative Spinning Systems

To take full advantage of alternative spinning systems, a thorough understanding of them is therefore essential. This volume contributes towards reaching this goal by describing the most important alternative spinning systems in detail. One of them is the well known Air-jet spinning technology.

Volume 7 – Processing of Man-Made Fibres

Ever since the introduction of man-made fibres on a commercial scale, the market share of synthetic fibres has shown an impressive growth rate. In this important field, the variety of man-made fibres with different properties is continuously increasing. For numerous applications today, fibres that are practically “tailor-made” are available. Spinners must therefore have detailed understanding of the fibre properties and the specific characteristics that affect their processing.

EDITORIAL

This sixth volume in the Short-Staple Spinning series of the Rieter Manual of Spinning deals with both the technical and technological aspects of alternative spinning systems. In the past twenty years, the search for new, more economic spinning systems has been pursued very actively throughout the world. As a result, Air-jet spinning has been introduced into the market, and, with more than 50 000 spinning positions in operation worldwide by the end of 2007 (equivalent to about one million ring spindles), it has already conquered a substantial part of the spinning market. We can expect that Air-jet spinning be on the point of gaining further market acceptance.

The first part of this volume covers briefly all the main known new spinning systems, and the second part gives a detailed description of the most important of these new spinning systems, i.e., Air-jet spinning.

The new spinning systems produce yarns and therefore end-products with a quality that differs to a certain extent from the ring-spinning standard. In addition, the main new spinning system, Air-jet spinning, are still in a phase of further development. In order to take full advantage of the new processes, it is therefore essential to have a thorough understanding of them. This volume is designed to contribute towards reaching this goal.

It should also be mentioned that some important basic technology has been dealt with in Volume 1, The Technology of Short-staple Spinning, in particular, drafting with opening rollers and the yarn-formation process in rotor spinning.

The structure of this manual and the organization of its subject matter were taken over from the original „New spinning systems“ published by the Textile Institute, Manchester, whom we thank for their kind permission to continue this standard work.

Our special thanks also go to Mr. Werner Klein, whose contribution to the first edition as co-author has decisively influenced this volume in which his extensive knowledge is also reflected.

We wish all users of this compendium pleasant reading.

Rieter Machine Works Ltd.

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1. ALTERNATIVE SPINNING PROCESSES

1.1. Synopsis

1.1.1. Introduction

New spinning processes have been available in a practicable form for almost forty years, and yet by far the largest amount of short-staple yarn is still spun on conventional machines. These are mostly developments dating from the period 1760 - 1830, in particular:

- mule spinner;
- flyer spinning machine;
- cap spinning machine;
- centrifugal spinning machine;
- pot spinning machine; and
- ring frame.

The mule spinner operates according to a discontinuous spinning method. It has gradually been replaced by the ring spinning machine even in its last domain, the wool spinning mill. Flyer, cap, and centrifugal spinners have been mostly confined to the worsted spinning mill; only a few still remain in use. The flyer spinning machines used in bast-fiber spinning represent exceptions. Even pot spinning is hardly used in today's woolen mills.

Accordingly, most yarn is now produced on the ring frame. Ring spinning has been able to supplant almost all other conventional spinning methods and has proved very resistant to inroads by the newcomers. This can be attributed mainly to its:

- flexibility;
- universal applicability; and
- yarn quality.

As regards yarn quality, ring spinning has recently made a remarkable step further ahead with the introduction of compact spinning (see The Rieter Manual of Spinning, Volume 4 – Ring Spinning).

However, there are also problems associated with the ring spinning machine. For one thing, this machine is difficult to automate. For another, ring frame productivity is currently limited by traveler speed (around 45 m/s), yarn tension in the balloon and spindle speed (around 25 000 rpm), and major improvements above these levels are not easily imaginable. Only the search for new solutions therefore offers the prospect of basic advances in the spinning field in future. This search began on a broad front at the end of the 1960s.

The main problems of the new spinning processes are:

- yarn character differing from that of ring-spun yarn, which still represents the basic standard for comparison;
- characteristics occasionally bordering on the unusable;
- difficulties in maintaining consistently uniform yarn characteristics;
- greater demands on the raw material;
- market segments limited to:
  - a narrow count range;
  - specific raw material types;
  - specific end products;
- a high level of process know-how; and
- expenditure on repair and maintenance.

However, compared with ring spinning, they offer the following advantages:

- high production rates;
- elimination of processing stages;
- a considerable reduction in:
  - personnel and
  - space; and
- relative ease of automation.

Advantages of this kind are persuasive for yarn producers, particularly the economic benefits of new methods of spinning, and some of the new spinning processes have therefore in fact achieved more or less broad acceptance in the market. These systems have to be taken into account in the near to medium term for several fields of use, even if these processes may still have some drawbacks.

However, the machine builders, research institutes, and several independent inventors offer such a large range of already operable, semi-developed, and downright utopian possibilities for spinning yarn that it is not always easy to keep a grasp of the full spectrum. This problem is made still worse by the lack of standardized terminology. Sometimes, the generic designation of a spinning system is used, e.g. „open-end spinning“, sometimes the name of the process itself, e.g. „friction spinning“, sometimes the trade mark of the manufacturer, e.g. „Dref“. The quantity of available literature is enormous. Unfortunately, however, it is difficult to find a simple, succinct overview. This volume is therefore intended to provide the spinning specialist with this overview and to present the spinning principles in general terms.

1.1.2. Summary of new spinning processes

Process group	Spinning process	Company designation	Yarn type	Twist in yarn	Yarn strength imparted by
Open-end	Rotor spinning Electrostatic spinning Friction spinning Disc spinning	Battelle process Dref-2 Masterspinner University of Manchester	Conventional single yarn	True twist	Mechanical twisting process
	Air-vortex spinning	Polmatex PFI			Aerodynamic twisting
Twist spinning		Sirospun Duospun	Two-fold twist	Twist in single and ply yarn	Mechanical twisting
Rubbing technique	Self-twist spinning	Repco	Two-fold yarn	Alternating twist	Mechanical twisting
Adhesive process	Bonding agent Bonding fibers	(Pavena) Twilo Twilo	Bonded-fiber band	Twist-free	Temporary bonding
	Polymer	Bobtex	Multi-component yarn		Permanent bonding
Felting process	Felting fiber, sliver, roving or yarn	Periloc	Felted yarn	With or without twist	Felting
False-twist process	Two nozzle Air-jet spinning	PLYfiL	Double thread	Core twist-free, wrapping fibers have twist	Aerodynamic wrapping
		Rotofil Murata MJS	Bundled single yarn		
	Friction spinning	Dref-3			Mechanical wrapping
Wrapping process	Hollow-spindle spinning	Coverspun ParafiL	Filament-wound single yarn	Staple fibers twist-free	Mechanical wrapping
Wrapping process with fibers	Air-jet spinning	Murata MVS Rieter J 10 air-jet spinning machine	Fiber-wound yarn	Core twist-free, wrapping fibers with twist	Aerodynamic wrapping

Table 1 – Summary of the main characteristics of the various novel spinning processes

1.1.3. Possibilities for using the various spinning processes

Spin-twist and self-twist systems are typical worsted spinning processes. Bobtex and Periloc systems produce yarns with a woolen-spun character, but with higher strength. The ParafiL and Dref-2 processes must also be allocated to the coarse yarn sector. All other methods produce yarns for the short-staple market segment. From this group, the following have prospects for practical operation:

- rotor spinning (firmly established in the market);
- friction spinning (for certain applications);
- wrap spinning (to a limited extent);
- false-twist spinning (established in the market); and
- Air-jet spinning (becoming established in the market).

Due to its significance in the market, rotor spinning is considered in a separate volume. The other more promising candidates will be treated in somewhat greater detail in the following descriptions.

2. THE VARIOUS SPINNING METHODS

2.1. Open-end spinning processes

2.1.1. The basic principle of yarn formation

In all other spinning processes, an uninterrupted stream of fibers proceeds continuously, but with gradual attenuation, from the feedstock to the take-up package. In open-end spinning, this flow of fibers is interrupted, the fiber strand being opened into individual fibers at a predetermined position, usually by means of an opening roller, followed by airborne fiber transport. This interruption or break in the fiber flow is physically achieved by increasing fiber speed locally to very high levels (up to 100 m/s), so that – according to the equation of continuity – the number of fibers in the cross-section drops to such low values that the fibers lose contact with each other. This enables twist to be imparted merely by rotation of the yarn end, which in turn leads to a significantly higher potential rotation speed. However, the break in fiber flow also leads directly to one of the most important and difficult tasks in open-end spinning, namely to control the configuration of the individual fibers, airborne at high speed, and the need to re-collect these fibers without losing their elongated configuration, which is essential to the formation of a new fiber strand. This very tricky problem of open-end spinning can be dealt with schematically as described below (see Fig. 1).
A constant stream of separated, individual fibers is allowed to flow to a rotating yarn end. The brush-like, open yarn end grasps the fibers brought into contact with it and continuously binds them into a yarn with the aid of the continual rolling movement. The continuously formed yarn has only to be withdrawn and taken up onto a cross-wound package. On the basis of the device used to reassemble the separated fibers, distinctions are drawn between:

- rotor spinning;
- electrostatic spinning;
- air-vortex spinning;
- friction spinning; and
- disc spinning.

Rotor spinning has meanwhile become so widespread worldwide in the market that this very important and well-established spinning system is dealt with in a separate volume. The other open-end processes are described hereafter.

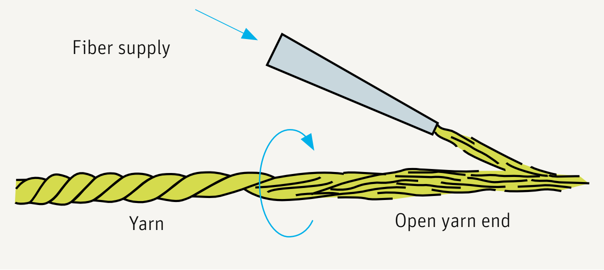

Fig. 1 – Formation of an open-end spun yarn

2.1.2. Electrostatic spinning

2.1.2.1. Operating principle

Several research teams, including some in the former Soviet Union, have investigated the possibilities of forming fiber strands with the aid of electrostatic fields. However, only the process proposed by the Battelle Institute has had a degree of success. The Electrospin Corporation (USA) demonstrated an experimental spinning machine based on this principle at the 1971 ITMA in Paris.

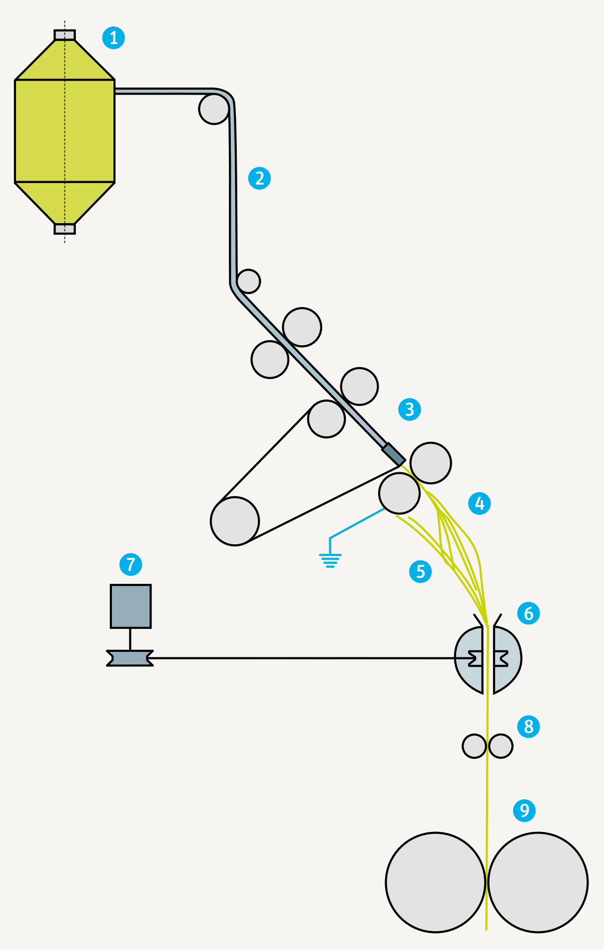

Fig. 2 – The electro-spinning principle

However, little has been heard about electrostatic spinning since then. In the process based on the Battelle principle (Fig. 2), a roving (2) taken from the roving frame is passed to a conventional double-apron drafting arrangement (3) and is subjected to a draft of up to 80-fold. The fibers exit freely from the front cylinder. They must then be collected to form a fiber strand and twisted to form a yarn. The first of these operations is performed by the electrostatic field, and twisting is carried out in a twist-imparting unit (6). Twisting presents no problems. The complexity of this method lies wholly in the electrostatic field generated between the front roller and the twist element (6) by earthing the front roller and applying a high voltage (about 30 000 - 35 000 V) to the twist element. This field has to accelerate the fibers and guide them toward yarn end (5) while maintaining the elongated configuration of the fibers. When the fibers enter this field, they take up charge and form dipoles, i.e. one end becomes positively charged and the other negatively charged. An open yarn end (5) projects from the twist element into the field. This yarn is negatively charged and is therefore always attracted to the front roller.
Due to the dipole pattern, there is thus a relatively high degree of fiber straightening between the front roller and the twist element. Fibers leaving the roller are accelerated and attracted to the yarn as a result of the charges carried by the two parts. They join continuously to the yarn. Since the yarn rotates, the fibers are bound in. A yarn is formed continuously and is withdrawn by withdrawal rollers (8), to be passed to a take-up device (9) for winding onto a cross-wound package.
The problem associated with this process is the formation of a yarn in an electrostatic field, as follows:

(a) Charging of the fibers, and hence their behavior in the spinning zone, is dependent upon air humidity. Accordingly, for each fiber type, a specific and highly uniform environment must be created. The machine may need to be air-conditioned.
(b) The charge on each fiber, and hence its movement, is dependent upon its mass. Short fibers with low mass will therefore behave differently from long fibers.
(c) A limit must be placed upon the number of fibers in the electrostatic field, because otherwise they will cause mutual disturbance when charging and dipole formation takes place. Only fine yarns can therefore be produced.
(d) The same effect is observed with high throughput speeds; there is a corresponding limit on the production rate.

Due to these problems, electrostatic spinning has no chance of being used in spinning mills.

2.1.2.2. Specification

Spinning positions per machine (1971)	20 (1 experimental machine)
Delivery speed	up to 40 m/min
Raw material	cotton
Count range	Ne 20 - 40; 15 - 30 tex
Form of feedstock	roving
Type of yarn	conventional, single yarn
Yarn characteristics	good yarn quality at low production speeds, ring-spun yarn character, yarn structure similar to ring-spun yarn, for fine yarns only
Special features	yarn quality heavily dependent upon ambient atmospheric conditions
Remarks	ozone formation

2.1.3. Air-vortex spinning
2.1.3.1. Operating principle

Extensive investigations have been made and testing has been performed by Goetzfried and Lord. However, the process was brought to industrial maturity by the Polish Wifama-Polmatex company. Several machines of this type are or have been in experimental use in Poland. However, this spinning system never achieved real industrial success.
In this spinning method (Fig. 3), yarn is formed by an air vortex in a tube (1). For this purpose, air is sucked by a vacuum source (6) into the tube through tangential slots (2). This incoming air moves upward along the tube wall in a spiral and finally arrives at the upper tube seal (3). Since the top of the tube is closed by the seal (3), the air then flows to the center of the tube and moves down again to the vacuum source. Thus an air vortex (5), rotating continuously in the same direction, is generated at the seal (3).
Opened fiber material is allowed to enter the system through a tangential opening (4). The rising air stream grasps this material and transports it upward into the vortex (5). To form a yarn, an open yarn end is passed into the tube through a passage in the upper seal (3). The vortex grasps this yarn end and whirls it around in circles in the same way as the fibers. Since the upper yarn length is held by the withdrawal rollers and the lower end is rotating, each revolution of the yarn end in the vortex inserts a turn of twist into the yarn.
Formation of the fiber strand itself arises because the rotating open yarn end in the vortex is presented with a multiplicity of floating, rotating fibers, which are caught by the bound-in fibers of the yarn end and are thus continuously twisted in.

One associated problem is maintaining good fiber configuration and achieving correct, ordered binding-in of the fibers, i.e. achieving adequate strength in the yarn. For this reason, synthetic fibers of the highest attainable uniformity were mainly used. A second deficiency is variability in the degree of twist in the spun yarn. In fact, the rotation speed of the fiber ring in the vortex (5) is not constant, due to mass variations in this fiber ring. Hence, the imparted yarn twist also varies as a function of time. On the other hand, a major advantage of the process is the absence of any kind of rapidly rotating machine parts.

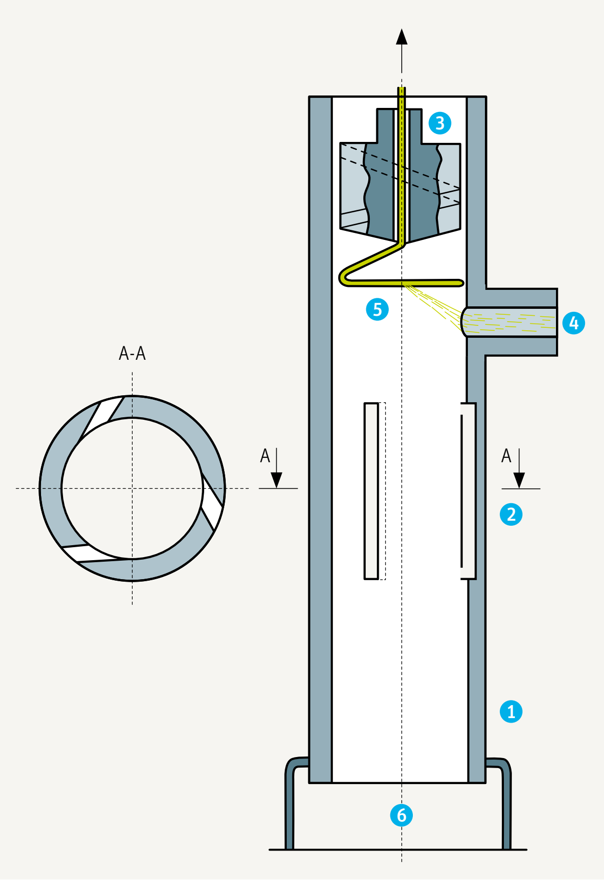

Fig. 3 – The air-vortex spinning principle

2.1.3.2. Specification

Spinning positions per machine	192
Delivery speed	100 - 150 m/min
Raw material	synthetic fibers, 40 - 50 mm
Count range	Ne 7.5 - 30; 20 - 80 tex
Form of feedstock	draw frame sliver
Type of yarn	conventional, single yarn
Yarn characteristics	low strength, twist variability, rough surface
Field of end-use	undemanding woven goods
Advantages	no rapidly rotating parts, simple machine
Special features	cotton cannot be spun, due to inadequate yarn quality

2.1.4. Friction spinning

2.1.4.1. Operating principle

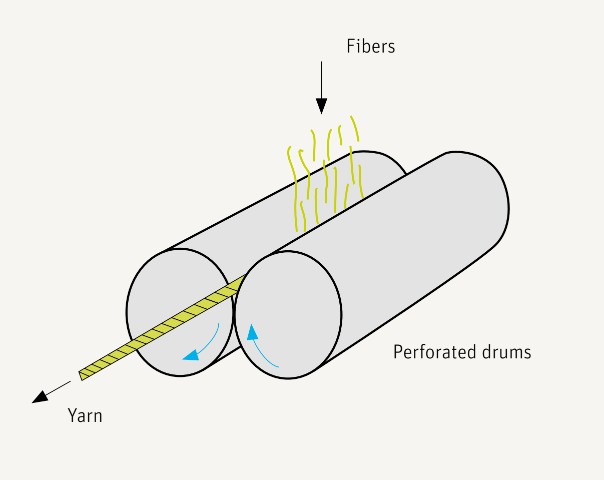

Fig. 4 – The friction spinning principle

This process is included in the open-end group because the fiber strand (draw frame sliver) must be opened completely into individual fibers and then reassembled to a new strand (yarn). The formation of a new strand is carried out by using suction to bring the individual fibers into engagement with the rotating open end of the yarn, e.g. by perforated drums with an internal vacuum. Binding-in fibers and imparting strength are effected by continuous rotation of the yarn end in the converging region of two drums. The rotation of the yarn end arises from the rotary movement of the two drums and is generated by frictional contact at the drum surface. The yarn formed in the convergent region by collecting fibers and binding them in can be continuously withdrawn and wound onto a cross-wound package.

The fineness of the resulting yarn is determined by the mass of fiber feed per unit of time and the withdrawal speed of the yarn; the number of turns is determined by the relationship between yarn end revolutions and withdrawal speed. The rate at which twist is imparted to the yarn is markedly lower than that which would be expected from the rolling of the yarn end between the two drums. This fact, often attributed to slip, is the result of the very complex details of the yarn formation process. The economic and technological limits of friction spinning and rotor spinning systems are in approximately the same count range. They are direct competitors in the marketplace.

2.1.4.2. Classification

The operations to be carried out in this spinning process are the same as those required for rotor spinning:

- opening of the fiber strand;
- acceleration of the fibers;
- collecting the fibers into a new strand;
- imparting strength by twisting;
- withdrawal of the resulting yarn;
- winding onto a cross-wound package.

Opening is performed by the elements already used for this purpose in rotor spinning. Collection of fibers can be performed on moving or stationary surfaces, and twisting can be effected by a transfer of forces from some kind of surface. Several different kinds of collection procedure and many different types of surface can be used. Accordingly, there is not just one kind of friction-spinning system, but there are several. They can be distinguished according to:

- feed:
  (a) single-sliver feed;
  (b) multiple-sliver feed (Dref-2000 and Dref-3000);
- opening assembly:
  (a) one opening assembly;
  (b) two opening assemblies or drafting devices (Dref-3000);
- separation of collecting and twisting functions:
  (a) collection and friction assemblies separated;
  (b) friction assembly also serves as collecting device;
- number of friction surfaces:
  (a) one friction surface (Dref-1);
  (b) two friction surfaces;
- type of friction assembly:
  (a) perforated drums;
  (b) one perforated drum with one smooth drum (blind drum);
  (c) two discs;
  (d) disc and roller in combination;
  (e) two crossed belts.

The most widely used types are those with the following characteristics:

- single-sliver feed;
- one opening roller;
- friction assembly also acting as collection device;
- two friction surfaces;
- two perforated drums or one perforated drum and one blind drum in combination.

2.1.4.3. Technological relationships

Feed
Multiple-sliver feed improves evenness but also leads to high costs and the need for a very high degree of opening.

Opening
Opening is performed as for rotor spinning. In this case also, straightening of the released fibers and the degree of longitudinal orientation are problematic, but exert a strong influence on yarn characteristics.

Fiber transport
The fibers can move to the collecting device in free flight (airborne) with (Platt Saco Lowell Masterspinner) or without (Dref-2000) guidance by a duct. Free flight of the fibers without guidance in a duct leads to fiber disorientation, which affects not only the yarn characteristics but also the spinning limits.

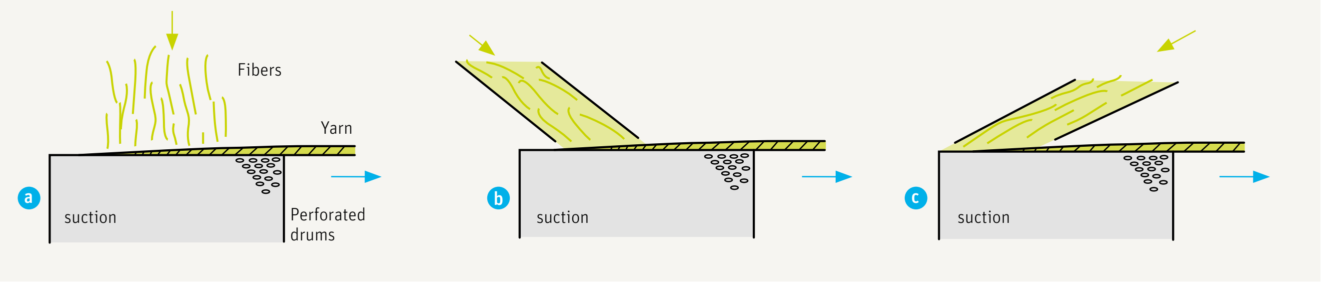

Fig. 5 – Direction of fiber flow in friction spinning

Fiber collection

The fibers are drawn by a suction airstream toward the collecting surface and the open yarn end (Fig. 5 (a), (b), and (c)). In rotor spinning, the fibers are additionally accelerated during collection and are thereby straightened, but in friction spinning the opposite happens. The fibers come into contact with a surface that is moving more slowly than they are. The result is fiber-buckling and deterioration in fiber orientation. The fibers are bound into the yarn in a loop form [1]; this effect is clearly visible in the yarn product and is more marked with longer fibers. The strength of friction-spun yarn is therefore lower than that of rotor-spun yarns.

In terms of flow direction, the fibers meet the drums and the open yarn end at right angles to the direction of yarn withdrawal (Dref), in the same direction, or in the opposite direction. In accordance with the system described by Luenenschloss and Brockmanns [2], reference is made to forward (Fig. 5 (b)) or backward (Fig. 5 (c)) spinning. In general, fiber guidance can perhaps be classified into (refer to Fig. 5):

- right-angle guidance (a);
- forward guidance (b); and
- backward guidance (c).

Back doubling is obtained in friction spinning as in rotor spinning, but the degree of doubling in friction spinning is smaller.

Imparting twist

Imparting twist presents problems as great as those of collecting and binding-in. A strand of loose fibers must take up twist by means of friction on the drums but without the aid of high contact pressure on the drums. The transfer of rotation to the yarn is dependent on the coefficient of friction and the contact pressure; both these quantities are difficult to keep constant between spinning positions and over time. The apparent slip is variable. A notable characteristic of friction-spun yarn is therefore uncertainty about the rate of imparting twist. Nevertheless, from the technical and economic points of view, this method of imparting twist exhibits remarkable advantages. In practically all other twisting assemblies, one revolution of the twisting element is needed to impart one turn of twist to the yarn. In friction spinning, one revolution of the twisting element can generate several turns of twist. This result is obtained because of the large difference in diameter between the drums and the yarn.

With reference to Fig. 6 (a) and (b), drum (1) has to rotate through a fraction of a revolution to cause the yarn to rotate once, i.e. one full drum revolution generates 100 and more yarn turns. The illustration also shows that the transmission ratio is still greater for fine yarns (with a smaller yarn diameter) than for coarse yarns. In the course of one drum revolution, the fine yarn therefore takes up more turns of twist than the coarse yarn. This remains true even though the smaller zone of contact of the finer yarn on the drums leads to greater apparent slip. This is the only spinning method in which the delivery speed is practically independent of yarn count [1].

The high transmission ratio (up to 200:1) has the further advantage that a lower rate of drum revolutions suffices, although, when considered in relation to the diameter ratio, the yarn takes up only 15 - 40 % of drum rotation [2]. Delivery speeds can be made correspondingly high. Spinning speeds of 500 m/min or even higher are conceivable. Unfortunately, the spinning speed is limited in practice by yarn quality to some 200 m/min. In fact, a higher fiber throughput rate leads to a deterioration in yarn quality.

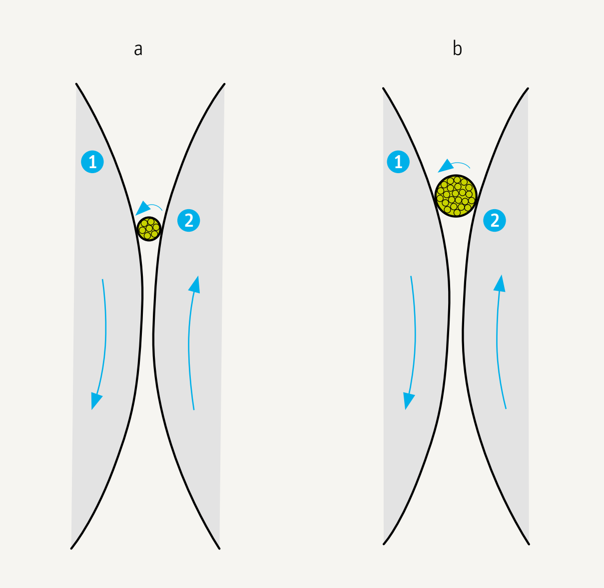

Fig. 6 – Fine and coarse yarns in the convergent region of friction-spinning drums

Withdrawal and winding up

In contrast to most other spinning processes, yarn tension (and hence end break frequency) is very low during withdrawal from the spinning zone. Tension therefore has no influence on the spinning limit. The yarn is wound up onto cross-wound packages so that, in comparison with conventional spinning, rewinding is eliminated.

2.1.4.4. Advantages and disadvantages

Advantages are as follows:

- high delivery speeds;
- low yarn production costs (lower than those of ring spinning);
- elimination of rewinding;
- low end breakage rates;
- yarn character similar to that of ring-spun yarn;
- no wrapping fibers;
- optically good mass evenness (well suited to knitted goods);
- better and softer handle than that of rotor-spun yarn;
- smooth yarn appearance.

Disadvantages are:

- low yarn strength;
- high tendency to snarl;
- higher number of fibers needed in yarn cross-section;
- difficulty of keeping spinning conditions constant;
- high air consumption;
- increasing unevenness and imperfections with increasing spinning speed, and further reduction in yarn strength.

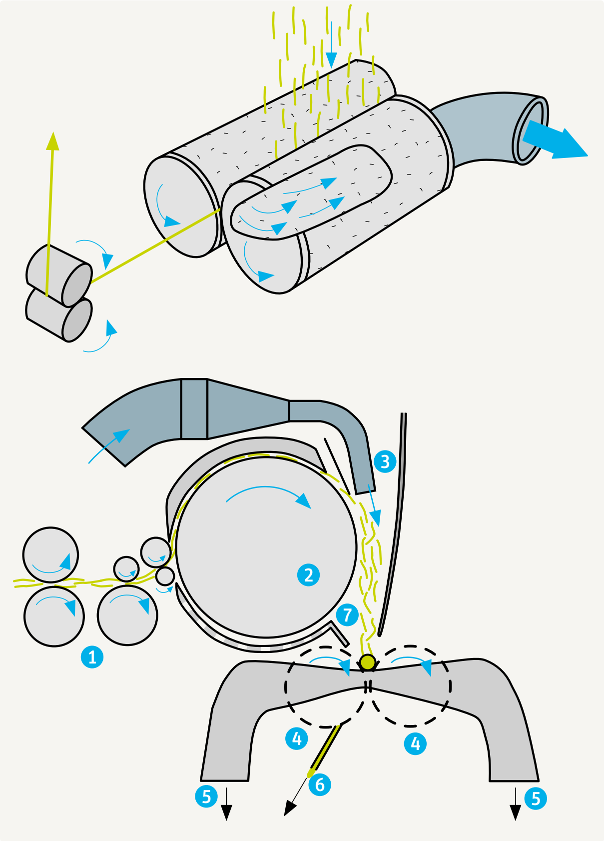

Fig. 7 – The Dref-2000 spinning system

2.1.4.5. Dref-2000

In this process by Dr. E. Fehrer (Fig. 7), one or more carded slivers are passed to the main opening roller (2) (i.e., a drum clothed with sawteeth) after leaving a drafting arrangement (1). While the drafting arrangement has only a slight drafting effect, the sawtooth roller opens the strand into individual fibers. The fibers separated in this way are lifted off the roller by a blower (3) and form a cloud (7), descending toward two perforated drums (4). One suction stream (5) per drum draws the fibers into the convergent region between the drums. The open end of the yarn (6) projects into this zone and is also sucked toward the perforated drums. Since these rotate, the yarn also rotates in the convergent region. The newly arriving fibers contact the rotating yarn and are thereby caught and twisted in. It is only necessary to withdraw the yarn continuously to twist fibers newly arriving in the convergent region into a yarn.
Dref-2000 is primarily suited to the production of coarse yarns (of medium to long staple fibers) and recycling yarns. In these market segments, Dref-2000 is well established.

2.1.4.6. Specification of Dref-2000

Spinning positions per machine	6 - 64
Delivery speed	250 m/min
Raw material	wool, bast fibers, synthetic fibers, secondary fibers
Count range	Ne 0.3 - 14.5; 2 000 - 40 tex
Feedstock	card sliver
Yarn packages	up to 8 kg
Yarn type	normal OE yarn
Yarn characteristics	woolen-spun character, round, even
Fields of use	home textiles, carpets, blankets, recycling products, technical products
Advantages	spinning of waste, elimination of process stages
Special features	recycling, production of fancy yarn, core-spun yarn

2.1.4.7. The Platt Saco Lowell Masterspinner

This is shown in Fig. 8 and Fig. 9. A draw frame sliver (2) as normally produced in short-staple spinning mills runs from a can (1) into an opening assembly. This consists of a feed roller (3) and an opening roller (4), and opens the fiber strand in the same way as the opening device in rotor spinning.

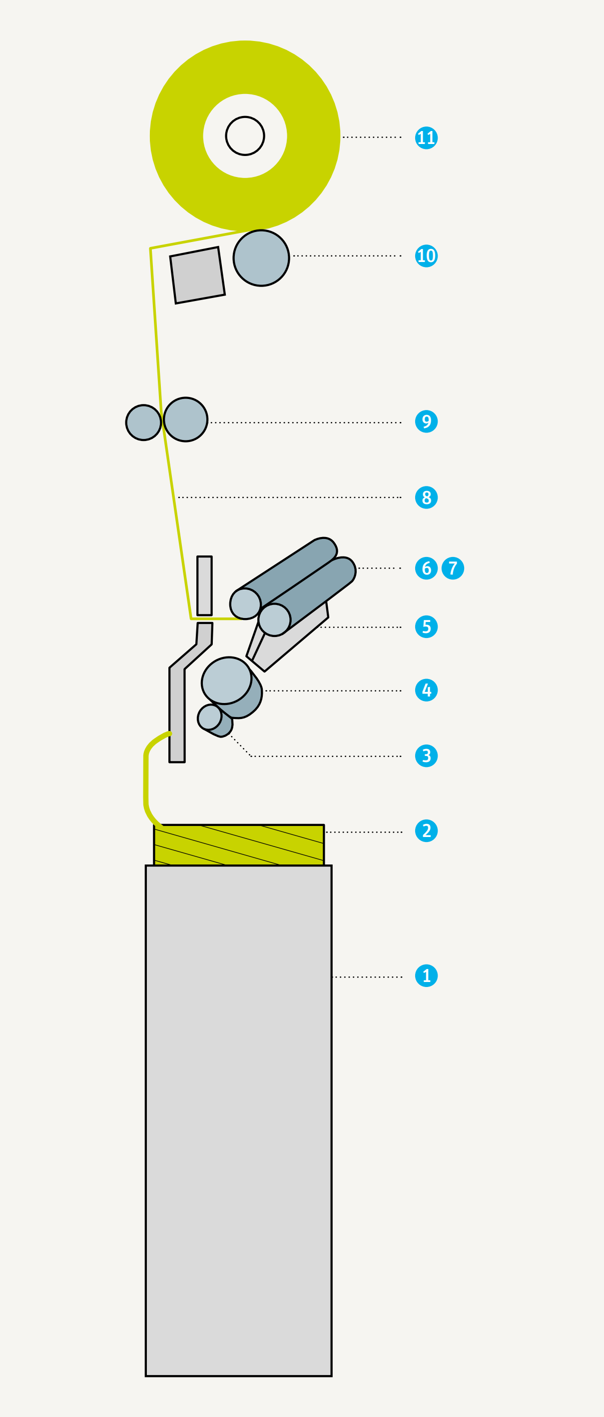

Fig. 8 – The Masterspinner friction-spinning machine

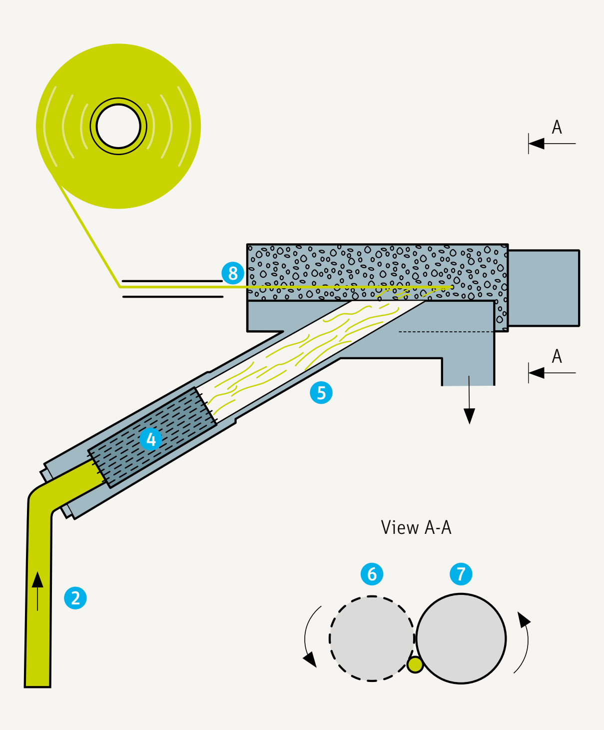

Fig. 9 – The spinning principle of the Masterspinner

The separated fibers pass through a specially shaped fiber channel (5), carried by an air flow from a vacuum inside the suction roller (6) into the converging region between the two friction rollers. As previously mentioned, one of these rollers is perforated to act as a suction roller (6), whereas the second roller is solid. A yarn (8) is formed in the convergent zone by the method already described and passes via delivery rollers (9) and winding rollers (10) to a cross-wound package (11). A number of ten-position machines and a few full-scale machines with 144 spinning positions were delivered in the 1980s. However, these machines have not been successful in the longer run, mainly for two reasons:

- inadequate yarn strength, i.e. low utilization of the fiber properties; and
- inconsistency of the spinning results.

The Masterspinner has therefore disappeared from the market.

2.1.4.8. Specification of the Masterspinner

Spinning positions per machine	144
Delivery speed	150 - 300 m/min
Raw material	cotton and synthetic fibers up to 40 mm in length; blends
Count range	16 - 60 tex; Ne 10 - 36
Feedstock type	draw frame sliver
Yarn type	open-end yarn with true twist (without wrapping fibers)
Yarn characteristics	low strength, good evenness
Field of use	knitting yarn, pile yarn, some weft yarns
Advantages	low production costs, capable of automation, no rapidly moving parts
Special features	field of use limited, delivery speed independent of yarn fineness, but limited by yarn quality

2.1.5. The University of Manchester Discspinner

Fig. 10 [3] shows that, as in the case of most open-end spinning processes, a single draw frame sliver (1) is passed via a feed device (2) to the opening roller (3), which opens the strand into individual fibers. A fan generates a partial vacuum (airstream 8) in the disc (4), and this draws the separated fibers onto the collection surface of the perforated disc (spinning disc 4). The open end of the yarn (5) is drawn by the suction into this spinning zone, which lies directly opposite the opening roller. The yarn continuously receives twist imparted to it by an external twist element (6), so that the open yarn end is continuously rolling on the perforated surface of the spinning disc.

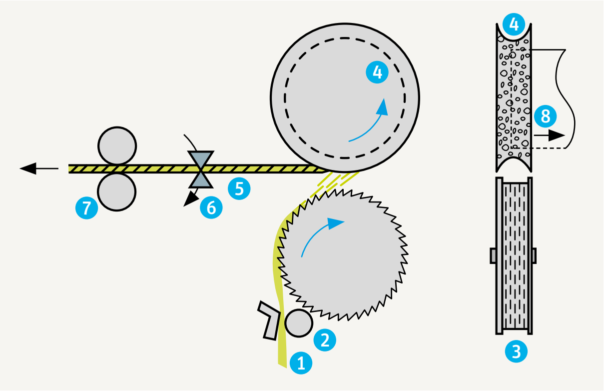

Fig. 10 – The disc-spinning principle

This in turn causes rolling-in of fibers engaging the yarn end and hence leads to continuous yarn formation in accordance with the open-end spinning principle (Section 2.1.1.). The yarn formed in this way simply has to be withdrawn by the withdrawal rollers (7) and wound up onto a cross-wound package.

It is an interesting feature of this process that collection and twisting of the fibers are separated. Each is performed by a different element. This makes it possible to use various types of twisting element. The process thus becomes very flexible. However, it has never advanced beyond the development stage.

2.2. Twist spinning

This is a process that has been known generally for some time but has been rediscovered in recent years. Today it is used mainly in worsted spinning mills. Two systems are available:

- Duospun, from Ems SA and Huber and Suhner AG; and
- Sirospun, from Zinser Textilmaschinen GmbH.

The difference, and the only patentable aspect of the process, lies in the procedure adopted when one of the two ends leaving the drafting arrangement breaks. In the Duospin process, the two yarns are recombined almost instantly, whereas the Sirospun system interrupts spinning at this single spinning position.

The mode of operation [4] is shown in Fig. 11 and Fig. 12. Two rovings are passed individually through a slightly modified, but generally conventional drafting arrangement of a normal ring spinning machine. The fiber strands, attenuated by a draft in the normal range, leave the delivery roller separately. At this point, they are each subjected to twist generated by a common spindle (cop); thus, within the spinning triangle, they are twisted into two single yarns, and these are simultaneously bound together to form a composite yarn. Each of the two single strands and the resulting composite yarn contains twist, and the direction of twist is the same for both the single ends and the composite product. This twist-on-twist (ZZ or SS) produces a yarn that is somewhat more compact, with a firmer core, than the usual ply yarn with opposing twist (ZS or SZ). To produce twist-spun yarn, it is only necessary to add several auxiliary components to the ring frame and to provide an enlarged creel to accommodate twice the usual number of packages.

This spinning process, which is already in use in worsted spinning, primarily offers economic advantages, because the production of the ring spinning and winding machines is roughly doubled (two ends instead of one at approximately the same speed). In addition, plying and twisting are eliminated.

In worsted spinning, twist spinning has therefore secured a certain share of the market. However, due to the different twist structure, it cannot completely replace the conventional 2-fold yarn process.

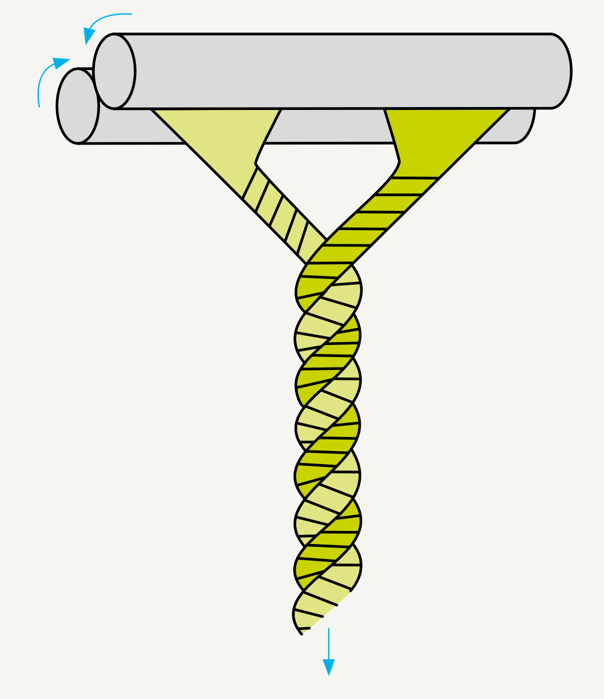

Fig. 11 – Formation of a twist-spun yarn

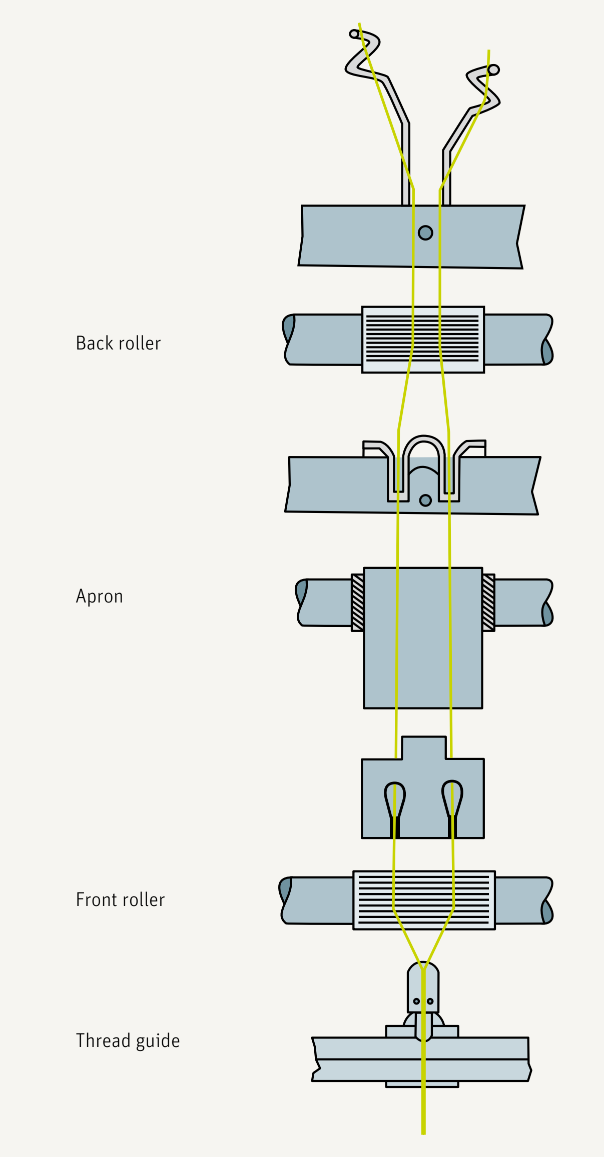

Fig. 12 – The twist-spinning process

2.3. Friction (self-twist) method

2.3.1. Technological interrelationships

This ingenious spinning system has been developed in Australia by the CSIRO research center. A fiber strand passed between reciprocating rubbing rollers takes up turns of twist, but in alternating directions (over a short length, in Z and S directions). The untwisting moment releases these turns of twist. However, if two fiber strands with the same twist direction pass through in parallel, closely adjacent to each other, the untwisting moment can no longer act separately on the individual yarns; it acts on both together to twist the yarns around each other. A two-fold thread is obtained with a continuously changing direction of twist: Z twist where S twist is present in the individual yarns, and S twist where the yarns have Z twist (Fig. 13).

However, since the stroke of the rubbing rollers has reversal points, there is always a small length of strand left without twist between each section of Z twist and the adjoining section of S twist. The plied thread will also have no twist in this zone (Fig. 14). Such a thread has no strength. It cannot be wound up or subjected to further processing.

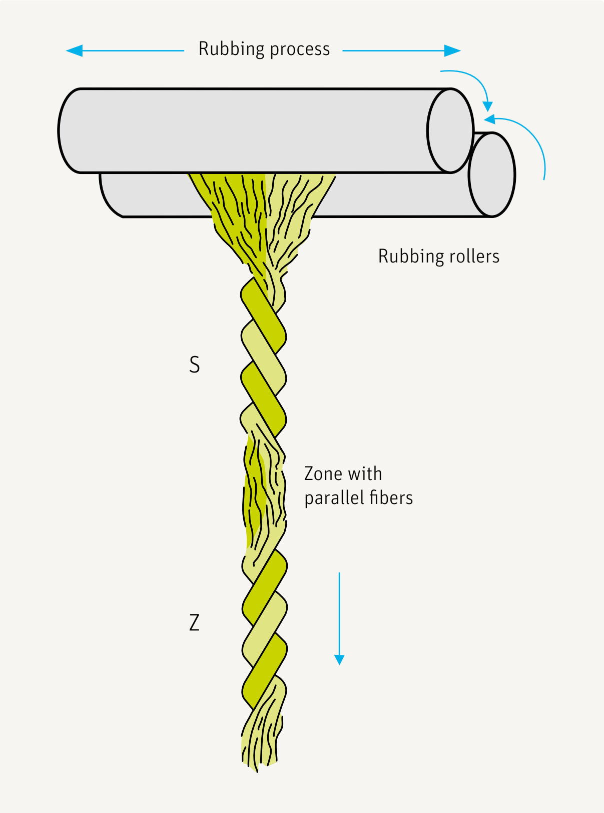

Fig. 13 – Reciprocating friction of a fiber strand

In order to obtain adequate strength despite these twist-free zones, the two yarns cannot be allowed to run in parallel, but instead they must be passed through with a relative phase shift. Then S twist will be generated in the plied yarn wherever one yarn has Z twist (with zero twist in the second yarn) or where both yarns have Z twist. Similarly, the plied yarn will have Z twist wherever at least one yarn has S twist (with zero twist in the other yarn) or where both have S twist. If a yarn section with S twist is combined with a section with Z twist, which cannot be avoided, the torsion forces stabilize each other so that no plying twist results. The two-fold yarn obtained with this process therefore always consists of three successively arranged zones (Fig. 15):

- folded yarn with S twist arising from two yarns with Z twist, with one of the yarns exhibiting a short twist-free length;

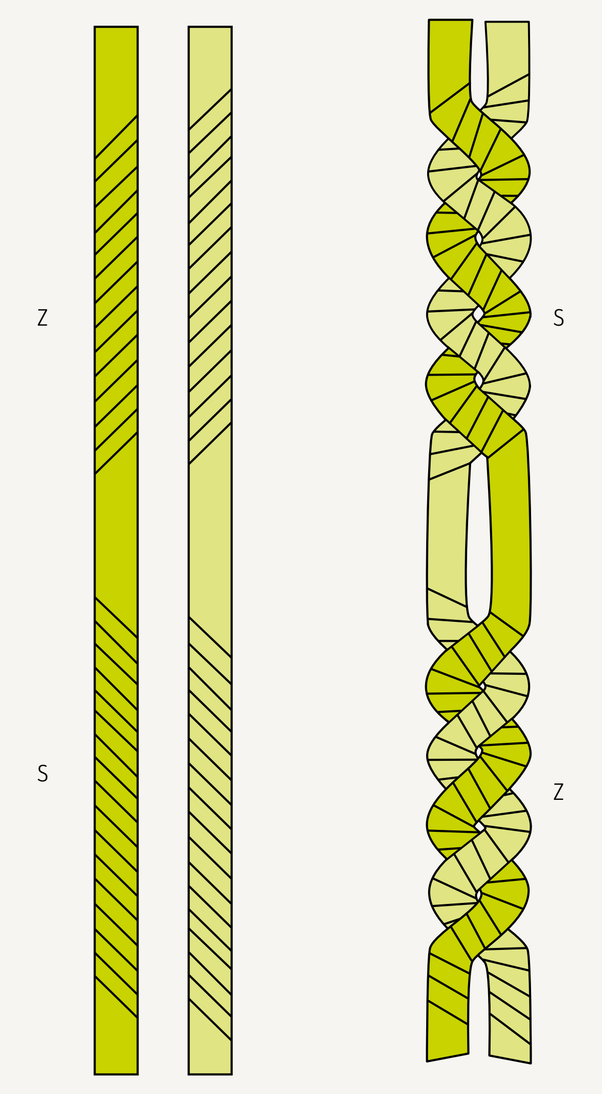

Fig. 14 – Combining two fiber strands previously strengthened by friction

- two yarn sections lying parallel to each other without plying, one yarn having S and the other Z twist;
- folded yarn with Z twist, where the yarns have S twist, with one of the yarns again exhibiting a short twist-free length.

Instead of one large weak point (Fig. 14), three smaller weak points have been created. The two-fold yarn has adequate strength to permit winding up but not for further processing. For that purpose, it must be twisted again. However, since the two-fold yarn has alternating turns of twist, a folded yarn with continuously varying sections of different twist is obtained upon further plying (two-for-one twisting process), (Fig. 16).

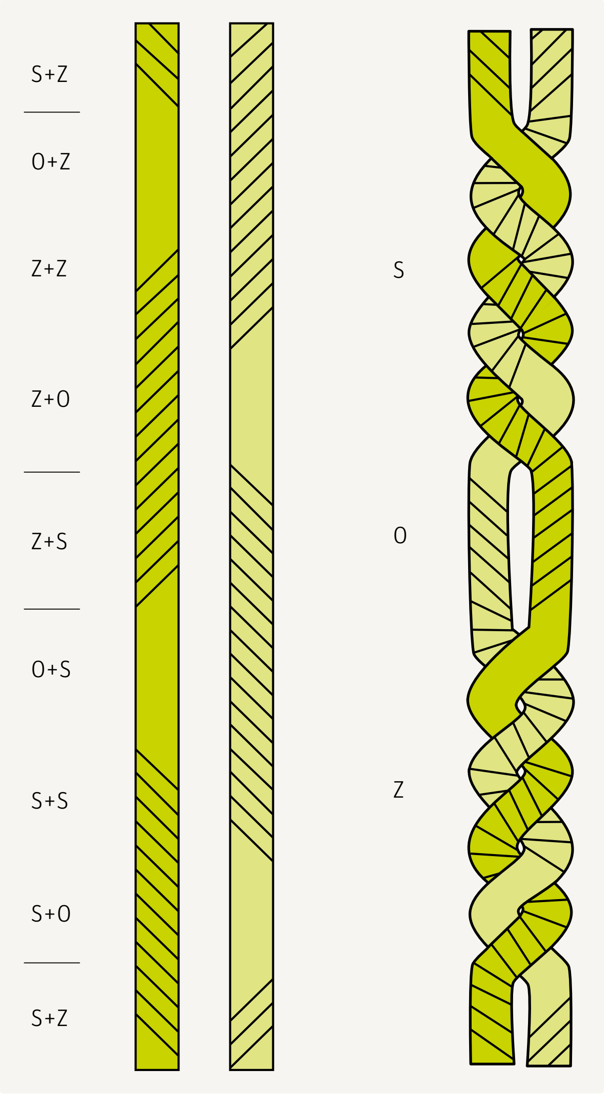

Fig. 15 – Combining two fiber strands with a phase shift

2.3.2. Repco spinning (self-twist spinning by Platt Saco Lowell)

Platt Saco Lowell has obtained a license from CSIRO for the self-twist spinning process. The corresponding machine has been called the Repco Spinner.
Eight roving strands (2) run from a creel (1) into a double-apron drafting arrangement (3), where they are drafted in a normal drafting range (Fig. 17). A friction assembly (4) adjoins the drafting arrangement and consists of two reciprocating friction rollers. In passing through this device, the fiber strands leaving the drafting arrangement are subjected to alternating twist. Before the turns of twist can cancel each other out, the strands are brought together in pairs with a phase shift between the components of the two strands (Fig. 15). This produces the previously described self-twist (ST) two-fold yarn. The four yarns proceed to a winding device (5), where they are wound onto cross-wound packages. This process is suited only to the spinning of long staple fibers and is therefore used solely in worsted spinning mills.

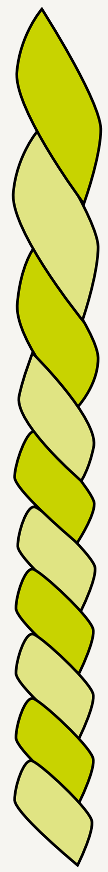

Fig. 16 – The twist structure in a Repco double thread

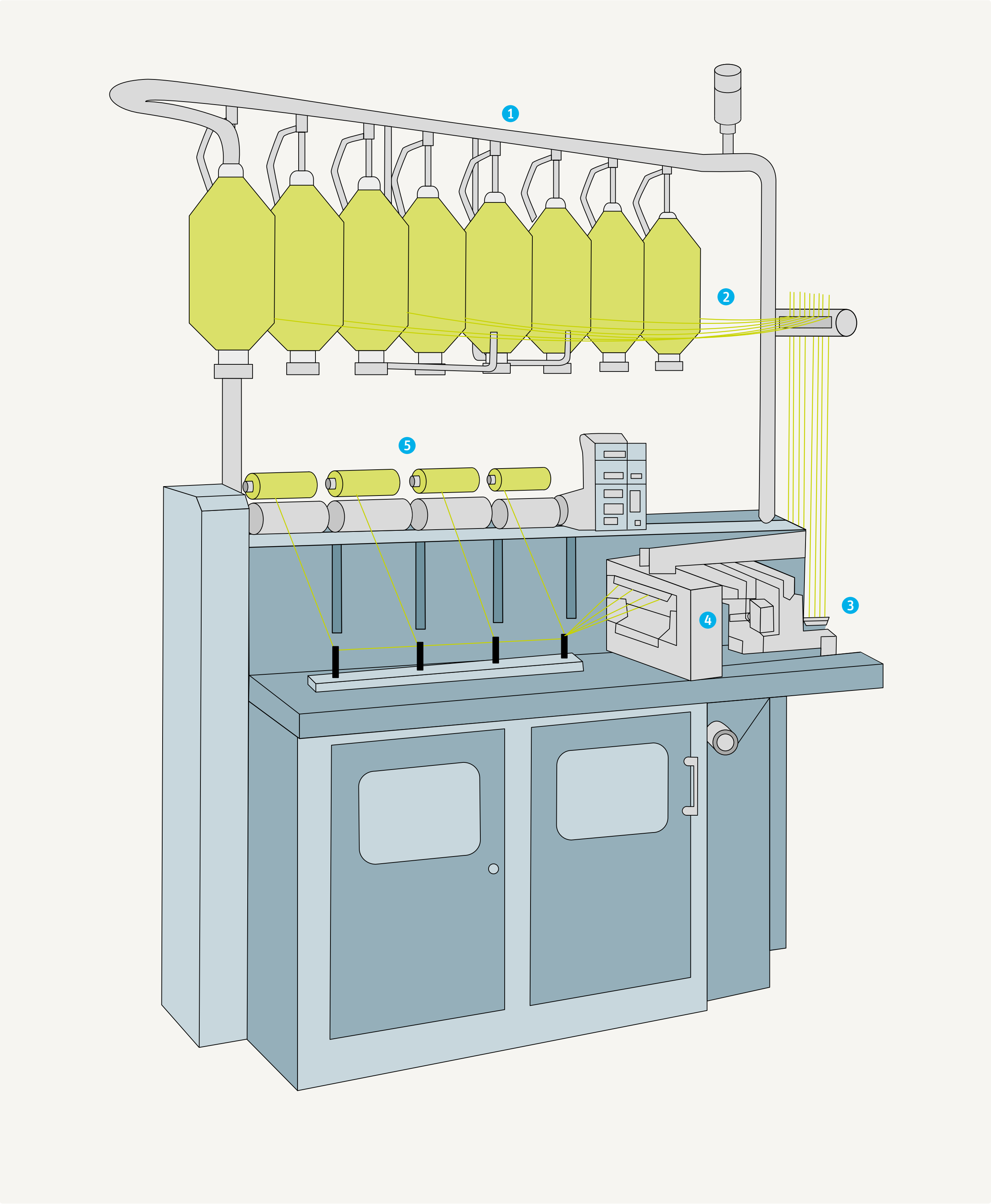

Fig. 17 – The Repco spinning machine

2.3.3. Specification of the Repco spinner

Spinning positions per machine	4 (5)
Delivery speed	up to 300 m/min
Raw material	wool and synthetic fibers
Count range	Ne 9/2-45/2; 13-65 tex x 2
Feedstock	roving
Type of yarn	two-fold yarn
Yarn characteristics	full, round, twist variations
Fields of use	outerwear, pullovers
Advantages	low energy consumption, low space requirement, low personnel demand, low-noise process
Special features	the preparatory machines of the mill are retained
Remarks	worsted spinning sector

In the 1980s Repco spinning captured a certain proportion of the worsted market, mainly due to its considerable economic advantages. In the meantime, however, most of the Repco machines have disappeared, for various reasons:

- Platt Saco Lowell discontinued the further development of this process (the Platt Saco Lowell company no longer exists);
- the twist structure of the Repco yarn is different from that of a conventional 2-ply yarn;
- the twist insertion is dependent on friction and thus quite delicate to adjust and keep constant.

2.4. Wrap spinning

2.4.1. Operating principle

This system is shown in Fig. 18 and Fig. 19. A roving or sliver feedstock (1) is drafted in a three-, four- or five-roller drafting arrangement. The fiber strand delivered runs through a hollow spindle (3) without receiving true twist. In order to impart strength to the strand before it falls apart, a continuous-filament thread (4) is wound around the strand as it emerges from the drafting arrangement. The continuous-filament thread comes from a small, rapidly rotating bobbin (5) mounted on the hollow spindle. Take-off rollers lead the resulting wrap yarn to a winding device. The wrap yarn thus always consists of two components, one twist-free staple-fiber component in the yarn core (a), and a filament (b) wound around the core. This process has been offered by several manufacturers, e.g., Leesona, Mackie, etc. The most common wrap spinning system is ParafiL by the Suessen company, and this process will be briefly described in greater detail.

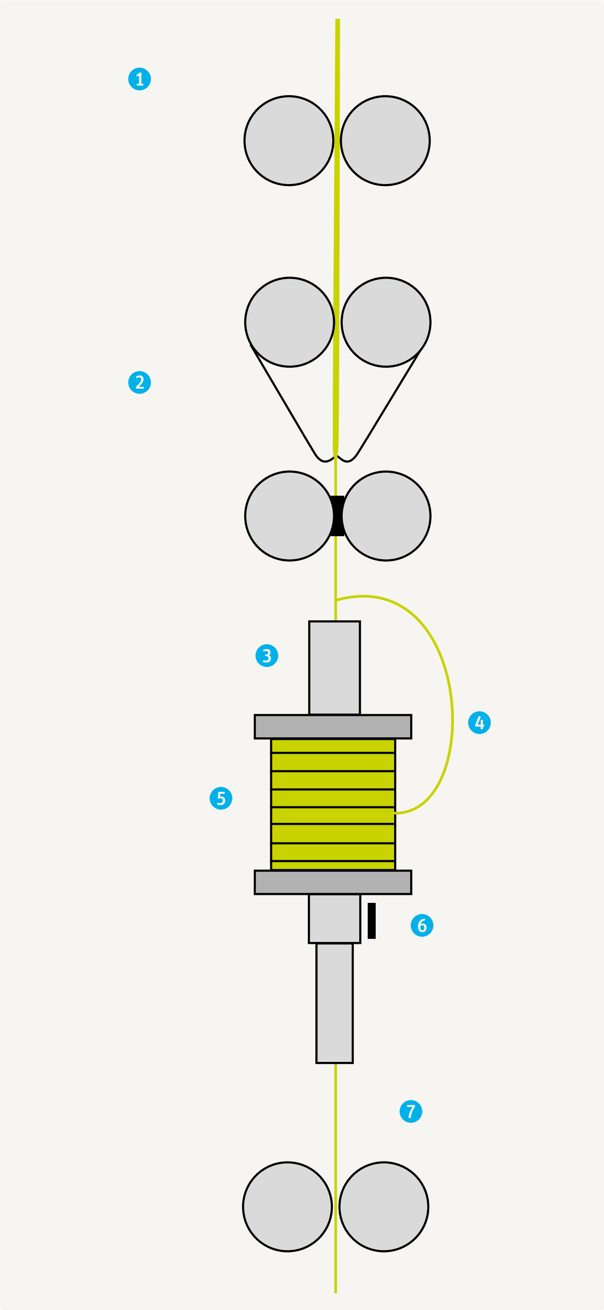

Fig. 18 – The wrap-spinning principle

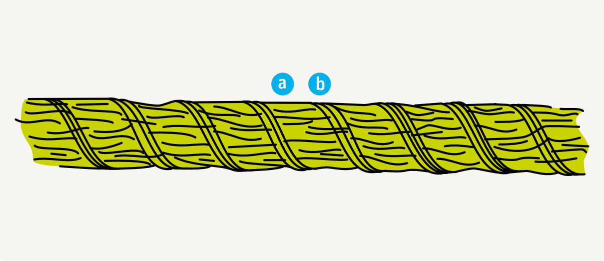

Fig. 19 – Wrap-spun yarn

2.4.2. ParafiL system by Suessen
2.4.2.1. Operating principle

Suessen has offered two machine types: PL 1000, with medium packages for yarn in the linear-density range of 25 - 100 tex, and PL 2000, with large packages for a yarn linear density of 25 - 500 tex. Three-, four-, or five-roller drafting arrangements are used, depending upon the raw material to be processed.
The hollow spindle (Fig. 20) permits rotation speeds of up to 35 000 rpm and is designed as a false-twist assembly.
The fiber strand (Fa) does not pass directly through the spindle vertically; instead, shortly after entering the spindle, the strand is led out again (1) and back around the spindle, with a wrap of about one-quarter of the spindle periphery. In this way, as the spindle rotates, the strand is provided with twist between the drafting arrangement and the head of the hollow spindle. These turns of twist are canceled out again in the spindle head in accordance with the false-twist principle. This false twist prevents the strand from falling apart in the length prior to wrapping with filament (Fi).
Slivers are used as feedstock; the roving frame is eliminated.
ParafiL yarn (called Parallelyarn by Suessen) is usually more even than ring-spun yarn. Its strength is also better because of the filament and because of the high degree of parallel orientation of the fibers. Covering power is high and hairiness low.
The yarns are used primarily for:

- machine-knitting yarn;
- velours (home and automobile upholstery materials);
- woven goods (men‘s and ladies‘ wear);
- carpet yarns (mainly for tufted carpets).

At present, the process is more suited to the long-staple than the short-staple field, i.e. for fiber lengths above 60 mm. In ParafiL yarns, the filament makes up 2 - 5 % of the yarn.

2.4.2.2. Specification

Spinning positions per machine	80
Delivery speed	200 m/min
Raw material	synthetic fibers 60 - 220 mm + filament
Count range	25 - 500 tex; Ne 1.2 - 24
Feedstock type	draw frame sliver
Type of yarn	filament-wrapped, single yarn
Yarn characteristics	high strength, good evenness, two-component yarn
Field of use	carpets, domestic textiles, outerwear
Advantages	fairly low production costs
Special features	separate winding machine needed for filament bobbins

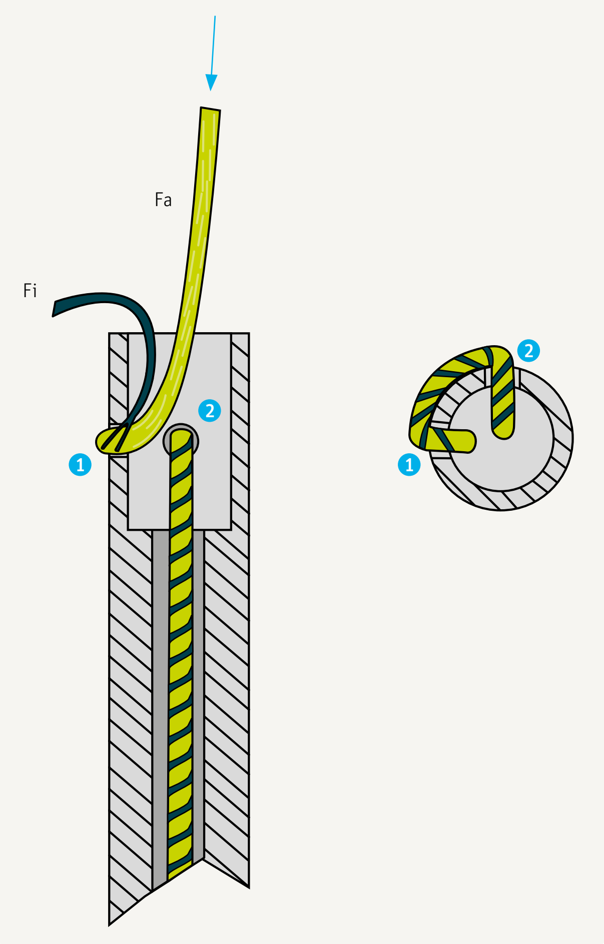

Fig. 20 – The false-twisting device in the ParafiL process by Suessen

2.4.3. Technological and economic interrelationships

A high percentage of filament always has a disturbing effect. These yarns are therefore found more often in the coarse-yarn sector, and to some extent in the coarse-to-medium-yarn range. With medium-fine to fine yarns, it would be necessary to use very expensive special filament. In general, the high price of filament relative to staple fibers exerts a strong influence on costs. Economic production of fine yarns using the wrap-spinning process is therefore not possible, due to higher raw material costs. Fine stocking filaments in the 20 - 110 dtex count range are usually used.

Filaments produced from all textile polymers are suitable as the wrapping element, the most common are polyamide fiber, polyester fiber, and viscose in the form of mono- or multi-filaments. If the final yarn is to consist of only staple fibers, poly(vinyl alcohol) filaments have to be used; these can be simply dissolved out of the yarn after spinning.
In relation to ring-spun yarns [5]:

- evenness is usually rather better;
- strength is greater, owing partly to the filament and partly to the high degree of parallel disposition and the fibers' binding together;
- covering power is better;
- hairiness is lower;
- plying can be eliminated;
- the tendency to snarl is practically zero.

Owing to the fibers' binding together, there is a slight wave character in the yarn, and this can be increased to the extent of an effect yarn. Splicing can be performed without problems on the rewinding machine, and sizing can usually be eliminated in the weaving mill, as also can plying.
The number of wrapping turns per meter usually corresponds approximately to a normal yarn-twist level. The filament must be rewound from the synthetic-filament manufacturers' large packages onto small bobbins (cops); this is done on a special winding machine.
Due to the negative impact of filament costs on the economic aspect of wrap spinning, the field of application of this system is quite limited. Suessen has therefore decided to discontinue sales of ParafiL machines.

2.5. Adhesive processes

2.5.1. Summary

Almost all currently used yarns obtain their strength from some kind of twist in the strand. However, this is only one possibility for generating strength in a staple fiber yarn.
In principle, the interconnection of the fibers must also be achievable by binding the fibers. It is therefore hardly surprising that attempts have been made over many years to enable such a spinning system to be developed. Pioneering achievements have been made by:

- the Vezelinstitut TNO (Holland), with the Twilo process;
- Rieter (Switzerland), with the Pavena process; and
- Bobtex Corporation (Canada), with the Bobtex process.

The line of thought is very attractive, but realization has proved difficult, so that these processes have been unable to achieve acceptance to date.
A strand of parallel fibers can be made to adhere by means of:

- a binding agent (Pavena, Twilo new);
- adhesive fibers (Twilo); or
- polymer (Bobtex).

Glue and adhesive fibers only have to hold the fibers together during processing. When the woven or knitted fabric is produced, coherence is provided by the yarn-binding points of the fabric structure. The binder is then superfluous and is therefore washed out during making-up. In the Bobtex process, however, the polymer remains as an integral part of the thread.
The end products of the Twilo and Pavena processes have good characteristics because the fiber strand consists of fibers arranged with a high degree of parallelism. These fibers are not subject to any degradation of their properties (handle, stiffness, suppleness, etc.) caused by twist. Furthermore, their covering power is high. An additional advantage of a practical process would be a high production speed.
On the other hand, a disadvantage is the somewhat poorer washing performance due to the lack of firm anchoring of the fibers in the yarn.
However, the main reason why all adhesive spinning systems have failed to achieve commercial success is to be found in the economic situation. In order to produce soft, attractive end products, the adhesive has to be washed out after weaving or knitting. This fact results in a drastic increase in raw material costs. In addition, applying adhesive and/or washing it out again requires cost- and energy-intensive heat processes. Therefore, adhesive spinning processes are not economically viable.

2.5.2. The Twilo process

2.5.2.1. Operating principle

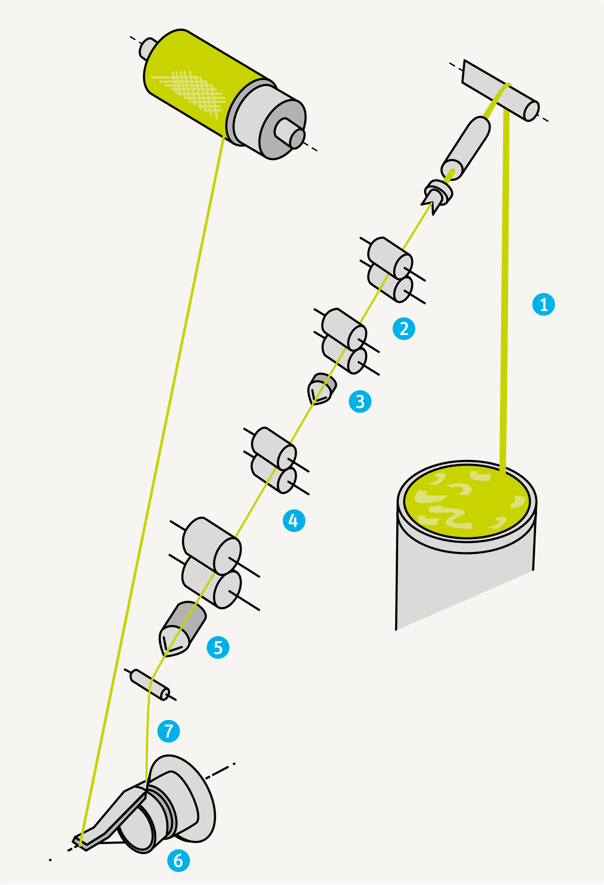

Fig. 21 – The Twilo spinning principle

In this method, which was used on machinery made by Signaalapparaten in Holland, third-passage draw frame sliver is used as feedstock. The first passage is usually carried out on a blending draw frame, where a small percentage (5 - 11 %) of adhesive fibers are blended with a sliver of cotton, synthetic fiber or viscose. The adhesive fibers can be polyvinyl alcohol (PVA) fibers, which become tacky and activated at a water temperature of about 70°C. The addition of water is therefore a precondition for bonding.

The draw frame sliver (1) passes into a first drafting zone (2) of a four-line drafting arrangement and is here predrafted in a still-dry condition with a draft of 5 - 10. The predrafting zone (2) is followed by the wetting position (3), which also contains a false-twist assembly. Here, the use of a water-jet leads to twisting of the strand (false twist). After this, final attenuation is performed in a twist-free condition in a second two-line drafting zone (4), with a draft of up to 40. To ensure that the strand leaves the drafting arrangement (4) as narrow and compact as possible, the drafting arrangement is followed by a second false-twist device (5). This device also serves to assist warming of the yarn to about 70°C (7). A steam-jet is therefore used here for twisting.

Complete dissolving of the PVA fibers does not yet occur. This happens only on the dryer drum (6), which has a temperature of 140°C. The wet fibers are warmed here to above 80°C, so that dissolving of the PVA fibers occurs in a first phase, after which the fibers are dried. The PVA fibers have thus been transformed into a strength-imparting adhesive.

Finally, cylindrical cross-wound packages above the machine take up the yarn. Instead of adhesive fibers, Signaalapparaten also used a bonding agent as an alternative means of imparting strength.

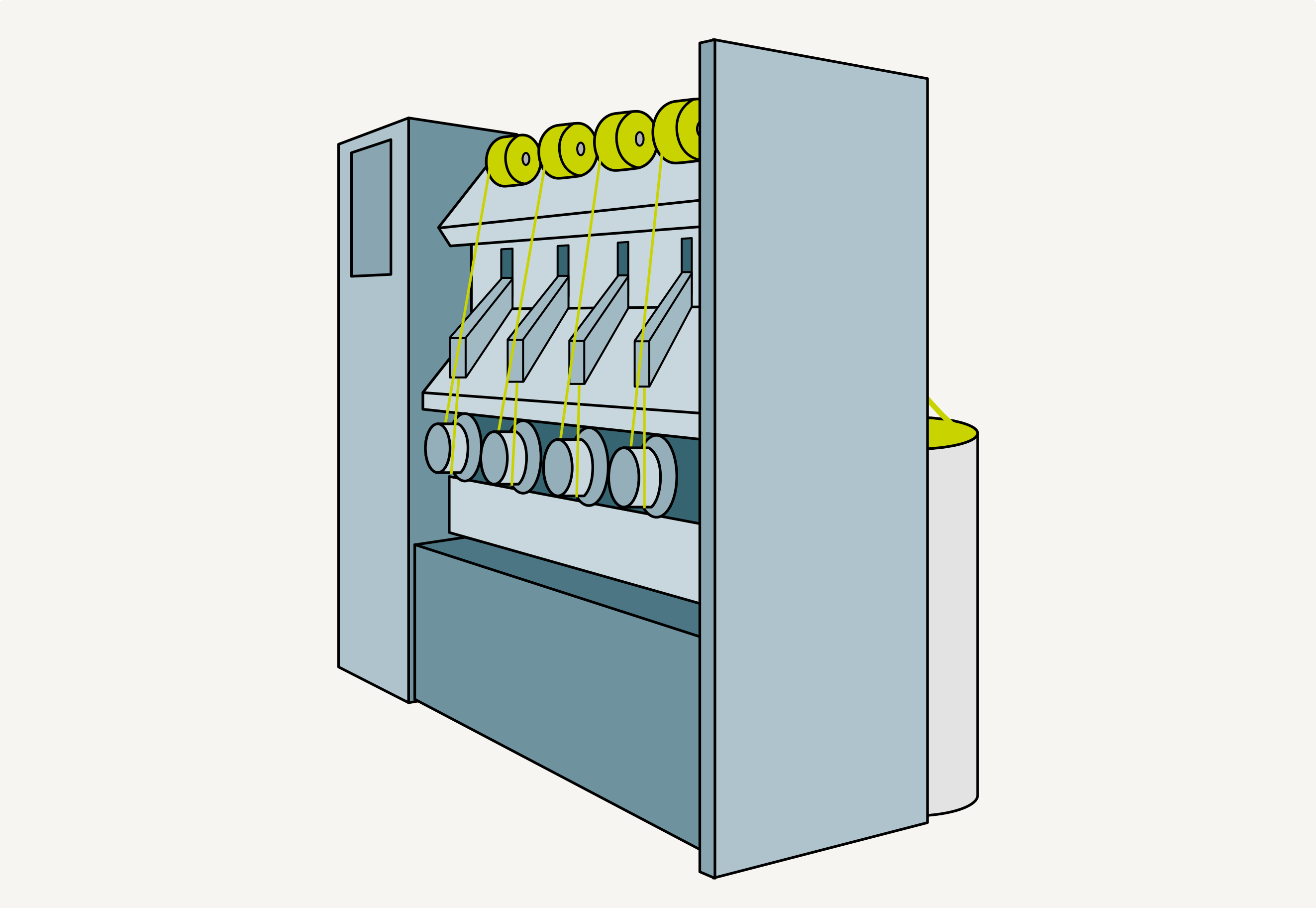

Fig. 22 – The Twilo spinning machine

2.5.2.2. Technological data

Raw material

Cotton and pure synthetic fibers can be processed, and so can blends. The range of fiber linear density lies between 1.4 and 6 dtex, with staple lengths in the 30 - 80 mm range. The finer the fibers, the more adhesive fibers must be used. The latter usually have a linear density of 1.7 dtex and length of 40 mm.

Yarn characteristics

The yarn is not round but flat, and therefore gives an end product with high covering power. Because of the binder, the yarn is stiff, with low elongation. Evenness corresponds to that of ring-spun yarn. Strength is partly dependent upon delivery speed.

Characteristics of the process are:

- relatively high energy consumption;
- use of water;
- adhesive fibers or binder must be washed out, and are therefore lost; if they were not washed out, the end product would be unusable;
- a great deal of specific know-how is needed.

2.5.2.3. Specification of the laboratory machine (about 1975)

Spinning positions per machine	8
Delivery speed	500 (600) m/min
Raw material	cotton and synthetic fibers (up to 80 mm)
Count range	Ne 6 - 40; 15 - 100 tex
Feedstock type	draw frame sliver
Yarn type	bonded yarn
Yarn characteristics	flat, high covering power, good evenness
Field of use	bath towels, interlinings, coating material
Advantages	elimination of twist
Special features	needs water and gas

2.5.3. Bobtex process

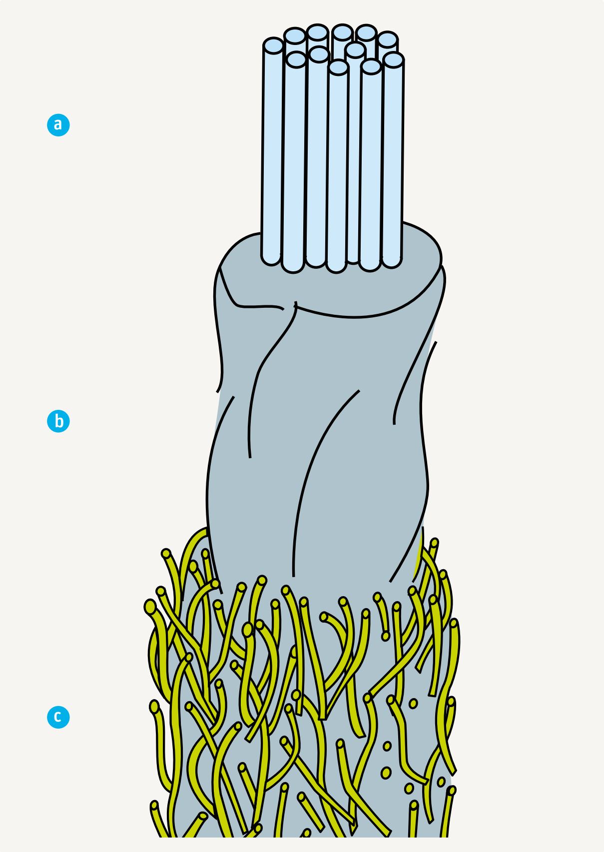

Fig. 23 – A Bobtex yarn

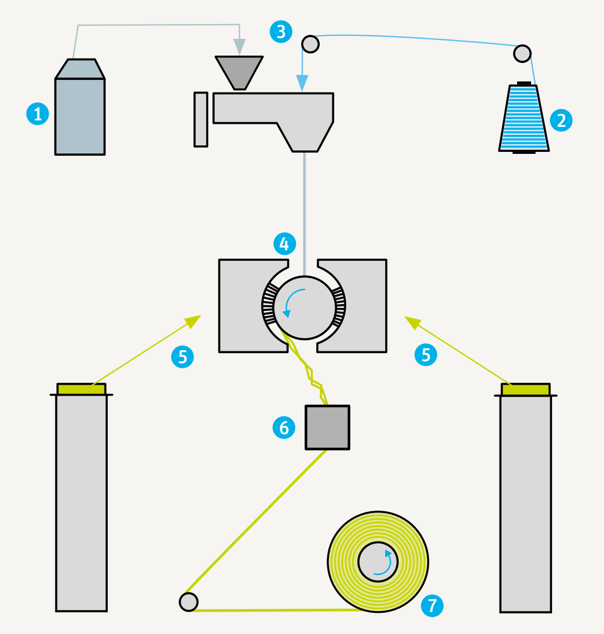

Fig. 24 – The Bobtex spinning principle

2.5.3.1. Operating principle

The Bobtex spinning machine (the name „Bobtex“ is derived from the name of the inventor, Bobkowicz) had two spinning positions and produced a multiple-component yarn, which is composed of (Fig. 23):

- a core of mono- or multi-filaments making up 10 - 60 % and forming the yarn carrier (a);
- a polymer intermediate layer (20 - 50 %) (b); and
- staple fibers embedded in the intermediate layer to provide a covering layer and making up 30 - 60 % (c).

In the course of production of this yarn, as shown in Fig. 24, the filament (2) runs through an extruder (3), after which a coating of molten polymer (1) remains stuck to it. Before this polymer can solidify, opened staple fibers forming a covering layer are pressed into the molten material in unit (4). This unit represents an opening assembly for the attenuation of two draw frame or card slivers (5) fed in from the side. A false-twist device (6) ensures good binding-in of the staple fibers. The resulting yarn is wound onto large packages (7) on the base of the machine.

2.5.3.2. Specification of a laboratory machine (about 1970)

Spinning positions per machine	2
Delivery speed	approximately 600 m/min
Raw material	filament/polymer/fibers
Count range	Ne 2 - 20; 30 - 300 tex
Feedstock type	card sliver
Type of yarn	three-component yarn
Yarn characteristics	high covering power, stiffness, evenness, wool-spun characteristics
Field of use	sacks, carpet backing, industrial woven fabric
Advantages	high production, package mass up to 50 kg
Special features	high consumption of energy and water

2.6. The False-twist process

2.6.1. The false-twist principle

2.6.1.1. Generation of false twist

If a fiber strand (Fig. 25 (A)) is held firmly at two spaced points by clamps K_1 and K_2 and is twisted somewhere between them, this strand always takes up the same number of turns of twist before and after the twist element (T). However, these turns have opposing directions of twist, which are represented in the example in Fig. 25 (A) as Z-twist on the right and S-twist on the left. If the clamps are replaced by rotating cylinders (Z_1 and Z_2 in Fig. 25 (B)) and the yarn is allowed to pass through the cylinders while twist is being imparted, the result is governed by the false-twist law and is different from the case of the stationary yarns, as previously assumed. A moving yarn entering the section (b) already has turns of twist imparted in section (a). In the example illustrated (B), there are turns of Z twist.
As the twist element is generating turns of S twist in the left-hand section, this simply means that each turn of the Z twist imparted in the first section (a) is canceled by a turn of S twist imparted in the second section (b). The fiber strand thus never has any twist between the twisting element and the delivery cylinder. In a false-twist assembly, turns of twist are present only between the feed cylinders and the twisting element. This principle is exploited, for instance, in false-twist texturing.

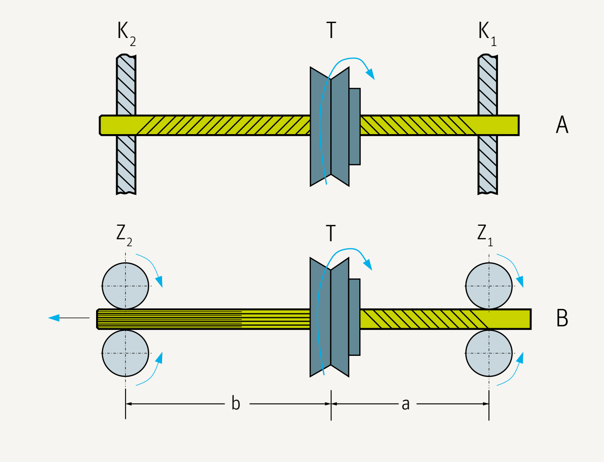

Fig. 25 – The false-twist principle

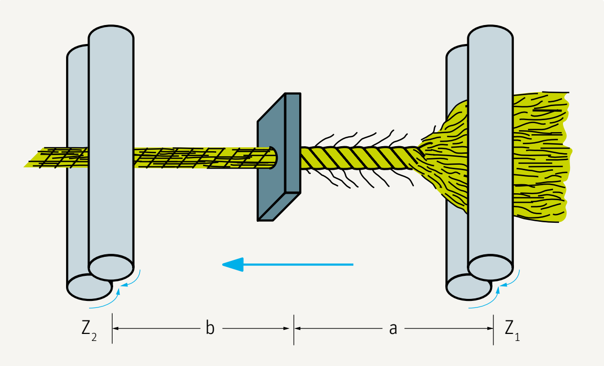

Fig. 26 – Spinning yarn by means of false twist

2.6.1.2. Forming a yarn with the aid of false twist

As shown above, a fiber strand leaving the false-twist assembly consists of parallel, non-twisted fibers. This principle is normally unsuited to the task of giving strength to the yarn. In spite of this, the principle is now exploited to enable yarns to be spun, admittedly with a modification of the system. For example, the fiber strand fed to cylinders Z_1, is allowed to enter the false-twist region (a) on a very broad basis, with the result that a greater or smaller proportion of edge fibers can escape the twisting action because of the broad spread of the strand upon entry.

In contrast to the description in the previous section, in Fig. 26, the strand entering the twist element is no longer fully twisted. The core – admittedly by far the greater proportion of the fibers – has twist, but the cover of fibers have either no twist or only a few turns. The opposing turns imparted by the twist element cancel all twist originally present, namely, that in the core, and give twist to all fibers that were originally untwisted, i.e., the envelope of fibers. These are wound around the core fibers so that a bundled yarn is obtained (Fig. 27).

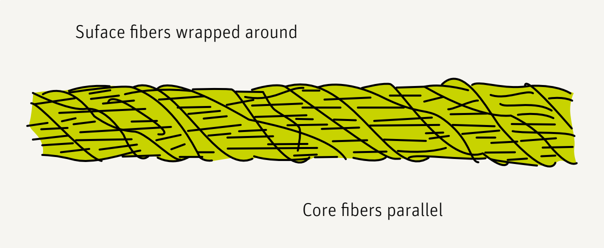

Fig. 27 – False twist (fasciated) yarn

Known processes operating on this principle are Rotofil by Du Pont (which has since been abandoned), Dref-3000 by Dr. Ernst Fehrer, Linz, and Murata Jet Spinning. The false-twist principle has opened up previously unforeseen possibilities for forming yarn.

2.6.1.3. Spinning elements

In false-twist spinning, in contrast to open-end spinning, the main fiber strand is not opened into individual fibers. It remains as a coherent strand from the feedstock through to the take-up package. Currently, drafting arrangements are used exclusively for attenuation. A variety of devices can be imagined as twist-imparting assemblies:

- pneumatic (one or two air jets);
- hydraulic;
- mechanical;
- perforated drums;
- double discs;
- double belts;
- rotating tubes; etc.

Some mechanical twist assemblies would require a higher spinning tension than the pneumatic systems.

2.6.2. Two nozzle Air-jet spinning

2.6.2.1. Operating principle

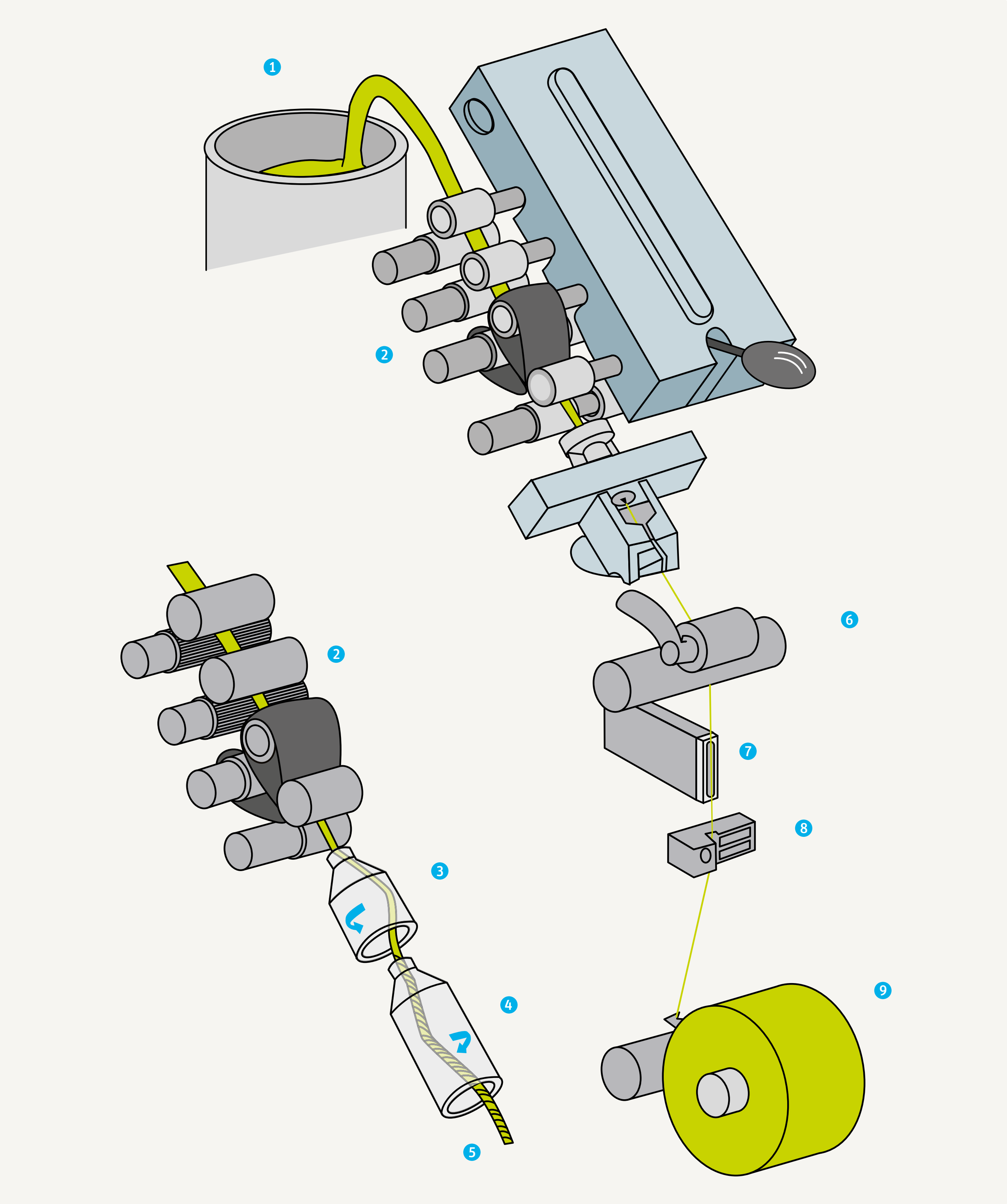

Fig. 28 – Two nozzle Air-jet spinning principle (Murata MJS)

As shown in Fig. 28, a draw frame sliver fed from a can (1) is passed to a drafting arrangement (2), where it is attenuated by a draft in the range of 100 - 200. The fiber strand delivered then proceeds to two air jets (3 and 4) arranged directly after the drafting arrangement. The second jet (4) is the actual false-twist element. The air vortex generated in this jet, with an angular velocity of more than 2 million rpm, twists the strand as it passes through so that the strand rotates along a screw-thread path in the jet, achieving rotation speeds of about 250 000 rpm. The compressed air reaches the speed of sound when entering the central canal of the false-twist element. Since the axial forces are very low during this rotation, only low tensions arise in the yarn.

The ability of the vortex to impart torque is so high that the turns of twist in the yarn run back to the drafting arrangement. The fiber strand is therefore accelerated practically to full rotation speed as soon as it leaves the front roller. The edge fibers which ultimately bind the yarn together by becoming wrapping fibers are in a minority. For process reasons, they do not exceed about 5 % of the total yarn mass. These edge fibers exhibit relatively few turns of twist in the same direction as the false-twisted core fibers or can even be slightly twisted in the opposite direction. This is partly ensured by causing the strand to emerge from the nip line in a broadly spread form, but mainly by generating in the first jet (3) a vortex with an opposite direction of rotation to the vortex in the second jet (4).
This first vortex is in fact weaker in intensity than the second and cannot really affect the core fibers, but can grasp the edge fibers projecting from the strand at one end. Since the first vortex acts against the twist direction generated by the second jet, it prevents the edge fibers from being twisted into the core or even twists them in the opposite direction around the core fibers. As the strand runs through the second jet, the following occurs.
The turns of twist generated by the jet (4) are canceled in accordance with the false-twist law. The core fibers, i.e. the vast majority, no longer exhibit any twist; these fibers are arranged in parallel. On the other hand, the edge fibers (which previously exhibited no twist, relatively little twist, or even twist in the opposite direction) receive twist in the direction imparted by the jet (4), as determined by the law of false twist; they are therefore wound around the parallel fiber strand. They bind the body of fibers together and ensure coherence. A twist diagram prepared by Dr. H. Stalder [1] demonstrates this twisting procedure (see Fig. 29).

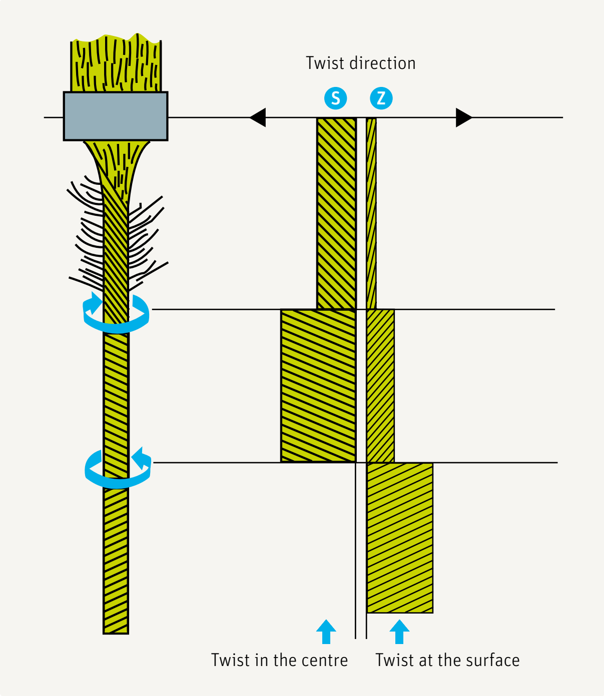

Fig. 29 – The distribution of twist in the running fiber strand

The resulting bundled staple-fiber yarn passes from the take-off rollers (6 in Fig. 28) through a yarn-suction device (7) and an electronic yarn clearer (8) before being wound onto a cross-wound package (9).
The two nozzle Air-jet spinning system represents a very interesting process, which has already been introduced into practical operation with some success.

2.6.2.2. Raw material requirements

The process has so far been restricted to spinning pure synthetic fibers, blends of synthetic fibers, or blends of synthetic with cotton fibers. Pure cotton can be processed only in combed form and usually still gives a low-strength product (with 50 - 70 % of the strength of ring-spun yarn, which means that processing 100 % cotton on two nozzle Air-jet machines is not an industrial solution). Dirt in the fiber material acts as a disturbing factor. Almost all the yarn characteristics are improved by the use of longer and finer fibers. About 80 fibers at least are needed in the yarn cross-section.

The fibers should have:
- high strength;
- fairly high fiber-to-fiber friction;
- low bending stiffness;
- low resistance to twist; and
- only a small proportion of short fibers.

2.6.2.3. Yarn characteristics

The yarn character is slightly different from that of ring-spun yarn. It is somewhat:
- weaker;
- stiffer; and
- harder.

The hardness can be reduced by using finer fibers and by treatment of the finished product with a softener (e.g. with a silicone).
Additional points of comparison with ring-spun yarn are:

Positive:
- good evenness (like ring-spun yarn);
- good abrasion resistance;
- low tendency to pilling;
- low snarling tendency;
- shrinkage similar to that of ring-spun yarn.

Negative:
- higher resistance to bending;
- slightly lower covering power;
- wrapping fibers not uniformly distributed over the length; sometimes there are slightly more on the surface, sometimes slightly fewer.

A large number of wrapping turns impart more strength but at the same time greater hardness. Synthetic fiber yarns and blends of synthetic fibers and cotton with a proportion of synthetic fibers of at least 50 % achieve strength levels of about 80 % or more relative to ring-spun yarn.

2.6.2.4. Interrelationships in spinning technology

Feedstock
Draw frame sliver is suitable as feedstock. Three passages should be used in order to obtain adequate parallelization of the fibers in the yarn. On account of the maximum draft of 200 in the drafting arrangement, relatively fine strands are needed. The sliver mass is in the region of 3 g/m (3 ktex).

Drafting arrangement
Four-line double-apron drafting arrangements are used, which permit drafts of 65 - 220. Both the upper and lower aprons are short. The fiber strand is not opened out into individual fibers but merely attenuated. The advantage of this is that it is not necessary to reassemble the fibers, which exhibit a higher degree of parallelization than fibers in open-end spinning, for example.

Twist jets
The two nozzle Air-jet spinning principle uses two jets in sequence. The twist level in the yarn is dependent upon both the throughput speed and the air pressure in the jets. The latter is usually in the range of 4 - 6 bar. The air vortex rotates with a speed of 1 to more than 2 million rpm, the speed being somewhat lower in the first jet than in the second. The yarn takes up about 6 - 12 % of the revolutions of the vortex.

Binding-in the fibers
Coarse yarns cannot be produced by two nozzle Air-jet spinning. This is due to the geometrical ratio between the surface area of a yarn and its cross-section. The coarser the yarn, the lower the ratio, i.e. it becomes steadily more difficult for the wrapping fibers on the surface to bind the increasing number of core fibers together effectively.
Influence can be exerted on the binding action, the spinning conditions, and the yield primarily via:
- the raw material;
- the width of the fiber strand leaving the drafting arrangement;
- the spinning draft;
- the spinning tension (yarn tension) between the front roller and the take-off rollers;
- the air pressure in the jets; and
- the twist relationship between the first and second jets.

These parameters are adjustable within limits.

2.6.2.5. Economics

The Murata two nozzle Air-jet spinnig machine (MJS) is fully automated. This reduces the labor requirement, of course, and economically is a very positive feature. Automation includes:
- automatic piecing, by a knotter technique;
- automatic doffing;
- yarn clearer;
- yarn length measuring device.

As in rotor spinning, the economics of jet spinning are further improved by the fact that the roving frame and the winding process are eliminated. Yarn manufacturing costs in jet spinning are therefore considerably lower than in ring spinning.

2.6.2.6. Specification of the MJS machine

Spinning positions per machine	up to 72 (single-sided machine)
Delivery speed	150 - 300 m/min
Raw material	synthetic fibers and blends (combed cotton)
Count range	7.5 - 30 tex; Ne 20 - 80
Feedstock type	draw frame sliver
Type of yarn	bundled single yarns
Yarn characteristics	reasonable strength, low hairiness, rough outer surface
Field of use	ladies‘ outerwear, shirting material, sheets
Remarks	low production costs, low personnel demand, no rapidly rotating parts, three draw frame passages necessary

2.6.2.7. Industrial impact of the MJS machine

At the turn of the millennium, about 220 000 MJS spinning positions (equal to approximately 3 000 machines) were installed in spinning mills. The bulk of these machines, i.e. about 2/3, are operating in the USA, and the rest mainly in Asian countries. However, there are no machines in European mills. This somewhat limited success of MJS is mainly due to the inability of this system to process 100 % cotton. This defect can obviously not be fully offset by the good economics of the process and the quite good overall yarn quality when spinning synthetic yarns or blends.

2.6.3. Dref-3000 process

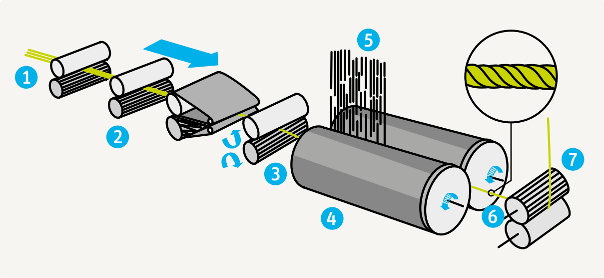

Fig. 30 – The Dref-3 spinning principle

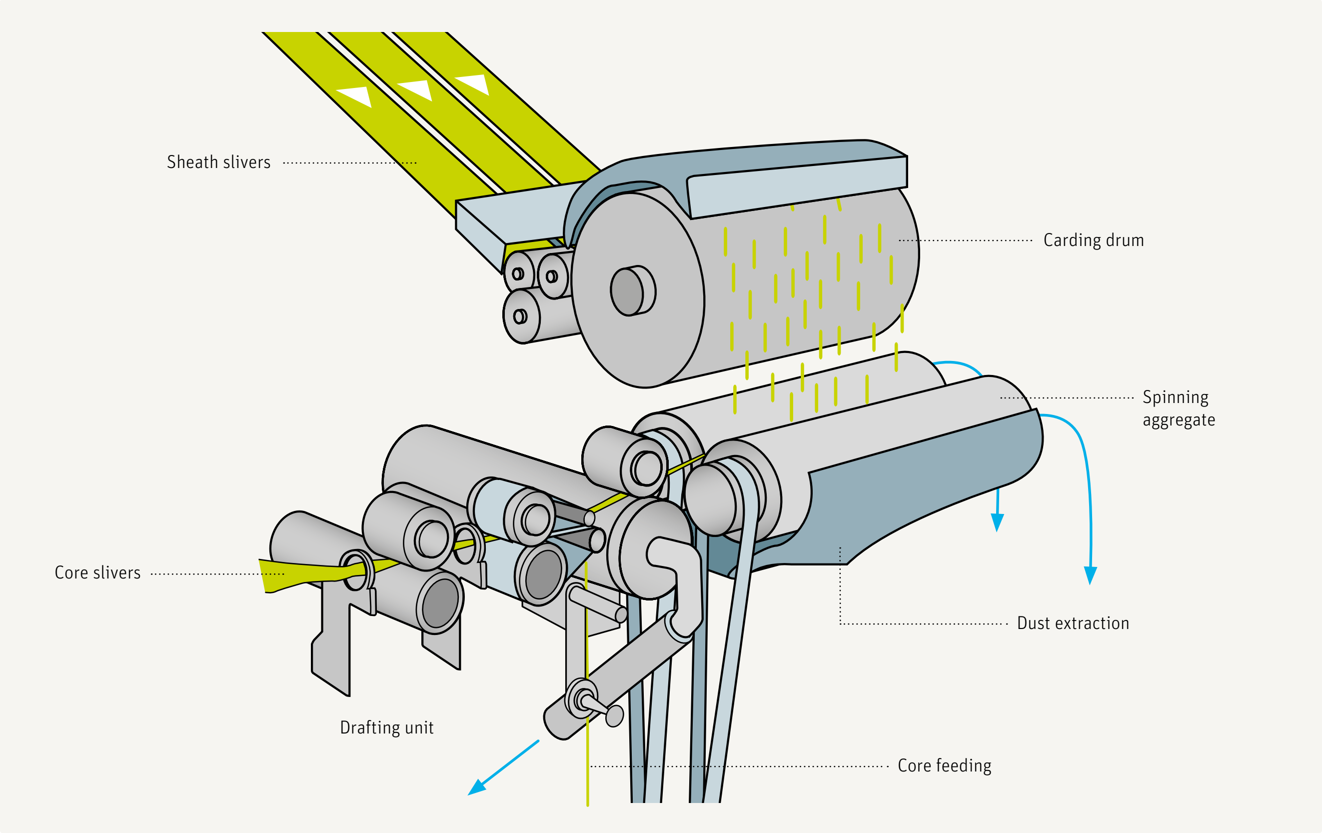

Fig. 31 – The Dref-3000 spinning unit

2.6.3.1. Operating principle

The Dref-3000 spinning system (Fig. 30 and Fig. 31) produces bundled yarn according to the friction-spinning principle. Basically, it is a Dref-2000 process expanded to accommodate a drafting arrangement (2) before the spinning drums (4).
A draw frame sliver (1) with a linear density of 2.5 - 3.5 ktex is passed into this three-line double-apron drafting arrangement (2). The strand (3) resulting from the draft of about 100 - 150 proceeds from the delivery of the drafting arrangement to the convergent region between the two perforated drums (4). A pair of take-off rollers (7) draws this strand through the convergent region of the perforated drums and out of the spinning zone.
The coherent fiber strand is nipped at the take-off rollers (7) and the drafting arrangement (2) and is rotated between these points by a pair of perforated drums (4). It is therefore false-twisted between the nips. This means that turns of twist are present between the drafting arrangement and the drums, but not between the drums and the withdrawal rollers. If this state of affairs were to continue, the strand would fall apart. Before this can happen, staple fibers are fed in free flight from above (5) into the convergent region between the drums. Owing to the rotation of the perforated drums, these incoming fibers wrap themselves around the horizontally moving strand. A bundled yarn is formed.

The fiber cloud (5) arriving from above emerges from a second drafting arrangement with two opening rollers. This arrangement is fed with four to six draw frame slivers with a linear density of 2.5 - 3.5 ktex.

From the take-off rollers (7) the yarn passes to a winding unit. The yarn leaves the machine in the form of cross-wound packages.

2.6.3.2. Raw material used

Almost all kinds of fiber material can be spun by this process, even those that present problems in other contexts, e.g., aramid and carbon fibers. Polyester and polyamide fibers are often used in the core and cotton in the envelope. The proportion of envelope fibers can be in the range of 15 - 60 %, due to the fact that core and wrapping fibers are fed from separate sources. Even filaments can be bound into the core to produce core yarns. The usable range of fiber linear density is from 0.6 to 6.7 dtex.

2.6.3.3. Specification

Spinning positions per machine	3 - 24
Delivery speed	250 m/min
Raw material	cotton/synthetic fibers
Count range	Ne 0.9 - 14.5; 40 - 700 tex
Feedstock type	draw frame sliver
Type of yarn	bundled yarn
Yarn characteristics	few envelope fibers = ring-spun yarn character; many envelope fibers = rotor-spun yarn character
Field of use	home textiles, sport and leisure clothing, outerwear, technical products
Advantages	elimination of process stages
Remarks	simple production process

2.6.3.4. Industrial impact of Dref-3000

Dref-3000 is a typical process for the production of yarn specialties:

- yarns made from unusual fibers;
- composite yarns with a special core/sheath structure;
- yarns with special properties (protective textiles).

Dref-3000 is therefore not a spinning process for mass production, but an interesting and successful system for niche markets, where special, tailor-made yarns are required.

2.6.4. PLYfiL spinning process

2.6.4.1. Improved market prospects for plied yarns

Plied yarns are seldom made from the products of new spinning processes (Repco and spin-twist processes are exceptions). Most plied yarns are made from ring-spun singles. Ply twisting is therefore usually a cost-intensive process, and folded yarn is generally significantly more expensive than single yarn. The field of application of plied yarn has thus shrunk in recent years. Nowadays, in short staple spinning, single yarns are used increasingly, although often a plied yarn would be more suitable. The PLYfiL process by the Suessen company has opened up the possibility of producing folded yarns relatively economically; ply twisting now has an opportunity to regain lost ground. The plied yarn made in accordance with this process exhibits slight differences in comparison with conventional ply-twisted

yarn; it is somewhat softer, fuller, and more open. However, PLYfiL yarn has the same strength as conventional ply-twisted yarn and is very even.
The PLYfiL process is particularly suitable for medium to fine plied yarns and is therefore a direct competitor of ring spinning and twist spinning (Siro).

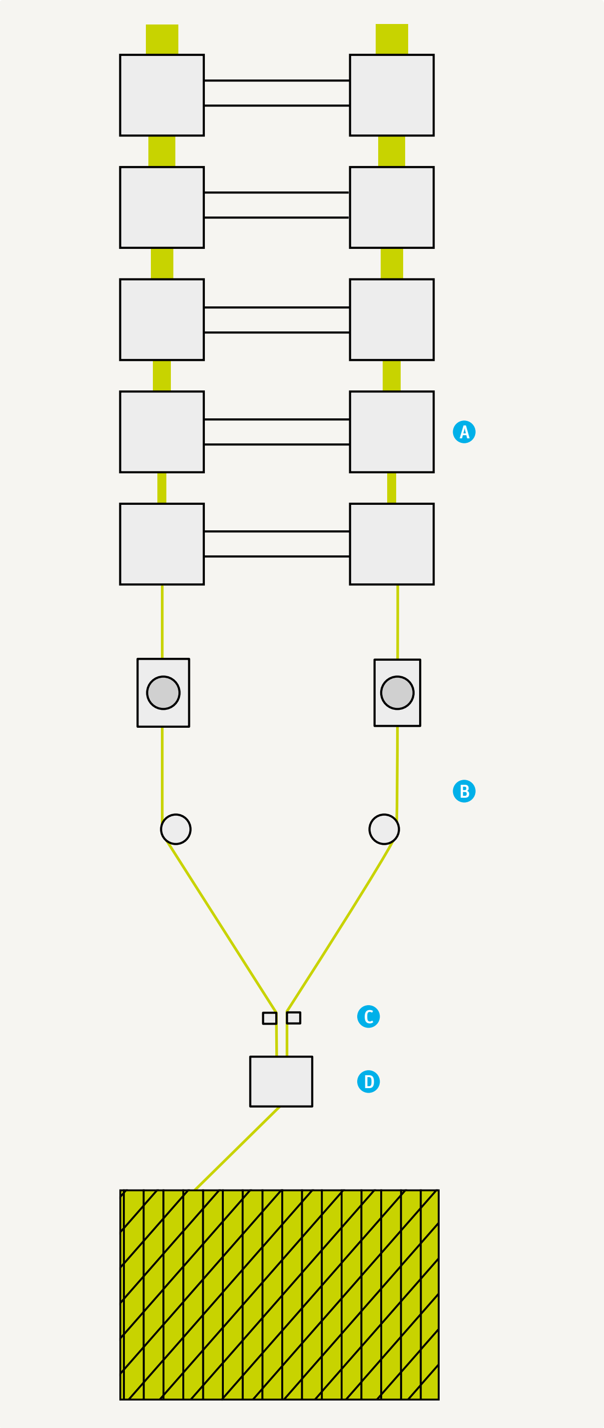

Fig. 32 – The PLYfiL spinning system

Principle of operation
Draw frame slivers provide the feedstock. These are passed through a five-line drafting arrangement (Fig. 32, A) with a draft of up to 350. The drafting arrangement (A) is followed by a strength-imparting unit (B). Here, as in the Murata false-twist method, an Air-jet winds edge fibers and projecting fiber ends around the strand. As previously described in this volume, a bundled yarn is produced in which the core fibers are aligned in parallel while individual fibers of the envelope are wound around the body of the yarn. In contrast to other processes of the same general type, the yarn only receives sufficient strength here to enable winding up and subsequent twisting to occur. The bindings typical of jet-spun yarn are missing; they would give the yarn a rather hard character.

Two such yarns are combined at C and taken away by the take-off rollers (D). The yarn is taken up in a cheese, and this is a ready-made feedstock for the twisting stage (ring or – preferably – two-for-one twisting); the assembly-winding step is eliminated.

The wrapping fibers are detwisted during the twisting operation; in the plied yarn, all fibers lie parallel. The process differs from classical twisting in that it is not necessary to detwist turns in the single ends in order to achieve a soft plied product. The twisting step can therefore be carried out with relatively low twist factors, enabling higher delivery speeds to be achieved.

2.6.4.2. Specification of the short-staple machine

Spinning positions per machine	20 - 100
Winding positions	10 - 50
Delivery speed	150 - 250 m/min
Raw material	cotton, synthetic fibers, blends (up to 90 mm)
Count range	8.3 - 25 tex x 2 (2 x Nm 40 - 120)
Feedstock	draw frame sliver, 2.5 - 5 ktex
Yarn type	plied, bundled yarn of low strength
Folded-yarn characteristics	even, strong, soft, fibers lie parallel in plied yarn
Field of use	shirts, underwear
Advantages	very economical, roving frame and assembly-winding are unnecessary

Field of application

Suessen has offered PLYfiL in two versions:

- PLYfiL 1000 for the short-staple spinning mill;
- PLYfiL 2000 for the medium-to-long-staple spinning mill.

PLYfiL folded yarns are suitable for woven and knitted products. The short-staple plied yarns are mainly suited to shirting, underwear, etc., and the long-staple yarns are used in the menswear and ladies' wear sectors.

Despite some quite attractive advantages of PLYfiL, Suessen has discontinued sales of these machines. The market for plied yarns is obviously limited, particularly in short staple spinning, and for PLYfiL this market is further restricted by the special structure of the PLYfiL ply yarns.

2.7. Air-jet spinning

2.7.1. Development

The two nozzle Air-jet spinning system (refer to section “2.6.2. Two nozzle Air-jet spinning”) achieves a fasciated yarn character, i.e. a structure with twistless core and twisted surface or wrapping fibers, through false twist during spinning. However, the false twist limits the percentage of twisted surface fibers to a relative low level of about 5 %. Two nozzle Air-jet spinning is therefore quite successful in processing man-made fibers and blends with cotton, whereas when spinning 100 % cotton, i.e. somewhat shorter fibers, Air-jet yarns do not achieve sufficient strength (Fig. 33). For this reason, the USA – with a large market for blended cotton/polyester yarns – has a considerable number of Air-jet machines in operation. In Europe and Asia, however, where predominantly cotton is processed, Air-jet spinning has had no success.

In view of this situation, Murata developed a new spinning process for fasciated yarns. The first patents erase were published in the 1980s. At that time an air vortex was combined with a rotating mechanical element. Since then, Murata has abandoned the rotating element, leaving just the air vortex with no movable mechanical part in the yarn formation zone. Murata presented this new Air-jet system under the name of Murata Vortex Spinning (MVS) at the Otemas 97 and then at the ITMA 99 (Fig. 34 a)). As in two nozzle Air-jet spinning, this system has a drafting unit for processing draw frame slivers and no moving parts in the spinning zone. Air-jet spinning, however, does not make use of false twist for yarn formation.

In 2008 Rieter launched its own J 10 Air-jet spinning machine in the market. A double sided machine with 100 individually driven spinning positions and 4 travelling robots aims at pushing the economy of this spinning system further (Fig. 34 b)).

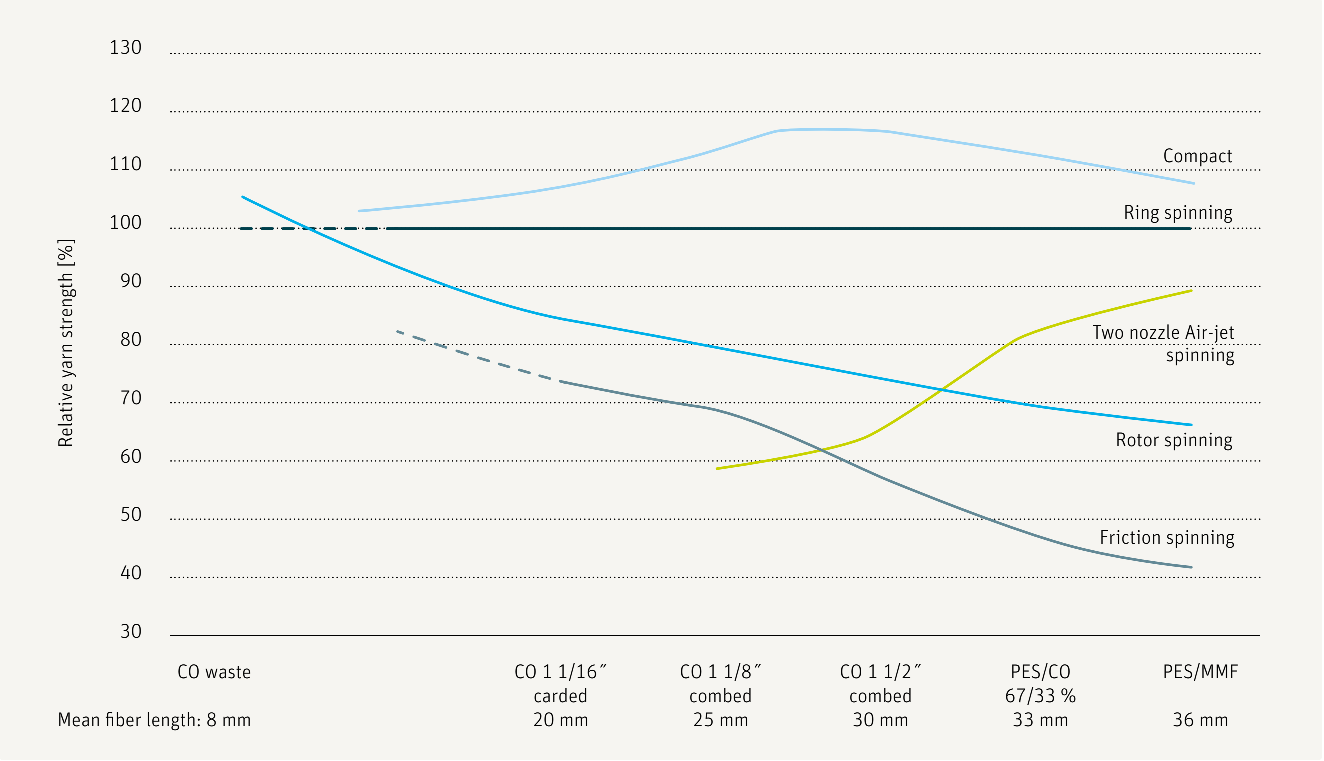

Fig. 33 – Relative yarn strength

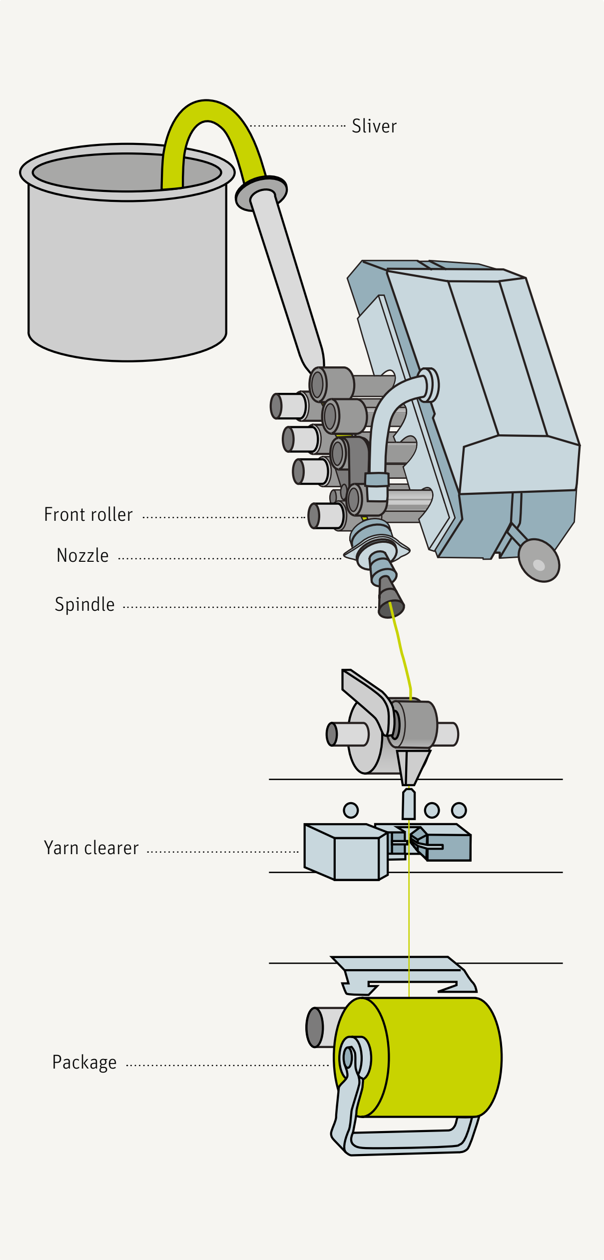

Fig. 34 a) – Air-jet spinning principle by Murata (MVS)

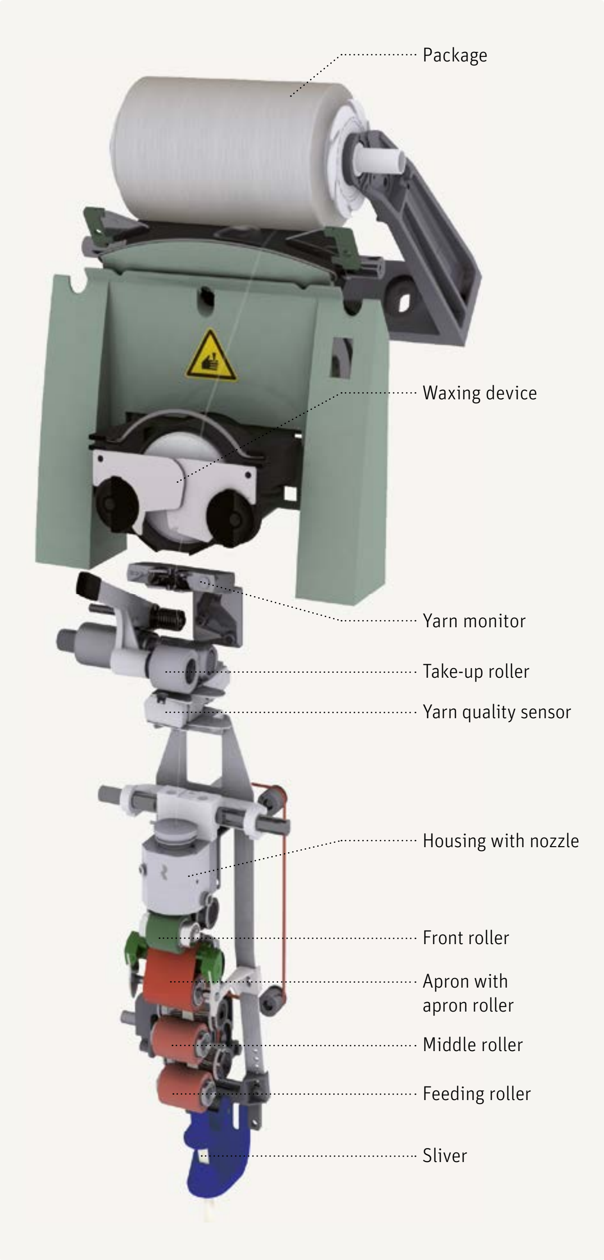

Fig. 34 b) – Air-jet spinning principle by Rieter (J 10)

Between the drafting unit and the point of yarn formation at the entry to a stationary spindle (tube), the fibers are conveyed absolutely parallel to each other (Fig. 35). During this fiber transport, a certain number of fiber ends are separated from the main fiber flow. These fiber ends are then twisted around the non-rotating yarn core at the entry of the hollow spindle by the action of a single air vortex.

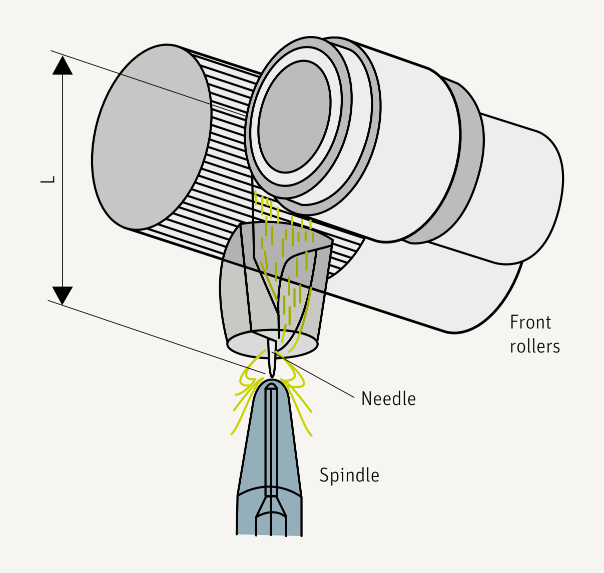

Fig. 35 – Fiber transport from front rollers (Murata MVS)

Compared to airjet spinning, this spinning process permits a considerable increase in the number of surface fibers, i.e. wrapping fibers, to the range of 15 to 30 %. This has a positive effect on yarn strength, particularly when spinning cotton. The Air-jet process has thus practically eliminated the main handicap of the two nozzle Air-jet spinning principle.

2.7.2. Principle of operation

In order to make Air-jet spinning possible, 2 quite difficult tasks have to be solved in the zone between the drafting system and entering the spindle.

- separation of free fiber ends;
- prevention of false twist formation.

The fiber feed channel and the spindle are surrounded by a housing (Fig. 36). The air vortex near the spindle entry generates a certain vacuum, which results in an air flow through this channel. This air flow transports the fibers from the drafting unit to the spindle entry.

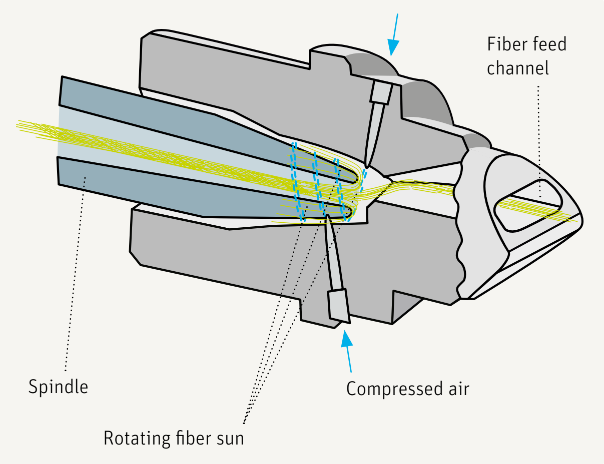

Fig. 36 – Nozzle area (Rieter J 10)

For generating free fiber ends, the correct choice of distance L (Fig. 35) is very important. This distance should be slightly shorter than the average length of the fibers being processed. This enables the transport air in the fiber feed channel to separate fiber ends from the main fiber flow. It is evident that the longer the distance L, the more free fiber ends become available. L is therefore an important process parameter. It is of course possible that during this process of fiber end separation, entire – mainly shorter – fibers are extracted from the main fiber flow. These fibers have no chance of being integrated in the yarn. They bypass the spindle and are lost. In Air-jet spinning, the fiber loss (relatively short fibers) is therefore relatively high (5 to 10 %). The higher the short fiber content in the sliver, the higher the ratio of fiber waste.

By the action of the vortex, the fiber ends eventually whirl around the spindle tip and are thus twisted around the twistless yarn core and transformed into a twisted yarn surface or cover fibers. This occurs at the spindle tip. The twist of these surface fibers generates a certain torque in the yarn being formed. This torque has the tendency to twist the fiber bundle between drafting unit and spindle. Twist of this kind must be avoided in order not to interfere with the generation of the necessary free fiber ends. This can be solved by means of a twist stop. For this purpose Murata uses a needle (Fig. 35), which detours the fiber bundle before entering the spindle, thereby acting as an efficient twist stop.

Once inside the spindle tip, the yarn formation process is finished, and the yarn can be taken off and wound onto a package.

2.7.3. Raw material requirements

Due to the relatively high percentage of wrapping fibers, the Air-jet process is perfectly capable of spinning 100 % cotton, from 1″ staple upwards. For finer yarn counts the cotton has to be combed, of course. Synthetics (up to 40 mm) and cotton/synthetics blends can also be processed without difficulty.

As in ring spinning, however, almost all the yarn characteristics are improved by the use of longer and finer fibers.

In Air-jet spinning, the fibers keep their orientation throughout the spinning process. Particularly the core fibers remain absolutely parallel to the axis of the fiber flow. To optimize the spinning results, it is therefore advisable to process slivers with very good fiber parallelization. This also helps to improve the performance of the drafting system. This means that slivers with 3 draw frame passages after carding should be used. As the total draft of the Air-jet machine is limited (180 - 220 fold, technology wise), it can be necessary to process slivers as fine as 2.5 ktex and even finer when spinning fine count yarn.

2.7.4. Drafting unit

As in two nozzle Air-jet spinning, the drafting unit is also a very important element in Air-jet spinning. High drafts have to be performed, with good evenness of the fiber flow and excellent orientation of the fibers, at very high production speeds. To achieve these goals, both suppliers have equipped the Air-jet machines with a 4-cylinder drafting system (Fig. 37).

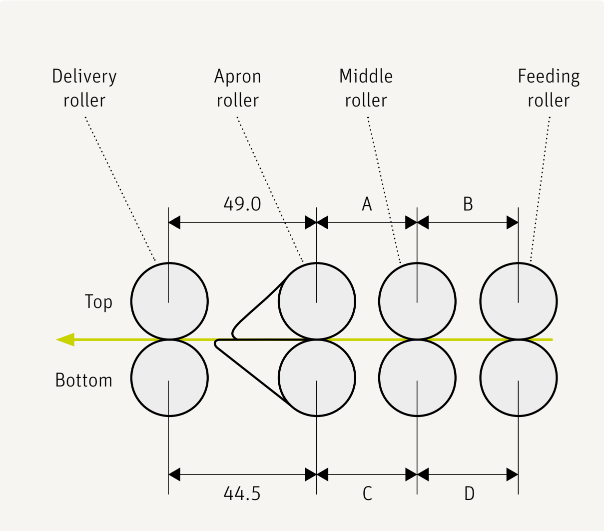

Fig. 37 – Drafting unit (Murata MVS)

In the pre-draft zone there is a draft ratio between 1.57 and 2.10. Distances B and D can be adjusted according to staple length. The resulting drafting distance in this first draft zone should be just slightly higher than the maximum length of the fibers to be processed.

The draft ratio in the break draft zone is variable in the range of 1.2 to 2.4. Here also, distances A and C are adjustable to suit the fiber material being processed, as in the pre-draft zone.

Fiber control in the main draft zone is achieved by a pair of aprons. To obtain optimal results, the main draft should be no less than 30-fold and no higher than 60-fold. As the aprons provide efficient fiber speed control, the drafting distance in the main draft zone is not adjustable.

The necessary cleaning of the drafting cylinders is performed pneumatically.

2.7.5. Spinning nozzle

The spinning nozzle is basically the yarn formation element, i.e. the heart of the Air-jet spinning process. Compressed air at up to 0.6 Mpa enters the actual spinning chamber through 4 small bores, thus creating a very strong air vortex (see Fig. 36). At the outlets of the bores, this air vortex has a rotation speed of up to 1 000 000 rpm. The vortex performs 2 functions through this high speed:

- generation of a vacuum and thereby an air flow through the fiber feed chanel;
- rotation of the free fiber ends around the spindle tip.

The vacuum is necessary in order to seize the fibers at the outlet nip of the drafting system and guide them securely through the fiber feed channel of the spinning nozzle toward the stationary spindle.

The fiber ends which have been split off from the main fiber flow between drafting unit and spindle entry eventually form a kind of fiber sun around the spindle tip (Fig. 36). In order to transform these fiber ends into wrapping fibers, they are rotated by the air vortex. The fibers thus reach a rotation speed of over 300 000 rpm. This speed is very high, but due to mechanical friction it is of course lower than the speed of the vortex.

In addition to generating twist, the rotation of the fiber ends also creates spinning tension in the yarn, i.e. tension in the yarn between nozzle and take-up rollers. This spinning tension P_{spinn} can be approximately calculated (Fig. 38). The shape of the fiber ends between spindle tip and nozzle housing is certainly curved. But with regard to the action of the centrifugal force acting on the fiber, it may be assumed that this fiber end f has a radial direction, as shown in Fig. 38. Under this assumption, force PA acting on the fiber at point A can be calculated by the formula for the spinning tension in rotor spinning, as it is the same physical situation, i.e. a rotating piece of fiber or yarn subjected to centrifugal forces [15]. The force in the fiber f at point A thus amounts to:

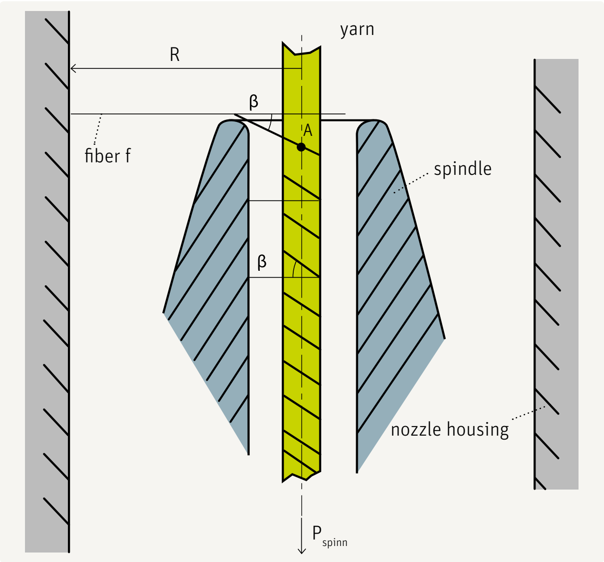

Fig. 38 – Calculation of the spinning tension (Rieter)

$$P_A = \frac{1}{2} T_{fiber}\,\omega_f^2\,R^2 e^{\mu\beta}$$

where:

T_{fiber} = fiber count in tex
ω_f = angular velocity in s^{-1}
R = radius of the spinning housing in cm
ß = fiber deflection angle

From this follows the component of the fiber force in the direction of the yarn axis P_{Aa}:

$$P_{Aa} = P_A \sin\beta$$

$$P_{Aa} = \frac{1}{2} T_{fiber}\,\omega_f^2\,R^2 e^{\mu\beta} \sin\beta$$

In order to obtain the spinning tension, the axial fiber force has to be multiplied by the number of wrapping fibers:

$$P_{spinn} = P_{Aa}\,n$$

This leads finally to:

$$P_{spinn} = \frac{1}{2} T_{yarn}\,W\,\omega_f^2\,R^2 e^{\mu\beta} \sin\beta$$

where:
T_{yarn} = yarn count in tex
W = portion of wrapping fibers, $0 < W < 1$

When spinning tension is calculated with this formula based on actual spinning data, the result shows tension values somewhat below 10 cN. This result corresponds very well with measured values of the spinning tension. It means that the spinning tension in Air-jet spinning is quite small, somewhere between 5 and 15 cN, and thus much smaller than in ring spinning. This low tension has an effect on end breakages. Unlike in ring spinning, end breakages mostly do not occur due to weak spots in the yarn, as spinning tension is far too low. If end breakages occur in Air-jet spinning, these are mostly due to irregularities in the fiber flow entering the spinning nozzle. Such irregularities can be the result of thick places in the feed sliver, drafting faults, fiber accumulations, large trash particles, etc.

2.7.6. Winding

The winding system has to be capable of handling the high yarn production speeds of the Air-jet spinning machine, i.e. up to 450 m/min. The Murata MVS machine is equipped with a traverse system common to all spinning units, as are the rotor spinning machines. But as the delivery speed in Air-jet spinning is at least double that in rotor spinning, this leads to a limitation of the possible number of spinning positions per machine side, due to the large increase in mass forces in the traversing system with increasing numbers of spinning positions and increasing winding speeds. The Murata MVS machine is single-sided with a maximum of 80 spinning positions whereas Rieter‘s J 10 Air-jet machine is designed as a double sided machine starting in the market with 100 spinning positions and potential of more spinning units per machine. Because of the single drive concept, the maximum number of spinning positions is not limited by the winding system. The yarn packages of Air-jet machine, cylindrical or slightly conical, can be used directly in downstream processing. Each spinning position of the machine is therefore equipped with a yarn clearer, which efficiently removes any undesired defects from the yarn.

2.7.7. Automation

Air-jet spinning is a high-output process. The Air-jet spinning machines are therefore fully automated, of course.

Automation deals with the following functions:

- repairing yarn breaks;
- doffing full yarn packages;
- insert empty tubes and start spinning.

For repairing yarn break, the machine is equipped with up to 3 carriages (or robots) traveling along the machine. When a yarn is broken, one of the robots seeks the yarn end on the package, then it restarts the spinning process and finally it recombines the yarn end from the package with the one which is leaving the nozzle after spinning has restarted. The yarn being spun during the splicing or knotting process is taken care of by a yarn storage system. The repair of an end breakage is therefore not performed by a piecing, as is the case in rotor spinning.

A special carriage travels along the front of the machine for doffing full yarn packages. This carriage takes a full package out of the package holder, puts it down on a conveyer belt and inserts an empty tube into the package holder.

2.7.8. Yarn structure

As already mentioned, Air-jet yarns have a fasciated (core / sheat) structure. In fact, Air-jet spun yarns consist of a core of essentially parallel fibers without any twist, which is surrounded and bound together by wrapping fibers. These wrapping fibers provide compression forces in the core and thereby the necessary fiber friction in order to achieve the desired yarn strength. As the wrapping fibers in Air-jet yarns account for 15 to 30 % of the total yarn mass, the core fibers are virtually completely covered by the wrapping fibers, so that Air-jet spun yarns look very much like a fully twisted yarn, such as a ring-spun yarn.

This particular structure of the Air-jet spun yarns influences the yarn properties, of course. These properties are mainly determined by 2 parameters:

- the percentage of wrapping fibers;
- the twist level of the wrapping fibers.

The percentage of wrapping fibers can be influenced by the spinning draft and by the distance L (Fig. 35), and it is also a function of the yarn count.

The spinning draft is the ratio between the speed of the take-up roller and the speed of delivery roller of the drafting unit. This ratio is usually slightly below 1, which means that the yarn take-up speed is slightly lower than the delivery speed of the drafting unit. If the spinning draft is reduced, the number of wrapping fibers increases.

L is the distance between the outlet nip of the drafting unit and the spindle. With an increase in distance L, more fiber ends have the chance to be separated from the main fiber flow, and thus more wrapping fibers are generated.

Experience has shown that with coarser yarn count, the number of wrapping fibers increases, but not at the same rate as the tex count. The percentage of wrapping fibers therefore tends to decrease as the yarns become coarser. While fine count yarns reach a level of up to 30 % of wrapping fibers, this percentage drops to 15 % or even below for coarse yarns.

The second parameter of great importance for the yarn properties is the wrapping twist. This twist can be influenced by the spinning speed and the flow rate of the compressed air.

For given nozzle conditions, the fiber sun rotates at virtually constant speed. An increase in the yarn delivery speed must therefore lead to a reduction in the wrapping twist level. This is in fact the case, as is shown by the spinning results in Fig. 39.

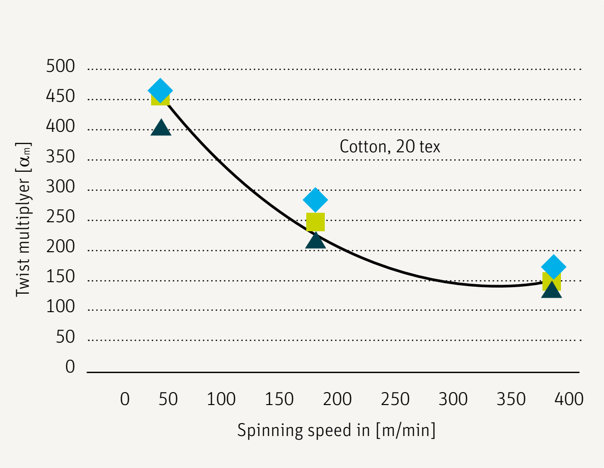

Fig. 39 – Yarn twist as a function of spinning speed (Rieter)

The wrapping twist level is furthermore a function of the flow rate of the compressed air. This flow rate depends primarily on the air pressure and on the cross-section of the injection holes. When the pressure of the compressed air increases, the wrapping twist level increases virtually proportionally (Fig. 40). Similarly, a larger cross-section of the injection bores leads to a higher wrapping twist.

In Air-jet spinning, it is therefore easily possible to accurately control the level of the wrapping twist.

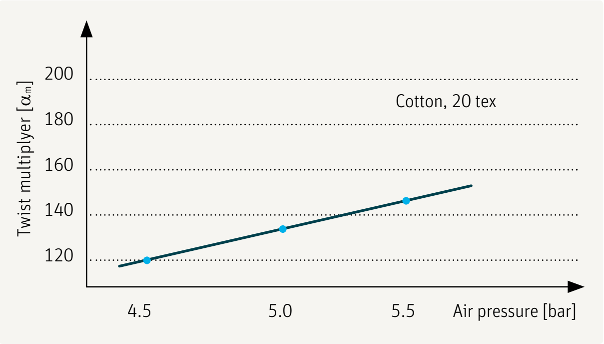

Fig. 40 – Yarn twist as a function of air pressure (Rieter)

2.7.9. Yarn properties

This chapter contains a description of the Air-jet yarn properties, together with an indication of how these properties can be influenced.

2.7.9.1. Yarn strength

Yarn strength is very dependent on the wrapping twist (Fig. 41). For optimal yarn strength, the wrapping twist should be in the range of 140 to 160 α_m. With lower or higher wrapping twist, yarn strength is reduced. The strength/wrapping twist ratio is thus very similar to the strength/twist curve of a ring-spun yarn. For optimal yarn strength, however, Air-jet spun yarns need a somewhat higher twist than ring-spun yarns.

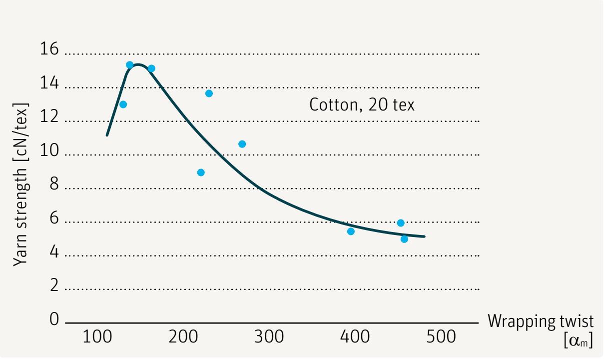

Fig. 41 – Yarn strength as a function of twist (Rieter)

The strength of Air-jet spun yarns depends to a lesser degree on the percentage of wrapping fibers. It is known from experience that good strength values are achieved with a wrapping fiber percentage of about 15 % or more. If the percentage drops much below 15 %, the yarn is no longer fully covered by wrapping fibers, the yarn axis becomes distorted into a corkscrew shape, and yarn strength is reduced.

Within the product range of Air-jet spinning, yarn strength is situated between the strength of ring-spun and rotor-spun yarns, the strength of Air-jet spun yarns being nearer to rotor-spun yarns for shorter staples, and nearer to ring-spun yarns for longer staples (Fig. 42 and Fig. 43).

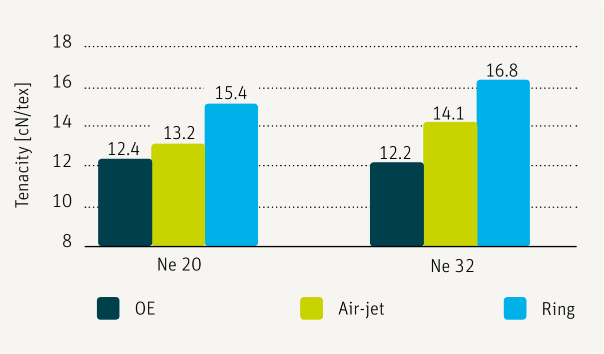

Fig. 42 – Comparison of yarn strength, 100 % cotton carded (Murata)

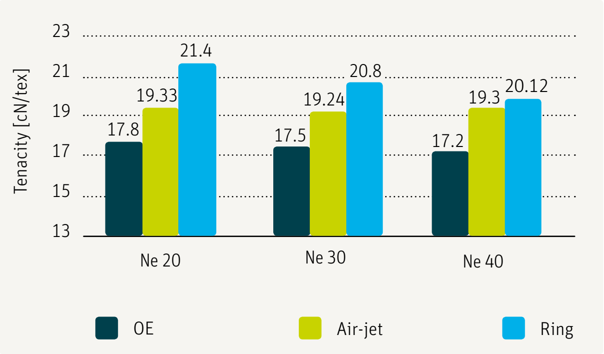

Fig. 43 – Comparison of yarn strength, 50 % polyester,
50 % cotton carded (Murata)

2.7.9.2. Yarn evenness, thin and thick places

As described in chapter 2.7.4., the drafting unit is a very important element. The settings of this unit have to be carefully adapted to the fiber material being processed. Under this presupposition, Air-jet spun yarns achieve good evenness values, comparable to those of ring-spun yarns. The drafting unit is in fact the main element for influencing the evenness values of the Air-jet spun yarns.

2.7.9.3. Neps

The number of neps in Air-jet spun yarns is more or less independent of the thin and thick places. This is particularly true for the 200 % neps. The spinning results have actually shown that sometimes wrapping fibers or fiber bundles might be counted as neps. The chances of this happening increase, of course, with increasing wrapping twist levels.

Spinning results in Fig. 44 demonstrate quite clearly that with decreasing spinning speed, i.e. increasing wrapping twist, the number of neps increases quite drastically.

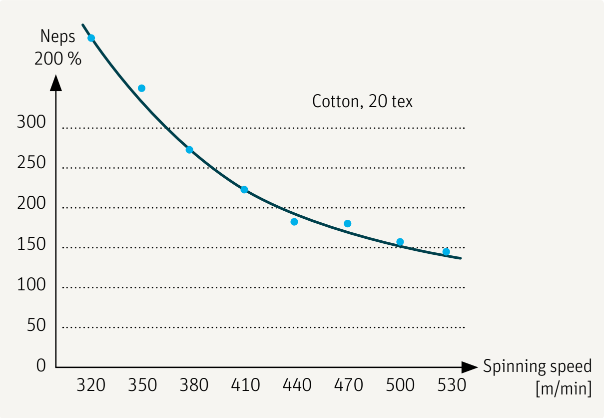

Fig. 44 – Nep count as a function of spinning speed (Rieter)

The nep count therefore gives some indication of the yarn structure. Even so, the 200 % nep count of the Air-jet yarns is similar to the nep count of ring-spun yarns, provided the Air-jet yarns do not have an excessively high wrapping twist.

2.7.9.4. Hairiness

The hairiness of Air-jet spun yarns is considerably lower than the hairiness of comparable ring-spun yarns (Fig. 45). This is particularly the case for longer hairs, with lengths of 3 mm and more. The lower hairiness is due to the particular structure of the Air-jet spun yarns. The core fibers do not actually reach the yarn surface, but are hidden inside the yarn. This means that these fibers basically make no contribution to yarn hairiness. The hairiness is therefore generated only by the wrapping fibers, which represent only a relatively small percentage of the total fiber mass.

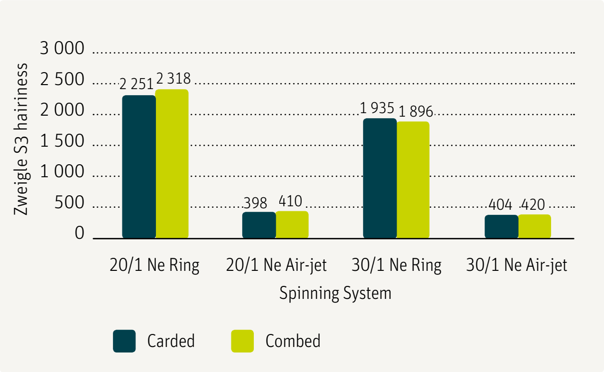

Fig. 45 – Zweigle S3 hairiness (Murata)

As in ring-spun yarns, the hairiness of Air-jet yarns depends very much on twist. The higher the wrapping twist, the lower the hairiness and vice versa (Fig. 46). It is therefore easily possible to influence the hairiness level of Air-jet yarns via the wrapping twist.

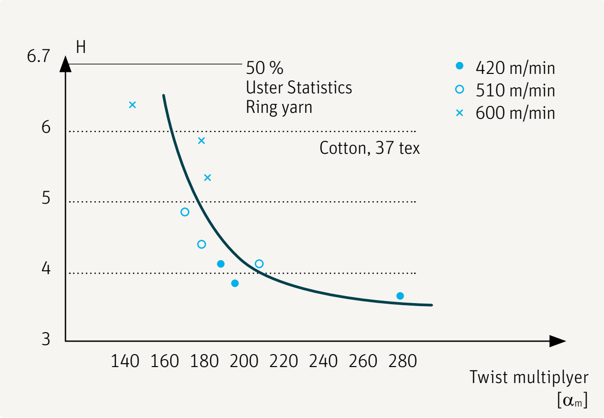

Fig. 46 – Uster Hairiness as a function of wrapping twist (Rieter)

2.7.9.5. Yarn abrasion resistance

Lower hairiness has a positive effect on the abrasion resistance of Air-jet yarns. The abrasion resistance of Air-jet yarns, as measured by the Staff Test, is in fact clearly better than that of ring-spun yarns.

2.7.10. Downstream processing and end products

Air-jet spun yarns display good performance in downstream processing, both in knitting and weaving. Their performance is in general at least as good as that of ring-spun yarns. The somewhat lower yarn strength is more than offset in downstream processing by positive yarn features:

- low hairiness;
- good abrasion resistance;
- fewer yarn defects.

As regards hairiness, the considerably reduced number of longer hairs in particular is favorable for processing Air-jet yarns, especially in the warp.

The good abrasion resistance of Air-jet spun yarns has already been mentioned. This is clearly confirmed by the results in Fig. 47. This leads to considerably reduced dust and fly generation in weaving and knitting.

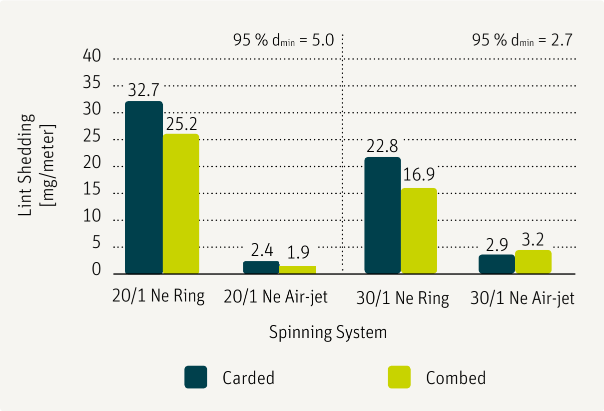

Fig. 47 – Lint shedding (Murata)

Air-jet spun yarns generally have fewer major yarn defects, which is of course positive with regard to yarn processing.

The quality of fabrics out of Air-jet spun yarn is surprisingly good. An overview of these quality aspects is displayed in Fig. 48. This summary is discussed in the following in more detail, in comparison with ring-spun yarn fabrics. Tensile strength is obviously slightly lower.

Pilling resistance is really excellent (Fig. 49), this being at least partly due to the fully covered core fibers.

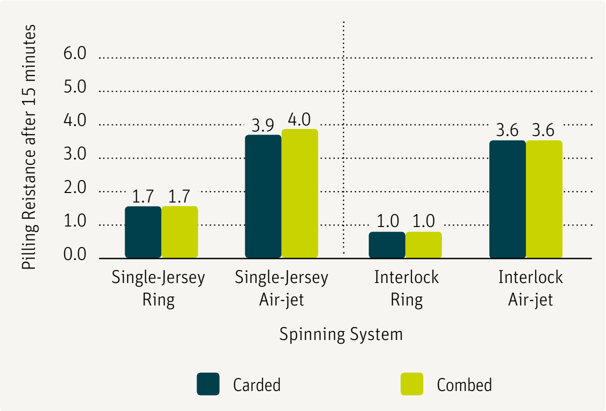

Fig. 49 – Pilling resistance after 15 min (Murata)

Air-jet fabrics have a very good appearance. According to tests performed at Cotton Incorporated, Air-jet fabrics have very good overall surface definition and slightly more brightness.

The hand of Air-jet fabrics, in terms of softness, is situated between the hand of ring-spun and rotor-spun fabrics.

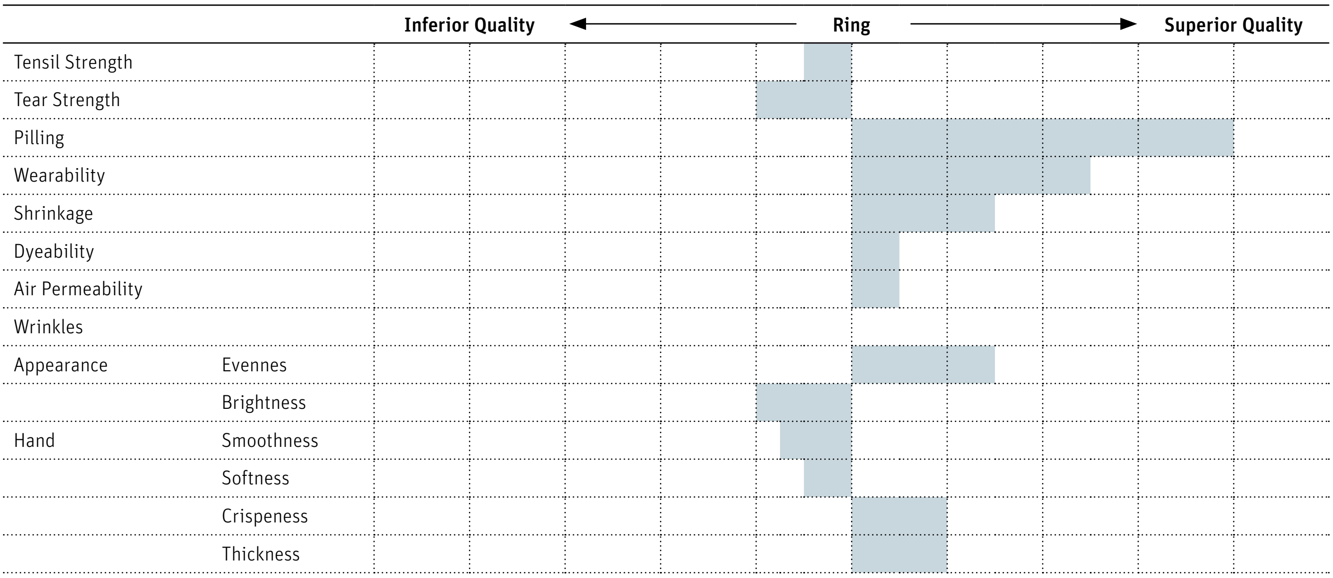

Fig. 48 – Quality of Air-jet fabrics compared to ring standard fabric

Due to the good overall properties of Air-jet products, Air-jet yarns can be used for most applications within the yarn count range in which Air-jet spinning is operating at present (Ne 15 to 60). The main products are summarized in Fig. 50.

Air-jet products

Home textiles	Apparel
Sheets	Bottom weight twills
Towels	Jersey
Curtains	Print cloth
Comforter	Work wear
Bed-linen	Career apparel
Table cloth	Military apparel

Fig. 50 – Air-jet products

2.7.11. Economics

It is extremely difficult to make comparisons of production costs, due to the considerable variation in cost structures from country to country and mill to mill. In order to evaluate the economic aspects of Air-jet spinning, it is therefore preferable to describe primarily the situation regarding the main cost components. This is done below, taking ring spinning as a reference.

2.7.11.1. Manpower

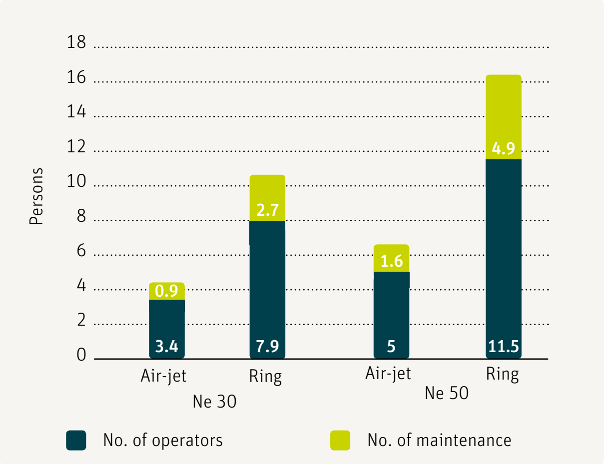

Fig. 51 – Manpower saving (Rieter)

Due to automation and the elimination of the roving frame and the winder, the operation of a Air-jet spinning mill requires considerably less manpower (Fig. 51).

2.7.11.2. Space

Air-jet spinning mills require considerably less floor space compared to ring spinning mills. The space requirement is typically around 50 % of that of a conventional mill.

2.7.11.3. Energy

A large part of the energy needed for Air-jet spinning is used, of course, for generating compressed air. On the other hand, the much smaller premises allow for a reduction in the energy required for the air conditioning plant. In addition, the energy required for mechanical drives is comparatively low. In total therefore, the energy requirement in Air-jet spinning is thus quite considerably lower than in ring spinning.

2.7.11.4. Waste

The higher fiber loss in Air-jet spinning inevitably results in correspondingly higher waste costs.

A few quantitative examples of cost calculations will just give an idea of the overall cost situation (Fig. 52, Fig. 53, Fig. 54). The energy costs for air conditioning are included in these results, but the capital costs for the air conditioning equipment are excluded. Fig. 52 compares the production costs for a Ne 30 (Viscose) yarn in Turkey. The Air-jet spinning costs are at a similar level to those for rotor spinning, but considerably lower than ring spinning costs. The costs for a Ne 50 (man-made fibers) yarn are compared in Fig. 53. This yarn is, of course, outside the range of rotor spinning, but again Air-jet spinning produces at much lower costs than ring spinning. Finally, Fig. 54 displays the production costs for a Ne 30 (Viscose) yarn, this time in India. It is surprising to note that Air-jet spinning is still considerably cheaper than ring spinning, despite the extremely low wage level.

Summarizing, Air-jet spinning is, in fact, an economically attractive spinning process.

2.7.12. Market impact

Air-jet spinning is a very young spinning system. Nevertheless, up to mid-2004 about 32 000 Air-jet spinning positions (equivalent to approximately 600 000 ring spindles) have been delivered worldwide. These machines are installed in more than 15 countries, including Europe.

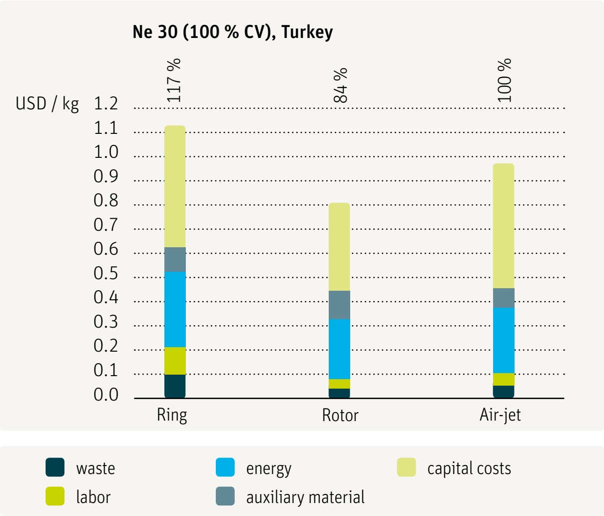

Fig. 52 – Comparison of spinning costs (Rieter)

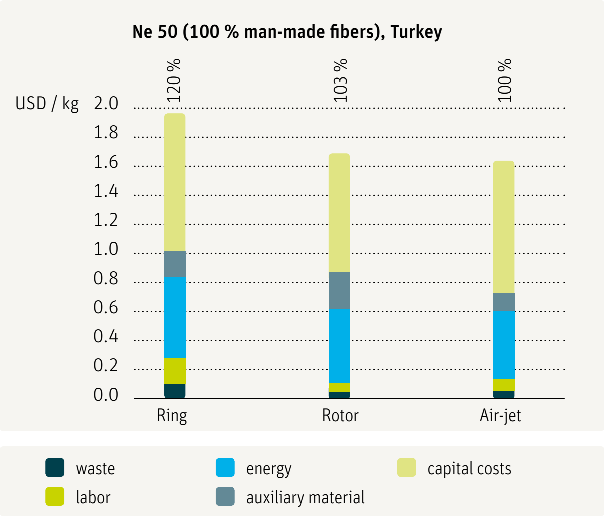

Fig. 53 – Comparison of spinning costs (Rieter)

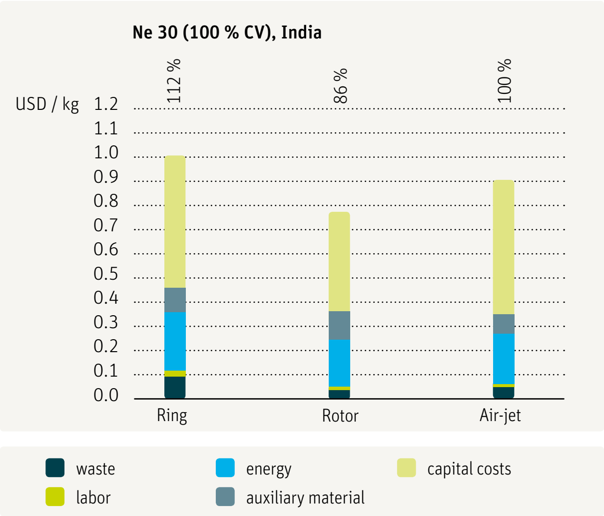

Fig. 54 – Comparison of spinning costs (Rieter)

2.7.13 Comparison of Air-jet spinning systems

Features	**Murata MVS 861**	**Rieter J 10 air-jet spinning machine**
Machine design	one-side machine	double sided machine with independent sides
Machine length (units)	up to 80	up to 100
Unit pitch (mm)	215	260
Delivery speed (m/min)	up to 450	up to 450
Automated processes	3 splicers (72 - 80 units), +1 - 2 doffers	4 robots
Air exhaust	upward, downward	downward
Waste filter disposal	automatic	manual (option: to be linked to an automatic system)
Can dimensions (mm)	behind the machine	500 x 1 200 (in 2 rows under the machine) or Cubicans 235 x 920 x 1 200

Table 1 a) – Machine data

Features	**Murata MVS 861**	**Rieter J 10 air-jet spinning machine**
Yarn count (Ne/tex)	15 - 60 / 39 - 10	20 - 50 / 29.5 - 12
Fiber length (mm)	up to 38	up to 40
Sliver count (ktex)	2.5 - 5	2 - 4.5
Total draft ratio (fold)	35 - 300	43 - 200 (mechanical 317)
Winding format	cylindrical, conical up to 5°57′	cylindrical
Package diameter (mm)	up to 300	up to 300
Type of yarn connection	splicer	piecer
Yarn clearer	Muratec Spin Clearer (standard)	Uster Quantum Clearer

Table 1 b) – Technological & technical Data

3. SUMMARY AND OUTLOOK

3.1. Processing principles

3.1.1. Types of Operation

	Open-end spinning			Twist spinning Sirospun / Duospun	Self-twist Repco	Wrap ParafiL	False-twist		Adhesive Twilo	Air-jet
	Rotor	**Dref-2000**	**Master Spinner**				**Two nozzle Air-jet spinning**	**Dref-3000**		**Murata MVS Rieter J 10**
Feedstock type:										
sliver	•	•	•			•	•	•	•	•
roving				•	•					
Form of feedstock:										
single strand	•		•			•	•	•	•	•
two strands				•						
in groups		•						•		
Opening and attenuating assembly:										
drafting arrangement				•	•	•	•	•	•	•
opening roller	•	•	•					•		
Fiber guidance:										
guided				•	•	•	•	•	•	•
freely floating	•	•	•					•		
Approach of fibers (to strand):										
linear forward				•	•	•	•	•	•	•
at right angles		•						•		
tangential forward	•									
tangential backward			•							
Collecting assembly:										
not necessary				•	•	•	•		•	•
rotor	•									
drum		•	•					•		
Twist unit:										
pneumatic							•			•
mech. rotor	•									
mech. drum		•	•					•		
mech. friction rollers					•					
mech. spindle				•		•				
Take-up package:										
cops				•						
cross-wound package	•	•	•		•	•	•	•	•	•

Table 2 – Comparison of various types of operation of the spinning processes described

3.1.2. Twist potential and system limitations

		System limited by	
Spinning process	**Twist-imparting potential/min**	**Imparting twist**	**Draft and fiber transport**
Ring	15 000 - 25 000	Yes	No
Rotor	80 000 - 120 000	Yes	Partly
Two nozzle Air-jet	150 000 - 250 000	No	Yes
Air-jet	250 000 - 400 000	No	Yes

Table 3 – Comparison of the twist potential and limitations of the main spinning systems [1]

3.2. Field of use

3.2.1. Spinning mill process

Process		**Short-staple sector**	**Worsted sector**	**Coarse yarn sector**	**Recycling**
Open-end:	Rotor	•		•	•
	Dref-2000			•	•
Twist spinning:	Duo / Siro	(•)	•		
False twist:	Two nozzle Air-jet spinning	•			
	Dref-3000	•			
Air-jet		•			

Table 4 – Overview of sectors in which the main processes are used

3.2.2. Yarn count range

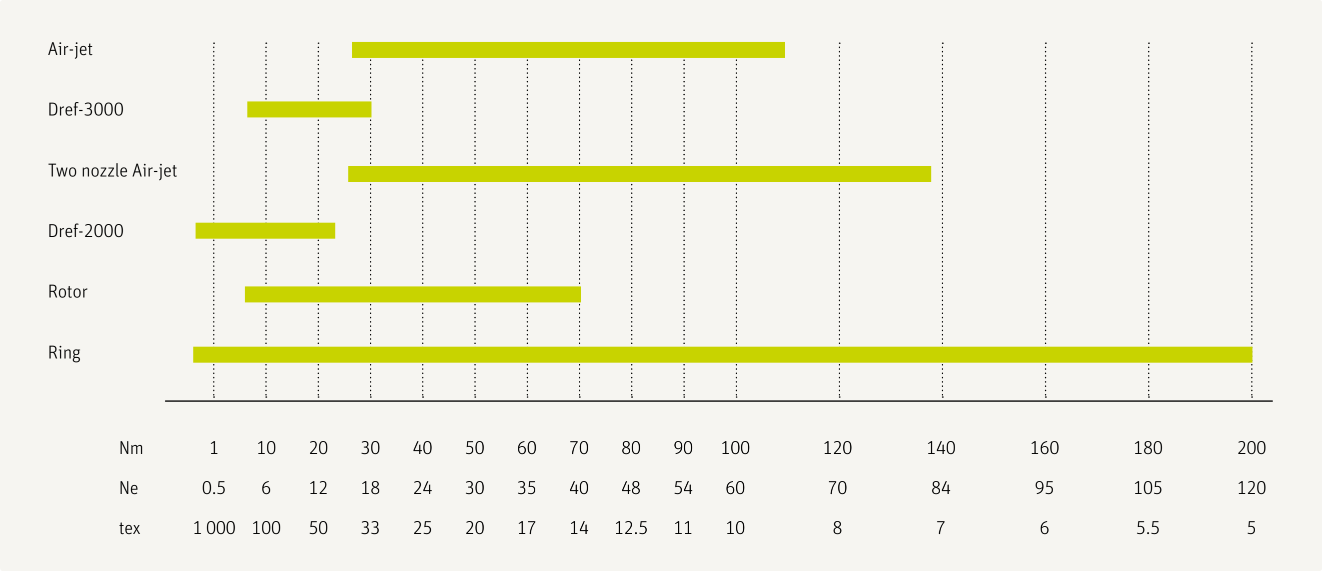

Fig. 55 – Yarn count range of the industrial spinning systems

3.3. Yarn characteristics

3.3.1. Number of fibers in cross-section

	Minimum	**Mostly above**
Ring-spun yarn: combed	35	60
Ring-spun yarn: carded	80	100
Open-end rotor	90	120
Filament-wrapped	40	50
Two nozzle Air-jet	80	100
Air-jet	80	100

Table 5 – Required number of fibers in the main yarn types

3.3.2. Characteristic yarn properties

Ring-spun yarn	**Rotor-spun yarn**	**Two nozzle Air-jet yarn (false-twist)**	**Air-jet yarn**
• tensile-strength values good	• tensile-strength values lower than ring-spun yarn	• good tenacity	• good tenacity
• good evenness	• very good to good evenness	• good evenness	• good evenness
• high hairiness	• higher stiffness than ring-spun yarn	• low tendency to snarl	• low hairiness
• low stiffness	• low tendency to snarl	• high stiffness	• stiffness slightly higher than ring-spun yarn
• high tendency to snarl		• high shrinkage	• good abrasion resistance

Table 6 – Summarized characteristic properties of the main types of yarn [8]

3.3.3. Differences in strength

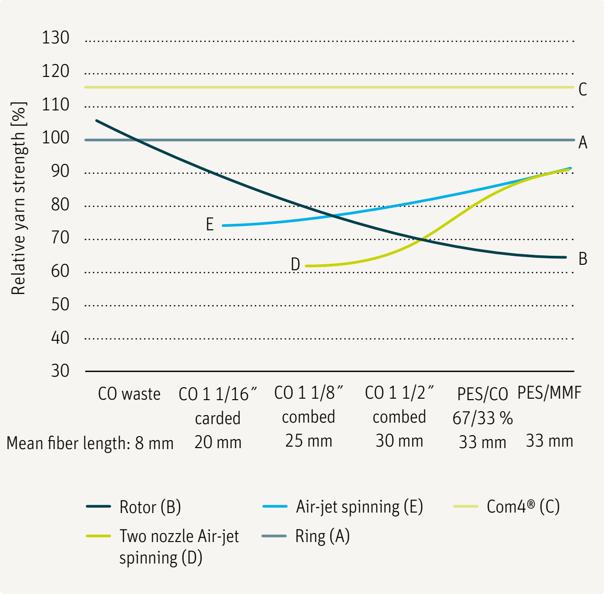

Fig. 56 – The relative strength values of the main yarns

3.4. Economic comparison

3.4.1. Productivity of the process

Fig. 57 – Production rates of different spinning methods [11]:
A Ring spinning, B Rotor spinning,
C Two nozzle Air-jet spinning, D Air-jet spinning

3.5. Outlook

The short staple spinning processes available today and in the foreseeable future

- ring spinning
- compact spinning
- rotor spinning
- Air-jet spinning

have quite different characteristics as regards yarn structure, yarn count range, degree of automation, cost structure, end product appearance, etc. The strength and weakness profiles also differ accordingly.

This results in specific fields of application for the different processes. On the basis of simplicity, yarn quality and universality, ring spinning, together with the increasingly important compact spinning process, will remain the dominant spinning process in the long term. Rotor spinning will certainly continue to display its strengths in medium to coarse yarn counts, and maintain its market share. Air-jet spinning will win specific application fields in the medium count range at the partial expense of ring spinning and rotor spinning.

In future therefore, the right process will find its use in the specific production location and the foreseen yarn application, making possible the optimum use of the different characteristics of the available processes and thus enabling tailor-made yarns to be produced.

Progress will certainly not come to a standstill. All the industrial processes mentioned will continue to be intensively developed and perfected. In this way, the spinner will be able to put the strengths of these processes to even better use. Spinning technology remains as dynamic as ever.

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ILLUSTRATIONS

The Rieter Manual of Spinning

Volume 6 – Alternative Spinning Systems

The alternative spinning systems produce yarn and hence end-products in a quality that differs to a certain extent from the ring spinning standard. In order to take full advantage of the alternative spinning systems, it is therefore essential to have a thorough understanding of them. This volume is designed to contribute towards reaching this goal and describes the most important alternative spinning systems in detail.

Rieter Machine Works Ltd.
Klosterstrasse 20
CH-8406 Winterthur
T +41 52 208 7171
F +41 52 208 8320
machines@rieter.com
aftersales@rieter.com

Rieter India Private Ltd.
Gat No. 768/2, Village Wing
Shindewadi-Bhor Road
Taluka Khandala, District Satara
IN-Maharashtra 412 801
T +91 2169 304 141
F +91 2169 304 226

Rieter (China)
Textile Instruments Co., Ltd.
Shanghai Branch
Unit B-1, 6F, Building A,
Synnex International Park
1068 West Tianshan Road
CN-Shanghai 200335
T +86 21 6037 3333
F +86 21 6037 3399

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