The Rieter Manual of Spinning
Volume 5

The Rieter Manual of Spinning

Volume 5 – Rotor Spinning

Heinz Ernst

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Heinz Ernst

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 fifth volume in the series The Rieter Manual of Spinning deals with both the technical and technological aspects of rotor spinning systems. In the past forty years, the search for new, more economic spinning systems has been pursued very actively throughout the industry. As one of the major achievements, rotor spinning was introduced into the market in the early seventies of last century and, with approx. 8 million rotors in operation worldwide by the end of 2007 (equivalent to about 48 million ring spindles), it has captured a substantial share of the spinning market.

One of the key drivers of this success was the outstandingly economical performance of rotor spinning. From the very beginning it became clear that rotor technology was able to set a new benchmark with regard to process cost. The field of coarse count yarn was soon conquered by this new technology, especially in those markets where increased labor costs represented a fundamental problem for the spinning industry. Later on, when automation of the entire rotor spinning process was available, this advantage became even more obvious and made the share of labor costs a minor issue. The rotor spinning process nowadays represents a well established alternative for processing all kinds of raw material with uncontested advantages over all other spinning systems in the field of short staple fibers and in specific energy consumption.

The rotor spinning system produces yarns and therefore end products with a quality that differs to a certain extent from the ring-spinning standard. In order to take full advantage of the new process, it is essential to have a thorough understanding of the details. 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 author of this volume, Heinz Ernst, is a former Rieter employee who recently retired from Rieter Ingolstadt, were he was responsible for rotor product management. He also used to lecture at numerous seminars throughout the world in his capacity of textile technologist. Heinz Ernst has many years of experience to his credit.

The structure of this manual and the organization of its subject matter have been taken from the original Technology of Short-staple Spinning published by the Textile Institute, Manchester, whom we thank for their kind permission to continue this standard work.

We wish all users of this compendium pleasant reading.

Rieter Machine Works Ltd.

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1. THE IMPORTANCE OF ROTOR SPINNING

1.1. Historical background

Rotor spinning has been characterized from the outset by incomparably higher production potential than ring spinning. This potential has been steadily increased by the continuous rise in rotor and winding speeds. Rotor-spun yarns have therefore always been successful where they could be manufactured more cheaply than ring-spun yarns and proved suitable for the range of application in question. Rotor spinning combines two process stages – spinning and winding – in a single machine. Saleable cross-wound packages could therefore be produced immediately, without first having to wind small spinning cops. Integrated yarn monitoring systems and auxiliary devices for waxing the yarns at each spinning position also eliminate the need for a subsequent rewinding process. The production of rovings, which is required for ring spinning, is also eliminated, since the rotor spinning system is able to process carded or draw frame slivers directly.
Last but not least, the rotor spinning system has benefited from the fact that operator functions on the rotor spinning machine were much easier to automate than those on the ring spinning machine. Automation of all operator functions is now standard on high-performance rotor spinning machines, automated can and package transport is already an essential feature in many textile mills.

The technological challenge – not only when launching rotor spinning – has always been to separate the assessment criteria for rotor-spun yarn from the structural features of ring-spun yarns. The dominance of rotor-spun yarns, for example in woven denim fabrics and knitted fabrics, shows that this has been successful in some important end product segments. New ranges of application are still continuously being developed for rotor-spun yarns, on the one hand through selective modification of yarn properties, and on the other through continuous improvements in spinning stability.

The essential feature of the rotor spinning system is the separation of the functional stages of fiber sliver opening and yarn formation, respectively imparting twist and winding up the yarn. In order to achieve this the fiber bundle has to be interrupted at one point at least. This occurs between the functional stages of opening the draw frame or card sliver into individual fibers and subsequently combining these fibers in the collecting groove of the spinning rotor, the twisting device of the rotor spinning system. Since the individual fibers are released from a compact fiber bundle during transport between the opening roller and the rotor collecting groove and are only combined again in the rotor groove, we can here refer to an open yarn end.

1.2. Development and current status of rotor spinning

The idea of producing yarn using the rotor spinning process is far from new:

- Patent applications for this method were filed allready in 1937 (basic rotor patent by Berthelsen).
- However, the first usable design was not proposed until 1951 by J. Meimberg at the Spinnbau company in Bremen, but further development of the machine was discontinued because performance proved unsatisfactory.
- The idea was taken up again in Czechoslovakia during the 1960s, and the first machine really suitable for industrial application was shown in 1965 at the Brno fair. This was followed in 1967 by the presentation of the BD 200 machine at an exhibition parallel to the ITMA of that year. This was also when the rotor spinning process came into industrial use in spinning mills.
- In the early 1970s Rieter, Schubert & Salzer and Platt formed a consortium to develop the rotor spinning process, and this resulted in the appearance at the 1971 ITMA of a number of prototypes at various stages of development.

The years that followed were characterized by intensive development effort aimed at exploiting both the technological and the economic potential of the rotor spinning system. Systematic work was pursued on:

- substantially expanding the count range of rotor-spun yarn, paying particular attention to yarn quality;
- optimizing the wearing properties of rotor-spun yarns, for example by improving their hand in end products;
- improving the yarns‘ physical textile properties in order to take account of the often rapid increases in performance of subsequent process stages.

Continuing research and further development have resulted in improvements in spinning elements and conditions, so that it is now hardly possible to distinguish rotor-spun yarn from ring-spun yarn.
The rotor spinning machine itself is no longer just a spinning machine in the traditional sense, but a highly productive, computerized and complex system for converting sliver into yarn.

The improvement in economics has been even more remarkable than the technological advances. For example, since the introduction of rotor spinning in the 1960s rotor speeds have increased from the original level of around 30 000 rpm to that of 160 000 rpm in practical use today (Fig. 1). Nowadays (in 2005) rotor speeds of up to 170 000 rpm are technically possible without any difficulty. A rotor spinning unit produces five to ten times as much as a ring spinning spindle. In countries with high wage levels, rotor spinning is more economical than ring spinning for yarn counts up to Ne 60.

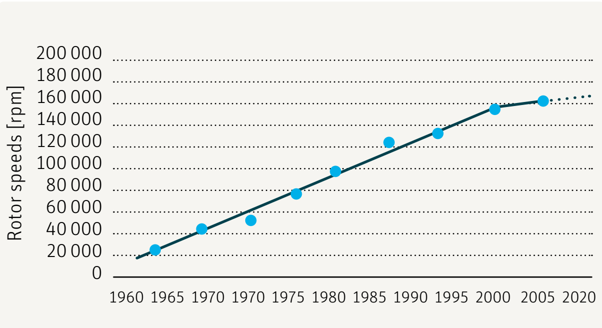


Fig. 1 – Development in achievable rotor speeds since the launch of the rotor spinning system

With more than 8 million rotor spinning positions installed worldwide (Fig. 2), some 20 % of staple fiber yarns have already been spun consistently for some years. In some countries (e.g. USA, Germany) the proportion of rotor-spun yarns is already around 50 % of total yarn volume. Developments in fashion and textile applications, as well as developments in spinning machinery manufacturing, continue to expand and also reposition the range of applications of rotor-spun yarns. Air-jet spun yarns have been able to secure a certain market share to date mainly in the USA. Despite intensive development effort, certain limitations in the processing of pure cotton remain a barrier to their wider use.

In recent years the share of automated rotor spinning machines world-wide is about 35 %. This figure is influenced

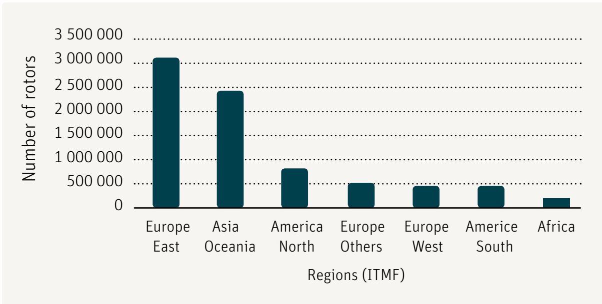


Fig. 2 – Installed rotor capacity worldwide in 2007 (total of over 8 million), by ITMF region (see references)

by the huge number of not automared machines installed in China. In other parts of the world the share is much higher. Fig. 3 is showing as an example the situation in Turkey, a big investor in rotor spinning during the last decade. Shortly after introduction of automated rotor spinning, in Turkey within a few years the share increased over 80 %.

Nowadays systems are also available for automatic can transport between the draw frame and the rotor spinning machine as well as systems for package transport from the rotor spinning machine to the material store or directly to downstream processing. This fact has contributed substantially to the improvement in the economics of rotor spinning.

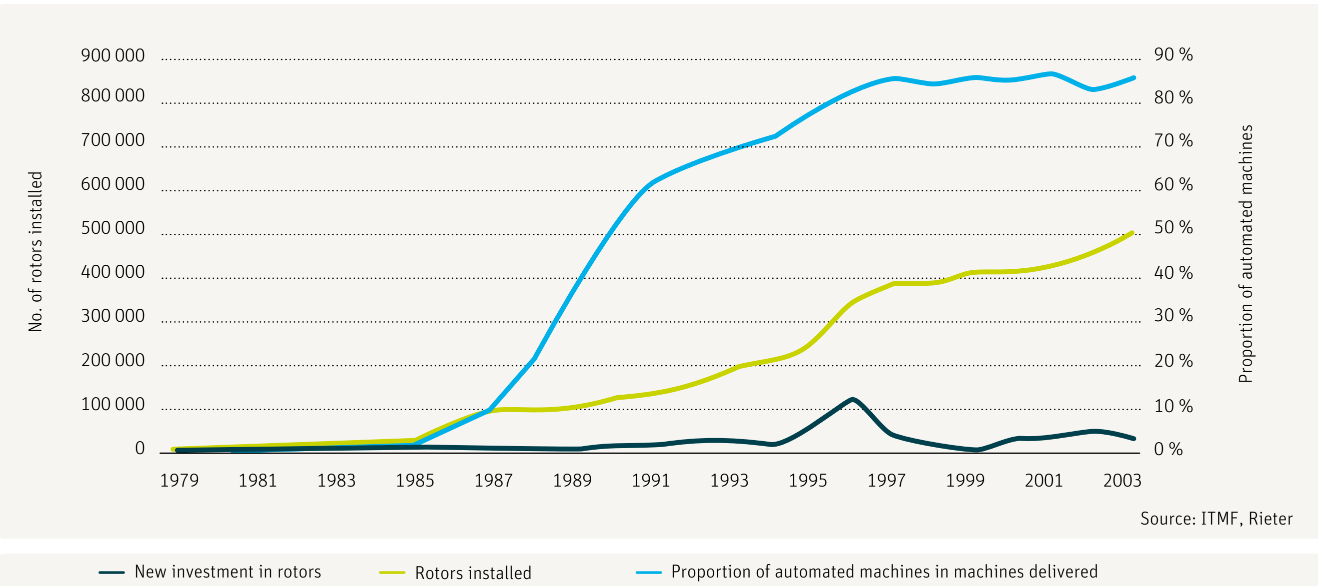


Fig. 3 – Number of rotors installed, showing the proportion of automated machines and new investment in rotors, using Turkey from 1979 to 2003 as an example

The rotor spinning process enables fibers up to 60 mm (2.25″) long to be processed and thus covers the classical short staple cotton range. The machines developed by various manufacturers (Schubert & Salzer, Duesberg Busson) for processing longer fibers with larger rotors were, however, unable to establish themselves on the market. Fig. 4 shows the distribution of yarn counts of rotor-spun yarns in the short staple range. The main emphasis of rotor-spun yarns is in the count range between Ne 6 and Ne 40, but covers the overall range from Ne 3 to Ne 60, albeit with a small proportion of yarn volume.

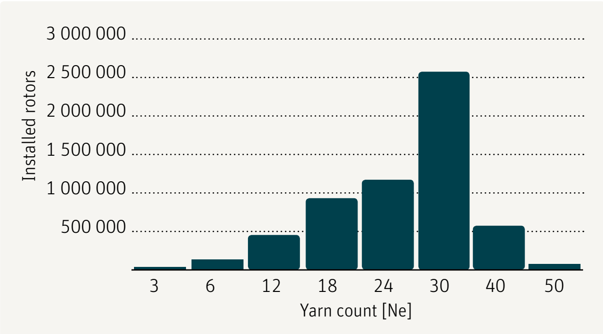


Fig. 4 – Installed rotor capacity (worldwide), by yarn count (ITMF)

Cotton is the predominant fiber for spinning on rotor spinning machines, with approx. 55 % of total yarn volume, but almost all short staple spinning materials can be spun pure or in blends. Besides cotton, the processing of polyester fibers (PES) has developed into a major field of application for rotor-spun yarns. The growth in world-wide fiber consumption of about 3 % p.a. will increasingly be met mainly by polyester fibers.

Viscose, Modal, polyacrylic and their blends with each other and with cotton also represent a fixed proportion of yarn volume. However, the processing of these and a whole series of other natural and man-made fibers is usually much more subject to the dictates of fashion, so that their shares fluctuate widely, both regionally and seasonally. A further economic aspect of interest in some applications arises from the possibility of spinning mill-waste fibers (secondary materials) on the rotor spinning machine. It was not previously possible to use these materials.

Since this spinning system was introduced, rotor-spun yarns have established themselves firmly in fields of application for woven and knitted fabrics. In many cases the processing of rotor-spun yarns into the end product actually resulted in advantages compared with ring-spun yarns, which led to a higher-quality end product. First of all, rotor-spun yarns could be used successfully where the specific properties of the rotor-spun yarns corresponded especially closely to the requirements of the end products. Fig. 5 shows the main end products in which rotor-spun yarns are used, subdivided according to yarn count. This chart shows that mainly denim weaves, trouser fabrics, sportswear and leisurewear, shirts / blouses and underwear are produced in the clothing sector, while terry products and upholstery fabrics are the main applications for rotor-spun yarns in the home textiles sector. Also worth mentioning as end products using rotor-spun yarns are socks and sweaters in the clothing sector, sheets and upholstery fabrics in the home textile sector, as well as technical textiles, for example as textile backing for emery cloth or for awnings and roller sunblinds.

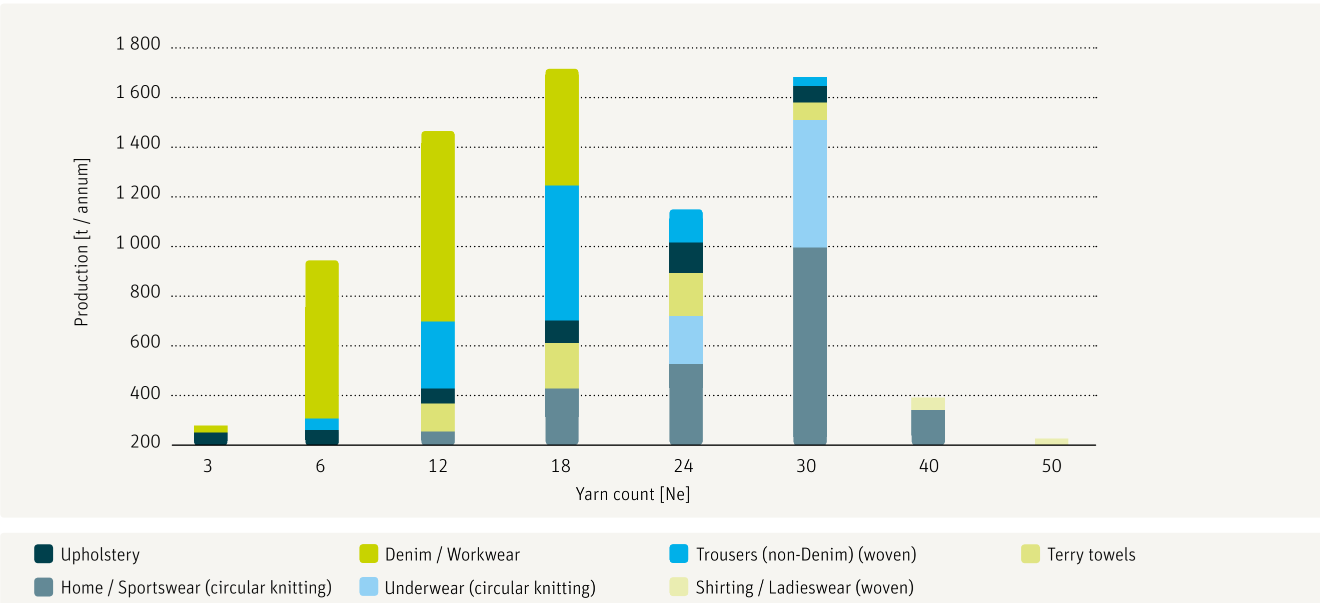


Fig. 5 – Annual output (tonnes worldwide) of end products from rotor-spun yarns, by yarn count

1.3. The potential of rotor spinning

From the multitude of spinning processes developed in recent decades, e.g. Bobtex, Repco, Twilo, friction, Air-jet and wrap spinning, only rotor spinning and – with reservations – Air-jet spinning have established themselves successfully on the market. Essentially, both the technological and the economic potential of rotor spinning are the decisive factors in the success of this spinning process.

1.3.1. The technological potential of rotor spinning

- Rotor spinning is a stable spinning process, i.e. it functions trouble-free under normal spinning conditions, without variations in running behavior or yarn quality.
- The process is reproducible with standard spinning equipment and settings and transferable to a large number of spinning positions. Quality consistency is therefore adequately assured both within the spinning positions of a machine or a group of machines and over an extended period of time.
- Rotor spinning is a genuine open-end spinning process, i.e. a genuine twist is imparted to the yarn, making it comparable to ring-spun yarn in its yarn structure and as regards its applications (differences in principle from ring-spun yarn will be dealt with in more detail in subsequent chapters). From the outset rotor-spun yarns therefore had a wide range of applications instead of the ring-spun yarns used to date.
- As a rule rotor spinning operates with normal draw frame sliver of a quality customary in spinning mills. Special preparatory passages, such as are sometimes necessary for other spinning processes (e.g. Air-jet spinning), are not required here.
- Rotor spinning is appropriate for mill operations in that its technology can be implemented with relatively simple and robust spinning elements.
- The process imposes no special requirements on the atmosphere in the spinning mill as regards temperature, humidity and air conditioning and in many cases is actually less critical in this respect that ring or Air-jet spinning.

1.3.2. The economic potential of rotor spinning

The economic advantages of rotor spinning very soon became evident and have increased in the course of its development with the result that its breakeven point has moved further in the direction of finer yarn counts. The following aspects are decisive in this respect:

- Rotor spinning was the first process that was capable of producing a cross-wound package ready for processing or sale in a single process stage from a draw frame sliver. Roving frames and winders could be dispensed with; there was thus a significant incentive from the very outset to utilize this process, despite the higher cost of a rotor spinning position compared with a ring spinning position.
- In terms of manufacturing costs per kg of rotor-spun yarn, direct labor costs occupied a position behind capital and energy costs.
- Rotor spinning operates with very high efficiency, significantly above that of a ring spinning line. Machine efficiency of up to 99 % is achieved in mill operations. Stopping the machine to remove packages, as on ring spinning machines, does not occur in rotor spinning.
- In many cases advantages in downstream processing in weaving and knitting mills result from longer, faultless running lengths on the cross-wound packages, i.e. fewer malfunctions and stoppages in the downstream process.
- Last but not least, rotor spinning is more environmentally friendly in terms of dust and noise emissions compared with ring spinning, despite its considerably higher output.

1.4. The principle of rotor spinning

The rotor spinning machine is unlike any other machine in the short staple spinning mill in the range of tasks it has to perform, namely all the basic operations:

- Sliver feed: A card or draw frame sliver is fed through a sliver guide via a feed roller and feed table to a rapidly rotating opening roller.
- Sliver opening: The rotating teeth of the opening roller comb out the individual fibers from the sliver clamped between feed table and feed roller. After leaving the rotating opening roller, the fibers are fed to the fiber channel.
- Fiber transport to the rotor: Centrifugal forces and a vacuum in the rotor housing cause the fibers to disengage at a certain point from the opening roller and to move via the fiber channel to the inside wall of the rotor.
- Fiber collection in the rotor groove: The centrifugal forces in the rapidly rotating rotor cause the fibers to move from the conical rotor wall toward the rotor groove and be collected there to form a fiber ring.
- Yarn formation: When a spun yarn end emerges from the draw-off nozzle into the rotor groove, it receives twist from the rotation of the rotor outside the nozzle, which then continues in the yarn into the interior of the rotor.

The yarn end rotates around its axis and continuously twists-in the fibers deposited in the rotor groove, assisted by the nozzle, which acts as a twist retaining element.
- Yarn take-off, winding: The yarn formed in the rotor is continuously taken off by the delivery shaft and the pressure roller through the nozzle and the draw-off tube and wound onto a cross-wound package. Between take-off and package, several sensors control yarn movement as well as the quality of the yarn and initiate yarn clearing if any pre-selected values are exceeded.

1.5. Performance parameters of rotor spinning machines

1.5.1. Technological setting parameters

Fiber length	Natural and man made fibers up to 60 mm
Sliver weight	Nm 0.14 - 0.40; Ne 0.08 - 0.24; ktex 7.0 - 2.5
Yarn count range	Nm 5 - 100; Ne 30 - 60; ktex 200 - 10
Draft range	40 - 400-fold
Twist range	T/m 196 - 1 500/TPI 5 - 38
Winding helix	adjustable between 30° and 40° in steps of 1°

1.5.2. Production-related setting parameters

Rotor speed	35 000 - 160 000 rpm
Opening roller speed	6 000 - 10 000 rpm
Delivery speed, cylindrical	up to 350 m/min (240 rotors) up to 270 m/min (500 rotors)
Delivery speed, conical	up to 60 m/min (500 rotors)
Package weight, cylindrical	up to 6 kg or 350 mm diameter
Package weight, conical	up to 270 mm diameter

1.5.3. Machine data

Number of rotors, total	up to 500
Numbers of rotors/section	20 or 24 rotors depending on machine manufacturer
Number of sections	up to 25 (with 20 rotors/section) up to 20 (with 24 rotors/section)
Number of robots	up to 4

2. MACHINERY AND PROCESS

2.1. Structure of the rotor spinning machine

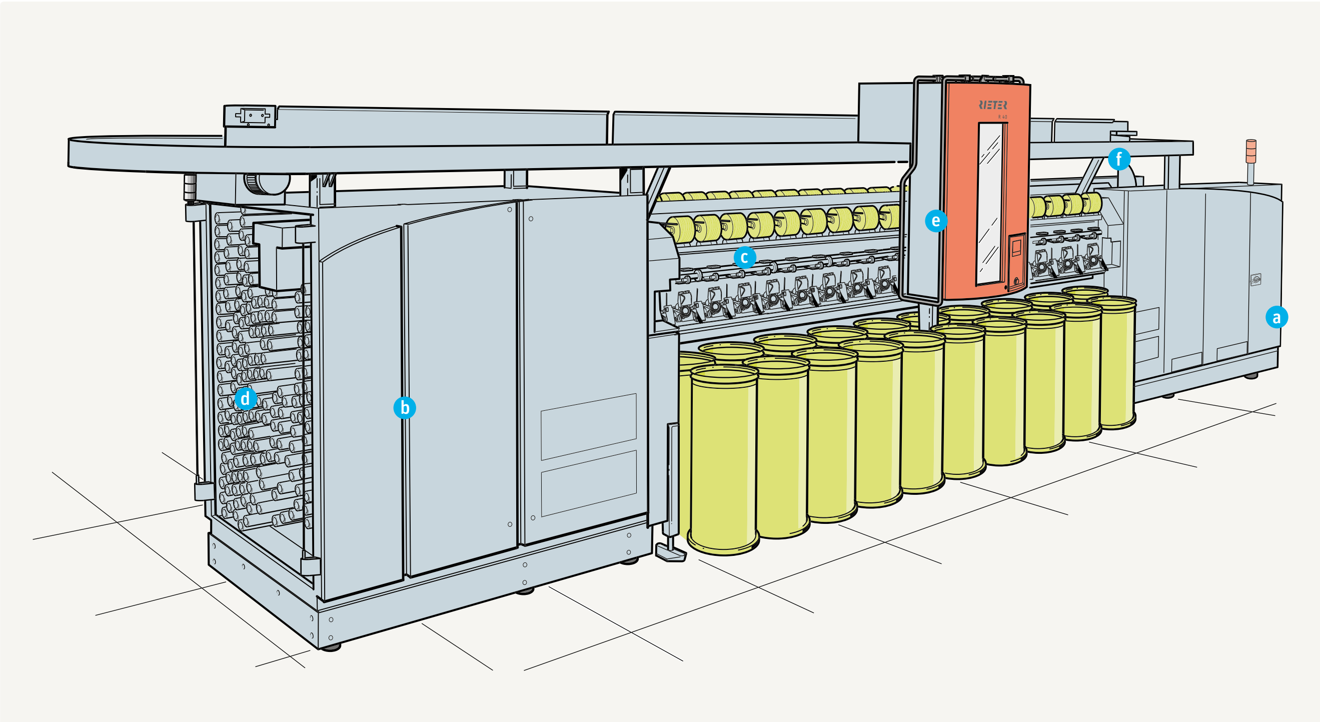


Fig. 6 – Structure of the rotor spinning machine

Modern rotor spinning machines are two-sided machines – with spinning boxes and winding units on both sides of the machine – in order to utilize the cost-intensive drives and spinning robots more efficiently. A rotor spinning machine consists essentially of the following functional units (Fig. 6):

- headstock (a) and tailstock (b) with central drives for rotors, feed, opening rollers and winding units;
- the spinning and winding units (c), combined into sections;
- empty tube supply (d) with empty tube magazine and empty tube transport system (at the tailstock);
- 1 - 2 operating robots (e) on each side of the machine for cleaning, piecing and package change;
- package conveyor belt for transporting the full cross-wound packages to the end of the machine (f);
- quality control and monitoring systems at each spinning position (optional).

2.2. Operating principle of the rotor spinning machine

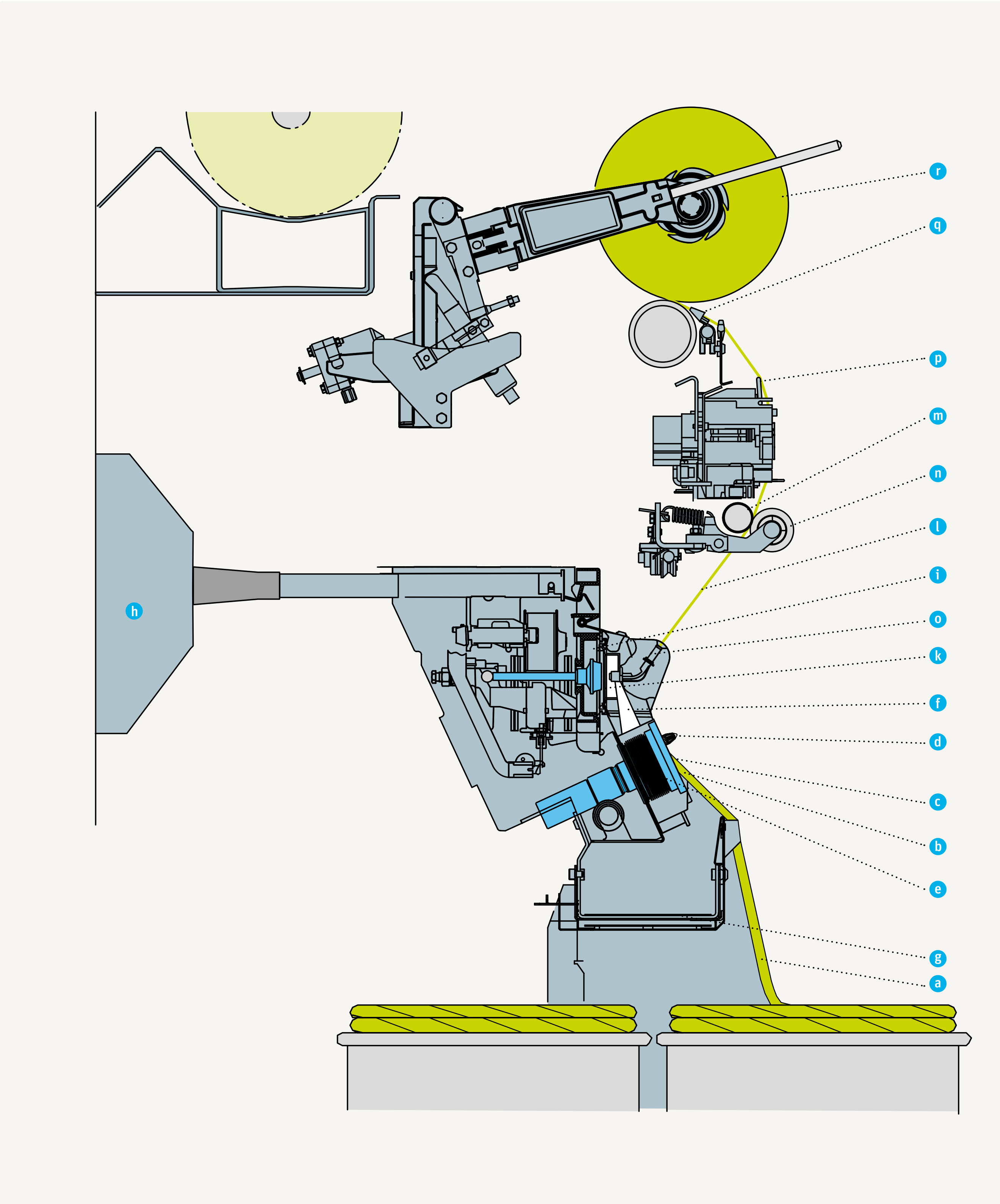


Fig. 7 – Path of the fibers from sliver feed into the spinning box to winding of the yarn onto cylindrical or conical cross-wound packages

The feedstock is in the form of either draw frame sliver (almost always) from first- or second-passage drawing or carded sliver (a) (see Fig. 7). The sliver runs from a round or rectangular can beneath the spinning unit through sliver guide (b) via feed roller (d) and feed table (c) to rotating opening roller (e). The rotating feed roller grips the sliver and pushes it over the feed table into the opening roller housing. The feed table is spring-loaded to ensure firm clamping of the sliver toward the feed roller.

In the event of a yarn end down, sliver feed is automatically stopped by disengaging the feed clutch and thus stopping rotation of the feed-roller. The signal pulse causing this is generated by a yarn-sensing device (thread monitor).
In the conventional ring spinning process the fiber bundle – i.e. the draw frame sliver – at the in-feed is maintained as a coherent structure and is merely attenuated during spinning. In rotor spinning the fiber bundle is opened into individual fibers. This task is performed mainly by the opening roller. This roller, which is usually clothed with saw teeth, combs through the fiber beard projecting from the nip between the feed roller and the feed table; it transports the released fibers to fiber channel (f).
An air current is needed to transport the fibers from the opening roller via the fiber channel to the rotor. This is generated by main duct (h) in the sections and then via a vacuum in the rotor housing (i). The vacuum is created by a central fan that draws air by suction through small ducts from each rotor housing. To facilitate generation of this negative pressure, the rotor box must be hermetically sealed as far as possible. Most of the transport air enters only at the trash removal slot and only a small amount via the draw-off tube.

One result of the centrifugal force of the opening roller is that impurities carried with the incoming sliver are expelled through an outlet of the opening roller housing. The expelled waste falls onto conveyor belt (g), which carries it either to one or to both ends of the spinning machine, where it is removed by suction nozzles on each side of the machine.
The suction current in the fiber channel lifts the fibers off the surface of the opening roller and leads them to rotor (k). In the course of this movement, both the air and the fibers are accelerated due to the converging shape of the feed tube. This represents a second draft following the nip trough / opening roller and results in further separation of the fibers. Moreover, partial straightening of the fibers is achieved in this air current. A third draft arises upon arrival of the fibers on the wall of the rotor, since the peripheral speed of the rotor is several times the speed of the fiber. This is a very important feature, since it contributes significantly to good orientation of the fibers. Final straightening of the fibers occurs as the fiber slides down the rotor wall into the groove under the influence of the enormous centrifugal forces acting within the rotor.
On average, one to five fibers (in section) emerge simultaneously from the exit of the fiber channel. After sliding down the rotor wall, they come to rest in a longitudinally oriented form in the rotor groove. Because the rotor is turning continuously under the stationary exit of the fiber channel, continual deposition of fibers in the groove is achieved (i.e., fiber is laid on fiber). In this way, a continuous fiber ring is built up in the groove. This operation is referred to as back-doubling (refer to section „5.1.2. Fiber collection in the rotor groove (back-doubling)”).

If nothing further were done, the rotor would be choked in no time. However, since the whole purpose is to form these fibers into a new yarn, the free end of yarn (l) is allowed to extend from the rotational axis to the rotor periphery. Centrifugal force (more than 100 000 times the weight of the fiber) acting at this point presses the yarn end firmly against the wall of the collecting groove, exactly as in the case of the fibers in the ring. The yarn end therefore adheres to the rotor wall. As the rotor turns, it therefore carries the yarn along, and the latter rotates around nozzle (o) like one arm of a crank.
Each revolution of the rotor generates one turn of genuine twist in the yarn. When the yarn has reached its maximum twist level as determined by the prevailing force conditions, the yarn end begins to turn about its own axis, i.e., it rolls in the rotor groove. Now the open yarn end is resting in the binding-in zone on a strand of parallel fibers; rolling of the yarn end therefore causes the brush-like yarn end to grasp fibers from the ring and twist them in to give a new yarn portion, which proceeds to grasp the next fibers and twist them in, and so on. A yarn is thus spun continuously. It is simply necessary to pull this yarn out of the rotor via yarn compensation bar (p) by means of take-off rollers (m + n) and wind it up on winding drum (q) into cross-wound package (r).

Machine automation by means of operating robots as well as package removal systems are described in the section „3.1. Machine automation in rotor spinning“ and transport automation in the section „3.2. Transport automation in the rotor spinning mill“.

2.3. The spinning box

The spinning box is an independently functioning unit. Opening rollers and rotors are driven centrally via tangential belts. On some spinning systems sliver intake is performed by means of a continuous feed shaft. The rotor housings are accessible via a hinged opening unit both manually and by means of an operating robot. Manual checking and replacement of the spinning elements as well as automatic cleaning of the rotor and draw-off nozzle by the operating robot can therefore be performed very easily. The spinning unit essentially consists of the following functional units (Fig. 8 + Fig. 9):

- Sliver feeding via sliver funnel (a), intake cylinder and feed table (b);
- Opening of the fiber sliver into individual fibers by means of opening roller (c);
- Trash removal;
- Fiber transport to and feeding into rotor (d);
- Yarn formation and twist insertion in rotor (e);
- Yarn take-off via draw-off nozzle and draw-off tube (f).

The main difference between rotor spinning machines from different manufacturers is in spinning geometry. This starts with the opening of the sliver into individual fibers, optimal trash removal paying particular attention to the opening roller, and yarn formation in the rotor, and continues to the geometry of yarn take-off by the draw-off tube. Attention is drawn to substantial differences.

2.3.1. Sliver feed

The carded or drawn sliver being fed in is guided through sliver funnel[1] (a) and fed between the feed shaft and spring-loaded feed table (b) to the rotating opening roller (c) (Fig. 8 + Fig. 9). Each spinning position is equipped with this combined feed shaft / feed table. The drive of the feed shaft for each spinning position is provided by a centrally driven, rotating worm shaft. In the event of an end down or a switched-off spinning position the feed shaft is disconnected from the worm shaft by an electromagnetic clutch and sliver intake is stopped. However, the clutch wheel of the feed shaft remains engaged with the worm shaft even if the spinning box cover is opened. This prevents damage to the clutch wheel when the rotor cover is closed, which can occur in systems where the drive shaft and feed shaft are disconnected when the cover is opened. Centralized setting of draft and delivery speed automatically determines the speed of the feed shaft and thus the intake speed of the carded or drawn sliver.

In systems where sliver feed is effected by means of a continuous feed shaft and spring-loaded feed table, the feed shaft is equipped with a brake / clutch unit at each spinning position, which switches off the spinning position in the event of an end down or in the absence of sliver.

[1] Sliver guides are available in standard size (for cotton, polyester and viscose fibers) or extended size (for acrylic and high bulk fibers).

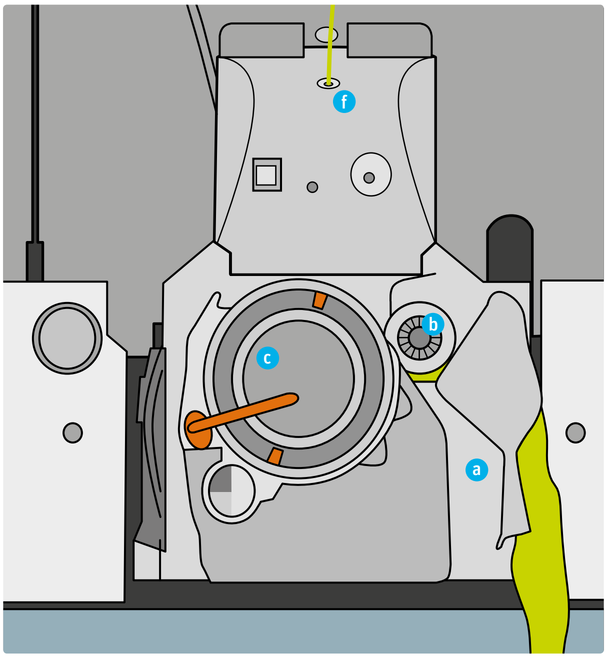


Fig. 8 – Front view of spinning box with opening roller and sliver intake

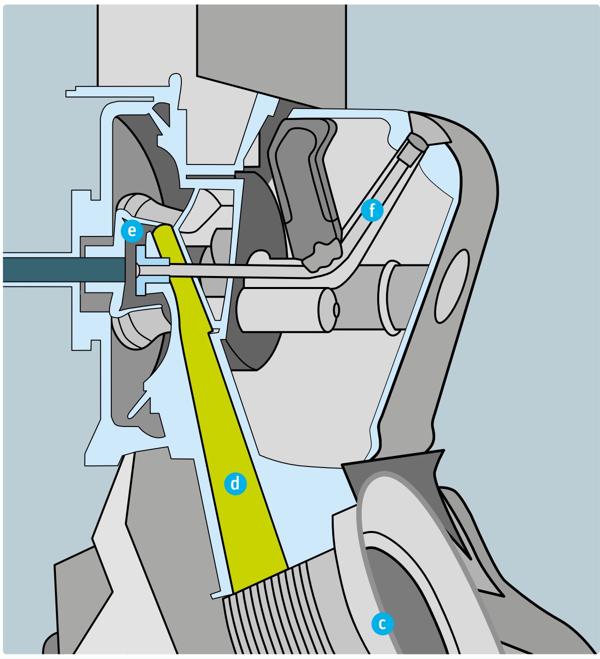


Fig. 9 – Spinning box cross-section

2.3.2. Opening unit

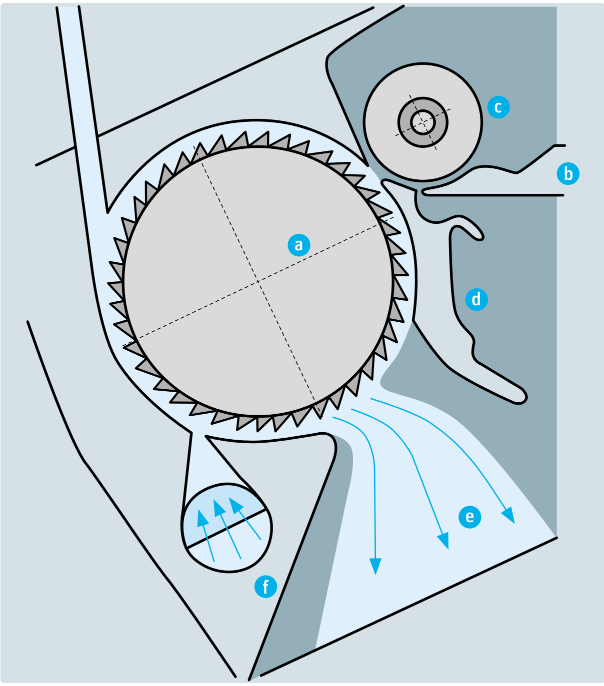


Fig. 10 – Opening roller housing with opening roller (a), sliver intake (b+c), fiber beard support (d), trash removal (e) and adjustable bypass (f)

The opening point at the spinning box is comparable with the infeed at the licker-in of the card. The rotating teeth of opening roller (Fig. 10, a) pass at high speed through the fiber beard and remove individual fibers from the sliver clamped between feed table (b) and feed roller (c). The sliver beard in this case is being moved slowly forward by the feed roller. By means of this continuous operation, the opening roller carries along by friction all fibers emerging from the clamping point between the feed roller and feed table. A fixed fiber beard support (d) provides uniform combing even in the event of mass deviations in the sliver. After leaving the rotating opening roller, the fibers are transported to the fiber channel. It is important to ensure that the speed of the air and fiber flow at the opening roller is greater than the peripheral velocity of the roller itself. If the roller velocity is equal to or higher than the air-flow speed, which can occur with very high roller speeds, this leads to fiber buckling at the lift-off point; this in turn causes deterioration in yarn quality and running performance. When the fibers are detached from the opening roller clothing, the trash included in the fiber material is removed via an opening under opening roller (e). The degree of trash removal can be adjusted via a bypass system (f) (refer also to section „2.3.3. Trash removal“)

The surface of the combing roll can consist either of a solid steel ring in which the appropriate tooth design has been machined by grinding or of a toothed wire which has been spirally wound on a ring or a body. Form, geometry and coating of the clothing and the opening roller itself are, alongside the rotor, of particular importance for the function and quality of yarn formation.

Opening rollers are available for every application to match both the thermal and physical properties of the raw materials being processed and the yarn properties required. Their clothing differs mainly in the following respects:
- in the shape of the teeth and their angle of inclination, tooth height and width of the tooth point;
- the density of tooth points;
- the geometric layout of the teeth; and
- different coatings.

Refer to section „4.4.1. Range of application of the opening roller“. for the correct choice of opening rollers with reference to their range of application.
The opening roller is a part subject to wear and must be periodically replaced, depending upon the rate of wear. If this is delayed too long, yarn quality and spinning conditions deteriorate.
In addition to the correct choice of opening roller clothing, special attention must also be paid to the setting of the opening roller speed. The opening roller speed range is between 6 000 and 10 000 rpm; speeds between 6 500 and 8 000 rpm are usually used. Opening roller speeds that are either too high or too low, always relative to the specific application, can have a negative impact on yarn formation and yarn quality. Opening roller speeds that are too low can result in:
- inadequate separation of the sliver into individual fibers;
- inadequate opening of fiber neps and fiber clumps;
- inadequate trash removal;
- tendency toward lap formation on the opening roller.

Inadequate removal of trash particles because opening roller speeds are too low not only affects spinning stability through an increase in ends down, the yarn itself also contains more trash particles. Yarn irregularity also deteriorates and the frequency of thick places, thin places, neps and Classimat defects (rarely disturbing yarn defects) increases.

However, opening roller speeds that are too high can also have a negative impact; an improvement in opening performance is by no means achieved. Excessively high opening roller speeds result in:

- more or less severe damage to – i.e. shortening of – fibers; and thus
- losses in yarn tenacity and the strength of the fabrics produced from them;
- an increase in fiber fly on the spinning machine and in downstream processing;
- smelting points when processing man-made fibers.

The manufacturer‘s recommendations regarding type and speed of opening roller should therefore be disregarded only in exceptional cases (for processing especially critical materials) and only after conducting thorough spinning trials.

Opening roller housings exist in both open and closed designs. Uncovered housings are an advantage to the extent that disturbing accumulations of fibers on the front of the opening rollers are avoided. The opening rollers themselves are protected against secondary air and ambient influences by means of effective multi-stage sealing. The opening rollers can be checked and replaced much more easily than with enclosed systems.

2.3.3. Trash removal

Basically, all trash removal devices in rotor spinning machines are the same, i.e. no more than a larger or smaller opening in the opening roller housing. The high peripheral speed of the opening roller results in all particles heavier than fibers (trash and other extraneous particles) being removed outward at this opening while the fibers continue with the roller, to be passed later into the fiber channel. The expelled waste falls onto a conveyor belt, which carries it alternately to the headstock or the tailstock. At both sides of the machine the collected waste is removed by suction nozzles and fed by vacuum to a central filter housing. Wipers on the conveyor belt continuously clean the housing under the opening roller.

As explained in detail in section „4.3. Preparation of raw material“, modern spinning preparation machines with the appropriate cleaning facilities are able to remove most extraneous, dust and trash particles reliably from the raw cotton. However, a certain amount of organic and inorganic extraneous matter can survive the cleaning process in the blowroom and draw frame, depending on the susceptibility to cleaning of the cotton(s) being used and due to the picking and ginning methods.

Efficient trash removal is therefore one of the most important preconditions in the rotor spinning system for stable spinning conditions and high yarn quality. Unfortunately, the collecting groove of the spinning rotor not only collects fibers; particles, trash, dust, etc., also accumulate in it, changing the groove‘s geometry and thus the yarn quality, and in the worst case causing a deterioration in spinning stability. Due to the extremely high centrifugal forces, a tiny trash particle of only 0.2 mg can exert a force of approx. 15 g on the fiber ring and thus prevent twist propagation, which results in a thread break. This clearly illustrates the importance of effective trash removal for the operation of the rotor spinning machine.

Trash removal in the spinning box ensures that the overwhelming majority of extraneous matter still in the fiber sliver and disturbing the spinning process is eliminated. However, trash removal in the spinning box can by no means replace careful cleaning of the cotton during spinning preparation. The lower the residual trash content in the drawn or carded sliver fed in, the more effectively can the remaining trash and extraneous particles be reduced in the spinning box.

Trash removal systems with an adjustable BYpass (Fig. 11, Fig. 12, Fig. 13), which enables the cleaning effect to be adjusted individually to the raw material being used, i.e. its trash content, are especially effective. On conventional spinning boxes almost all the air necessary for the vacuum is sucked in through the trash removal opening, i.e. in the opposite direction to the expelled trash. In some cases secure trash removal might be impeded, mainly in the case of small and/or light impurities.

The BYpass permits adjustment of the air flowing into the trash removal opening depending on the raw material. The larger the amount of air provided through the bypass, the smaller the quantity of air drawn in at the trash removal opening, and the easier it is to separate impurities. Furthermore, it prevents any trash particle already disposed of from being sucked back into the spinning box again.

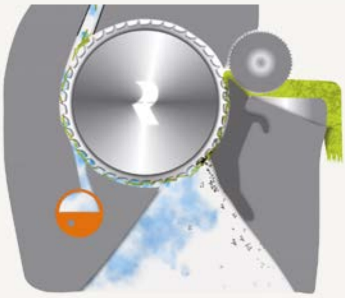


Fig. 11 – BYpass open
(maximum trash removal)

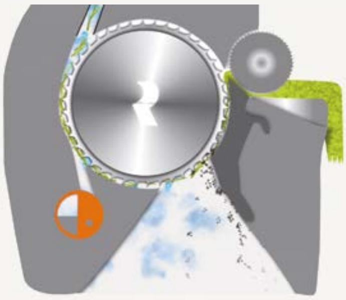


Fig. 12 – BYpass half open
(medium trash removal)

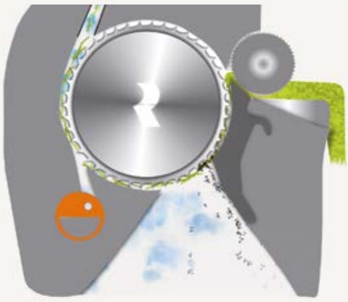


Fig. 13 – BYpass closed
(minimum trash removal)

2.3.4. Fiber transport to the rotor

After opening, the fibers must be supplied to the rotor. For this purpose, a closed fiber channel in the shape of a flow passage serves as a means of guidance. Centrifugal forces of the opening roller and a vacuum in the rotor housing cause the fibers to disengage from the opening roller. Transport of the disengaged fibers through the fiber channel to the rotor is effected by an air current generated by suction of air from the hermetically sealed rotor housing. The partial spinning vacuum on spinning systems with perforated rotors is generated by the rotors and thus depends on rotor size and rotor speed. The partial spinning vacuum therefore declines as rotor diameters become smaller or if dirt (trash, dust, fiber fragments) accumulates in the openings in the base of the rotor.

The shape of the fiber guide channel (Fig. 14, a) is crucial for fiber transport and the desired longitudinal orientation of the fibers. The inlet and outlet openings of the fiber guide channel must be designed and produced so that the transfer of fibers from the opening roller, fiber transport in the guide channel itself and the transfer of fibers to the inside wall of the spinning rotor (Fig. 14, b) are trouble-free. The fiber channel narrows toward the rotor, which causes acceleration of the air and fiber flows. This acceleration is of great significance because it leads to further separation of the fibers, down to between one and five fibers in section, and also straightens the fibers. The narrowing region represents a second draft zone (following the feed roller/opening roller).

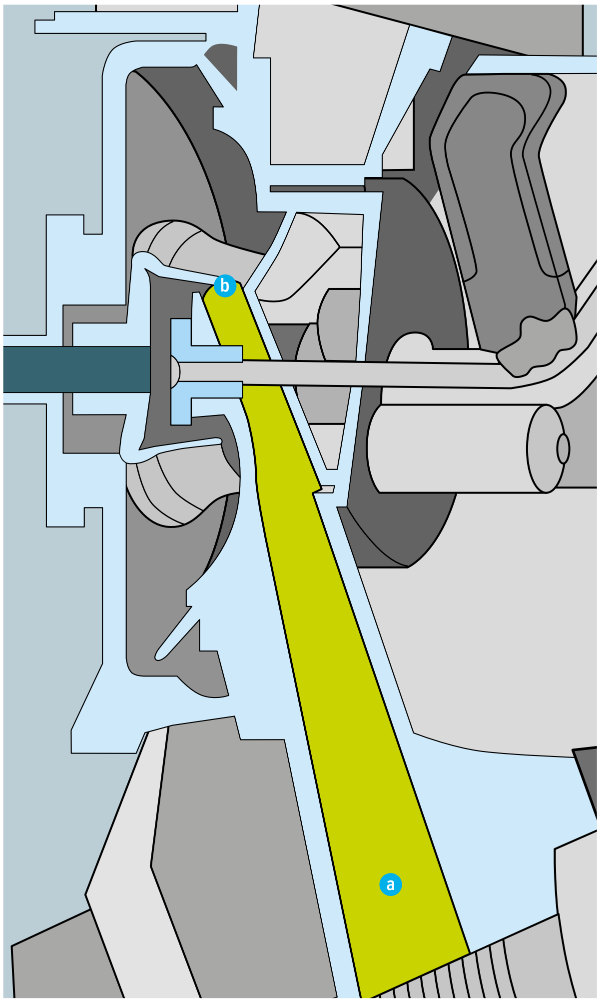


Fig. 14 – Cross-section through fiber guide channel (a) and spinning rotor (b)

Spinning box systems with both one-part and two-part fiber guide channels are used in mill operations. A two-part fiber guide channel is necessary in these systems on design grounds in order to facilitate opening of the rotor cover. The interface on the two-part fiber guide channel must be hermetically sealed in order to prevent the entry of secondary air and also be designed so that no air turbulence can occur. After leaving the exit port of the fiber channel the fibers are guided directly onto the rotor wall for deposit in the rotor groove, while the air – together with the remaining dust – flows over the rotor rim to the central filter housing. The outlet opening of the fiber guide channel must be positioned very close to the rotor wall to ensure that good fibers are not also sucked out over the edge of the rotor. Interchangeable channel inserts – in which the fiber guide channel is integrated – are available for this purpose and used depending on the given rotor diameter. Extensive mill trials have demonstrated that several rotor diameters, albeit in close proximity with each other, can be served by one channel insert. This significantly improves flexibility when changing spinning parameters, since the complete rotor cover does not need to be replaced with every change in rotor diameter. The channel inserts are sealed against the rotor housing to prevent air losses in the rotor housing.
However, if the distance between the fiber guide channel and the rotor wall is outside the optimum range, for example due to using channel inserts that are too small, good fibers can pass uncontrolled into the extraction system: this becomes apparent not only through an increase in ends down, but also – which is much more serious – through a change in yarn count (usually undetected) and the resulting enormous costs arising from defective final fabrics.

Channel inserts equipped optionally with a so-called SPEEDpass (Fig. 15) are a special feature. This is an additional opening in the fiber guide channel through which a certain proportion of the fiber transport air is extracted in order to increase the air volume and thus the rate of flow in the fiber guide channel. This promotes the disengagement of fibers from the opening roller clothing and is thus especially suitable for processing man-made fibers and blends containing more than 50 % man-made fibers. At the same time the higher volume of air proves especially beneficial in the manufacture of coarse count yarns and thus for high material throughput.

Cotton dust (finishing abrasion in the case of man-made fibers) is also extracted through this opening. Fine dust therefore does not accumulate in the rotor groove, and yarn characteristics and yarn values remain stable.

2.3.5. Fiber transport to the fiber collecting groove in the rotor

The rotors, acting as fiber collecting and at the same time twist inserting elements, are the most important and also the most complex components in yarn formation (Fig. 16). As already mentioned, in addition to yarn formation in the rotor groove, the fibers fed in are also separated from the transport air in the rotor, this air being dispersed either over the rotor wall (systems with indirect rotor bearing) or through holes in the base of the rotor (systems with direct rotor bearing).

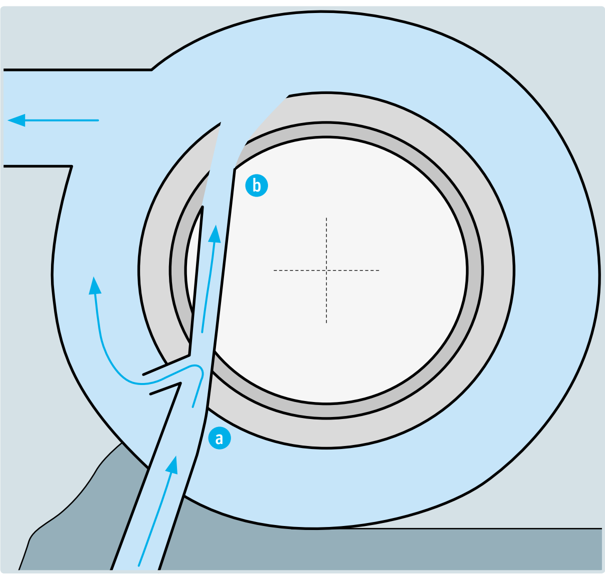


Fig. 15 – Fiber guide channel (a) with SPEEDpass (b)

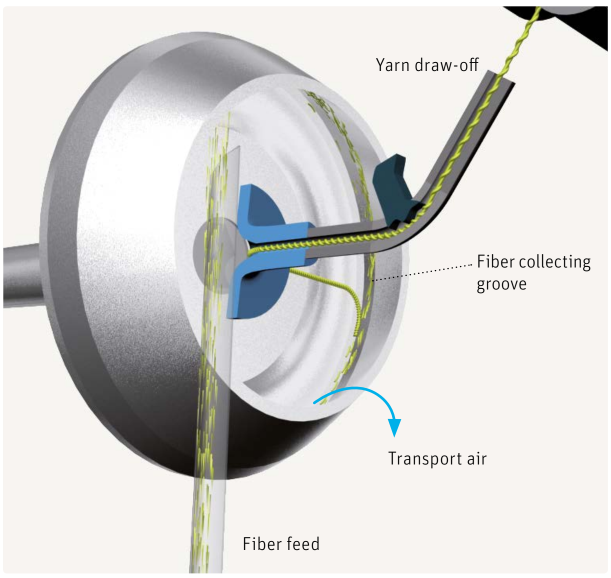


Fig. 16 – Tangential fiber feed into the rotor and fiber transport to the fiber collecting groove of the rotor

Transfer of the fibers fed from the fiber guide channel into the rotor groove occurs via another intermediate stage, the rotor wall.
This feeding method is absolutely essential for orderly yarn formation. The peripheral speed of the inside wall of the rotor must be significantly higher than the speed at which the fibers are transferred to the rotor wall. This difference in speed ensures that the fibers encountering the inside wall of the rotor are accelerated to many times their transport speed. Since the fibers do not assume the peripheral speed of the inside wall of the rotor instantly on encountering it, they lag behind the slipping surface of the rotor wall and drift downward into the collecting groove in a helical line contrary to the direction of rotation of the rotor due to the slope of the rotor wall. The fibers are transferred neatly, arranged in the longitudinal direction, from the rotor wall to the rotor groove by the increasing centrifugal force of the widening inside diameter of the rotor in the direction of the rotor groove. The difference in speed between the fibers and the inside wall of the rotor also ensures that the fibers are extended in the longitudinal direction when they encounter the rotor wall, which in turn promotes the (desired) parallel arrangement of the fibers in the rotor groove.

2.3.6. Yarn formation and twist insertion

The collecting groove of the rotor combines the fibers delivered to it into a ring of fibers which changes into the twisted thread at the integration point (refer to Fig. 17), while the integration point moves forward relative to the rotor collecting groove at yarn take-off speed. The integration point starts immediately after the point at which the yarn is lifted out of the rotor groove. The fiber ring formed in the rotor consists of individual layers of fiber. A thin layer of individual fibers – their number corresponding to so-called back-doubling – is deposited in the rotor groove with each revolution of the rotor:

$$\textit{back-doubling} = \frac{\textit{rotor circumference x yarn twist}}{1\ 000}$$

The number of fiber layers from which the spun yarn is formed results from the rotor diameter, the twist multiplyer and the yarn count. Since back-doubling increases and declines in a straight line relative to the rotor diameter, using smaller rotor diameters implies a reduction, using larger rotor diameters an increase in the number of fiber layers from which the yarn is formed (refer to section „5.1.2. Fiber collection in the rotor groove (back-doubling)“). Doubling linear bundles of fibers, i.e. forming a sliver or yarn from several layers, implies in principle an improvement in the regularity of the fiber bundle, with back-doubling exerting a positive influence on variations that amount to no more than the length of the rotor circumference.
When the number of fibers required for a given yarn count have been deposited in the rotor groove, the end of the yarn already spun, which extends into the rotor groove and rotates with the rotor, transmits the twist to the fiber ring. The integration zone operating with constant overfeed is described as the „twist zone“, the zone in which the thread leaves the rotor groove as the „lift-off point“ (Fig. 17).

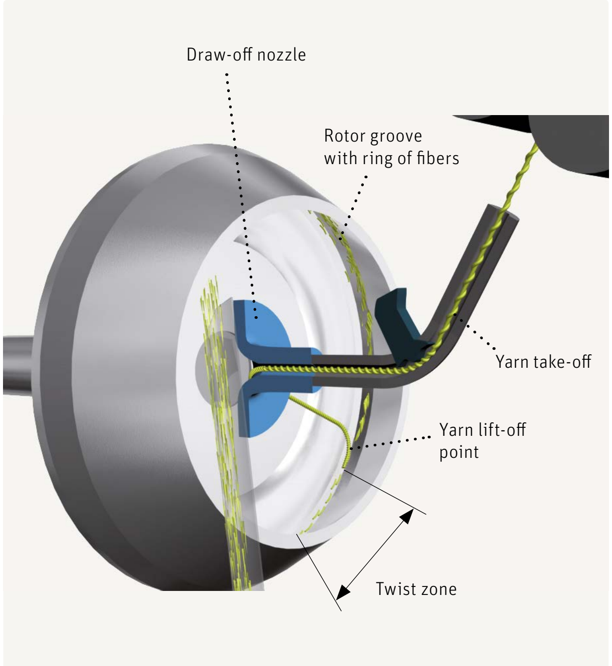


Fig. 17 – Yarn formation and twist insertion in the rotor groove

Rotor spinning is an open end process which generates a genuine yarn twist. In this case the component imparting the twist is the rotor, which twists the thread around its axis. The resulting yarn twist is the decisive factor for yarn tenacity. However, in order to maintain the spinning process, i.e. integrate the fibers in the rotor groove, a spinning twist is required, which as a rule must be higher than the yarn twist required for yarn tenacity. This means that an additional twist must be imparted to the radial section of yarn (imparting false twist). This false twist is imparted by the unrolling motion of the yarn on the draw-off nozzle, which is therefore much more than a thread guide. Depending on spinning conditions, the false twist can be up to 60 % of the set yarn twist.

The false twist effect generated between the draw-off nozzle and the yarn unrolling from it has Z twist between the draw-off nozzle and the rotor groove and S twist between the draw-off nozzle and the nip of the take-off shaft and the pressure roller. At this nip the false twist effect has again reached its zero point and the yarn body has only the preset genuine Z twist. The false-twisting effect of the draw-off nozzle can be increased by inserting a twist accumulating element in the draw-off tube immediately following the draw-off nozzle (refer to section „5.2. Genuine and false twist").

All rotor spinning machines are designed to spin yarns with Z twist. Z twist is the customary direction of twist used in practice. Manufacturing yarns with S twist would imply redesigning the rotor drive, sliver feed into the spinning box and fiber feed to the rotor.

In light of the large quantities of fibers a rotor has to cope with, the centrifugal forces already referred to and the abrasive components sometimes present in the material or the fibers themselves, rotors and also the clothing of the opening rollers are subject to natural wear and tear. Solid steel rotors, usually protected against wear by boron, diamond or boron/diamond-coated surfaces, currently offer exceptionally long service lives of up to 30 000 hours for rotors and opening rollers, depending on fiber throughput volumes.

2.3.7. Rotor speed and rotor diameter

In the course of development, rotor speeds have been increased from approx. 30 000 rpm originally to 160 000 rpm today. However, this has only been possible by simultaneously reducing rotor diameter. It can be demonstrated that all rotor speeds and diameters introduced in recent decades are closely related, as can be shown by a graph of the same centrifugal force. Fig. 18 shows centrifugal force cN/tex as a function of rotor speed and the resulting spinning range for different rotor diameters. Assuming that the centrifugal force acting on the thread in the rotor can never exceed yarn tenacity, this represents a theoretically absolute spinning limit which cannot, however, be reached in practice and is also not intended to be reached. Spinning tension must always lie with a sufficient safety margin below the „normal" variations in inherent strength existing in the yarn, otherwise economical running behavior cannot be achieved.

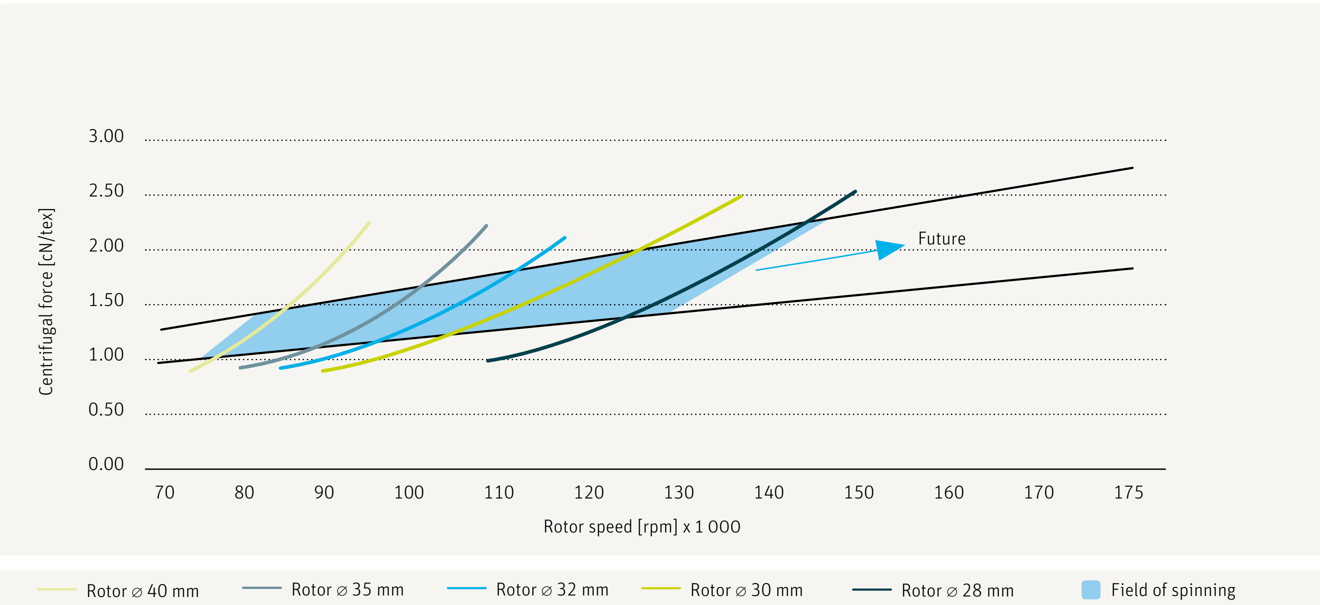


Fig. 18 – Centrifugal force as a function of rotor diameter and rotor speed

However, not only a maximum, but also a minimum possible speed is allocated to each rotor. If the rotor speed and thus spinning tension decline to such an extent that the centrifugal force in the rotor groove is no longer sufficient to generate the twist retention and false twist effect (between nozzle and rotor groove) on the draw-off nozzle which are necessary for spinning stability, twist integration in the rotor groove is seriously disturbed or interrupted and a thread break occurs. This situation is clearly apparent when calculating the so-called minimum twist multiplyer (α_{min}), from the course of which the optimum speed range for each rotor diameter can be derived (refer to Fig. 19).

Reducing rotor diameter for the sake of higher rotor speeds and thus higher output has worked surprisingly well as a rule. The repeatedly predicted (lower) limits for rotor diameter have consistently been breached by development, with the result that quality yarns are spun nowadays with 28 mm diameter rotors operating at speeds of up to 160 000 rpm (and suitable raw material). It should also be mentioned in this context that the frequently prophesied need to increase twist when reducing rotor diameter has not materialized.

However, the fundamental relationship between rotor diameter and fiber length, although not invalidated, is decisively modified by the considerable development advances in rotor technology (refer to section „5. Technology“).

2.3.8. Rotor cleaning

An essential element of a functioning spinning unit is automatic rotor cleaning capability. This is one of the major advantages of the rotor spinning system compared with other spinning processes, which are unable to clean the raw material fed in again at the spinning position itself.

While the large majority of these extraneous particles are eliminated by trash removal in the opening roller housing (refer to section „2.3.3. Trash removal“), light trash particles and dust in particular can reach the rotor in the air required for fiber transport and be deposited together with the fibers in the fiber collecting groove of the rotor. These deposits can either interfere with twist integration in the rotor groove to such an extent that thread breaks occur, or the deposits continue to accumulate in the rotor groove without provoking thread breaks, but continuously changing the groove geometry. This in turn results in a creeping change in yarn quality. Deposits in the rotor groove which are not distributed uniformly over the rotor circumference, but occur at certain points, result in periodic yarn defects known as moiré effect.

In order to limit the negative impact of these deposits, the rotor groove must be cleaned at certain intervals. This can involve automatically interrupting the spinning process after a preset period of time, whereupon the spinning robot

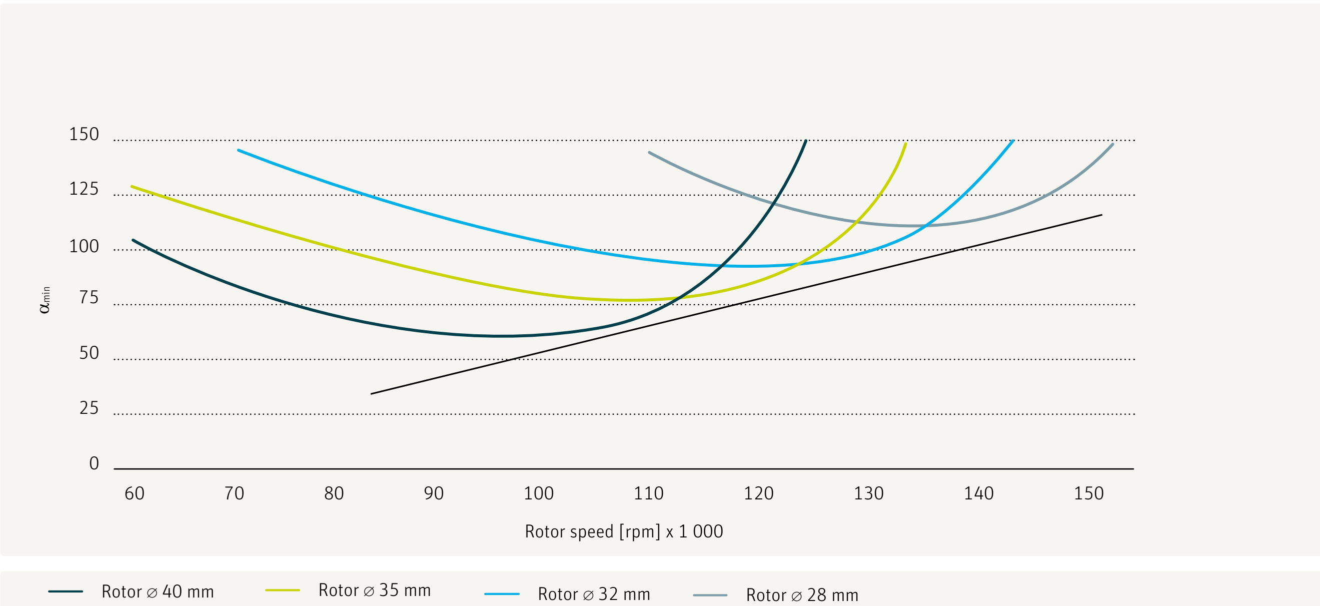


Fig. 19 – α_{min} values for different rotor diameters as a function of rotor speed (Source: ITV Denkendorf)

approaches the spinning position and cleans the rotor. However, this preventive cleaning means that each cleaning process entails an interruption of the spinning process and this results in principle in an additional join in the yarn due to the subsequent piecing process. Furthermore, this also causes a deterioration in machine efficiency. Preventive cleaning of the rotor is therefore performed only in exceptional cases, especially when spinning linen and severely soiled raw materials.

In mill operations and the overwhelming majority of applications rotor cleaning is performed automatically at each piecing operation at the spinning position, i.e. at each end down, each quality stop and each package change. Since a clean rotor groove is the precondition for both successful spinning start-up and high piecing quality, on modern systems the rotor groove is cleaned by means of a rotating cleaning head. The cleaning head cleans the rotor groove with 2 scrapers, while 3 air jets clean the rotor slip wall and the groove. The cleanliness of the rotor groove and the rotor that is required for trouble-free spinning operations is adequately assured by the frequency of the piecing process and the resulting cleaning intervals.

Although it sounds paradoxical, the absence of ends down during spinning, which many mill operators may wish for, is not always worthwhile. If a package were to reach its full size without any thread breaks, the risk that deposits would form in the rotor groove when using contaminated raw materials and thus cause creeping changes in yarn quality would naturally be very high. The resulting costs in downstream processing would then be considerably higher than the minimal loss of efficiency due to remedying a certain number of ends down. For one thing, piecings produced automatically do not differ substantially from ordinary yarn, either in cross-section or in tenacity, nor is the efficiency of the machine significantly affected by a limited number of ends down.

Essentially, two systems are used to clean the rotors: pneumatic cleaning by means of compressed air and mechanical cleaning by means of scrapers. Both systems are also used in combination (see Fig. 20).

During rotor cleaning the surface of the draw-off nozzles and the draw-off tube are also cleaned. Further modules clean the nozzle surface and the draw-off tube attached to it, either mechanically with a brush, or pneumatically with an Air-jet.

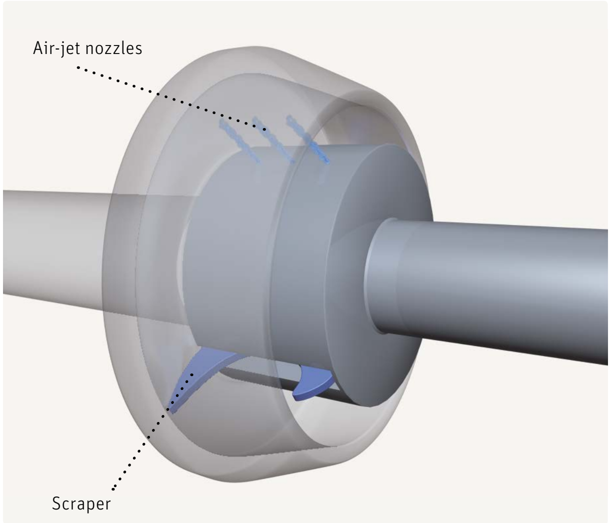


Fig. 20 – Rotor cleaning module with Air-jet nozzles and scrapers

2.3.9. Rotor bearing and drive

Nowadays, the rotors on all rotor spinning machines are driven using the friction drive principle, i.e. by a tangential belt in contact with the rotor shafts on each side of the machine. Other systems, such as driving the rotors by individual motors, have not become established in mill operations. We distinguish between two different rotor bearing systems:

- Direct rotor bearing (Fig. 21), in which tangentially driven rotor shaft (a) is encased in ball bearing housing (b). The ball bearing rotates at the same speed (rpm) as the rotor shaft driven by the tangential belt. This bearing principle limits rotor speeds to approx. 110 000 rpm. Although direct bearings would be ideal, individual motors have also been unable to establish themselves for this rotor drive, on cost grounds.

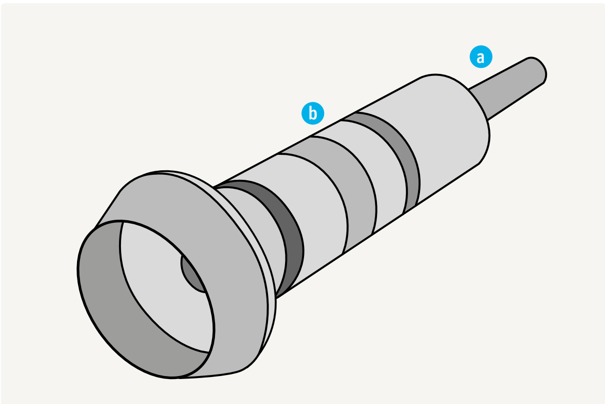


Fig. 21 – Direct rotor bearing, with rotor shaft (a) encased in ball bearing housing (b)

- Indirect rotor bearing, in which the rotor shaft, also driven tangentially, runs on two pairs of supporting discs arranged side by side (see Fig. 22). With the support-disc bearing the rotor speed is reduced at a ratio of 1:8 to 1:10 relative to the bearing of the supporting discs, depending on the diameter of the discs, so that these bearings run at speeds of only 16 000 to a maximum of 20 000 rpm (depending on the diameter of the supporting discs), even at rotor speeds of 160 000 rpm. For one thing, this bearing system permits much higher rotor speeds than direct bearings, and at the same time the service life of indirect bearing systems is significantly higher than that of directly driven bearing systems. High-performance rotor spinning machines operating at speeds of up to 160 000 rpm are therefore operated only with indirect rotor bearing.

As already stated, with both bearing systems the rotors are driven by a tangential belt on each side of the machine, the speed of which can be adjusted either by stepped speed pulleys or steplessly by means of an inverter drive. Tangential belt (a) is engaged with the rotor shafts via pressure rollers (b) to drive the rotors (see Fig. 23). If a spinning position is stopped and the rotor cover opened, the tangential belt is disengaged at this spinning position by raising the pressure roller and the rotor shaft is brought to a standstill by a brake positioned between the supporting discs. Since the rotor is held in position only by the light pressure of the tangential belt on the support-disc coatings, it can be removed very easily without the use of tools for replacement or examination and re-fitting.

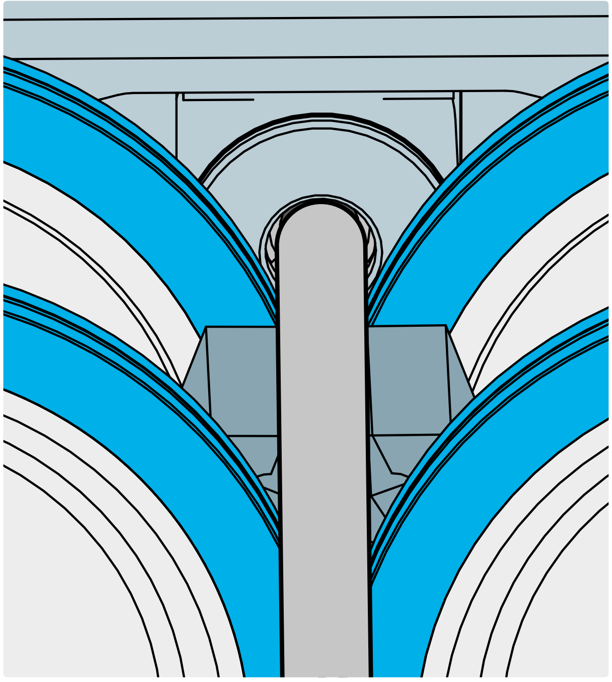


Fig. 22 – Support-disc bearing (Twindisc bearing) with rotor fitted

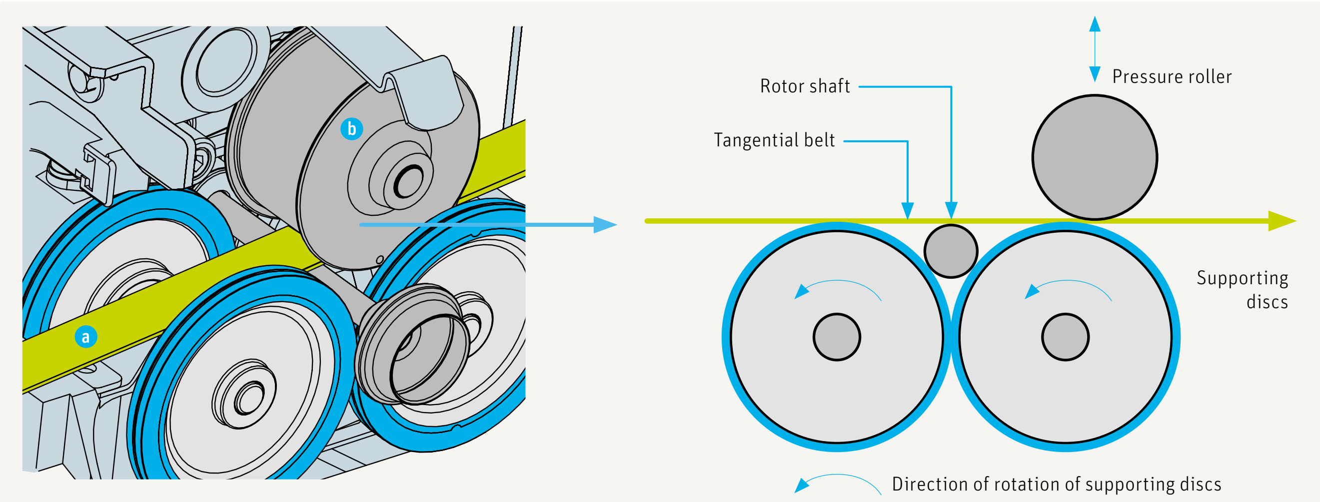


Fig. 23 – Support-disc bearing (Twindisc bearing) with pressure roller (b) for tangential belt (a)

While the tangential arrangement of the rotors is important for the rotor drive, the axial positioning of the rotor is the prerequisite for fiber feed to the rotor and thread take-off from the rotor to occur under absolutely identical conditions at each spinning position. Whereas both the tangential and the axial position of the rotor are defined by the fixed ball bearing housing in the case of direct rotor drive, the rotor on support-disc bearings also has to be fixed in position in the axial direction. The rotor is fixed in position axially by slightly crossing the pair of supporting discs, so that the rotor is pressed backward with some force (toward the spinning beam). Various bearing systems are available for absorbing this backward axial pressure:

- **Steel ball or hybrid bearings:** the axial thrust of the rotor is absorbed by a steel ball rotating in an oil bath. The front of the rotor shaft and the steel ball are subject to severe wear due to mechanical friction, despite oil lubrication. In more modern bearing systems the front of the rotor shaft is therefore ceramic-coated. This axial bearing system has been used by almost all machinery manufacturers in recent decades. However, the fundamental drawbacks of this system – high spare parts consumption, a high level of cleaning and maintenance effort and severe soiling due to sticky deposits in the axial bearing zone – have encouraged the development of modern bearing systems which are now used at least on high-performance rotor spinning machines.
- **Magnetic bearings** (see Fig. 24 + Fig. 25). The end of the rotor shaft is fixed in position without contact in a magnetic field created by annular magnets. Accurate radial positioning of the rotor shaft is the precondition for the functioning of this system, which as far as is known to date has no speed limitations.
- **EC bearings** (Fig. 26 + Fig. 27). The end of the rotor shaft runs (in contrast to the oil bearing) on a steel ball embedded in grease. The housing is sealed, grease cannot escape, and the bearing is largely maintenance-free.
- **AERObearings** (Fig. 28 + Fig. 29). In this bearing system an air cushion provides axial support for the rotor. This air cushion is provided by a compressed air supply of 6 bar to each spinning position. This system requires neither oil nor grease, sticky deposits are avoided, and in the immediate vicinity of the air cushion the permanent current of air ensures continuous cleaning (self-cleaning effect). Other advantages of this system are low maintenance effort and spare parts consumption. The accurate, level surface of the end of the rotor shaft is the precondition for trouble-free operation.

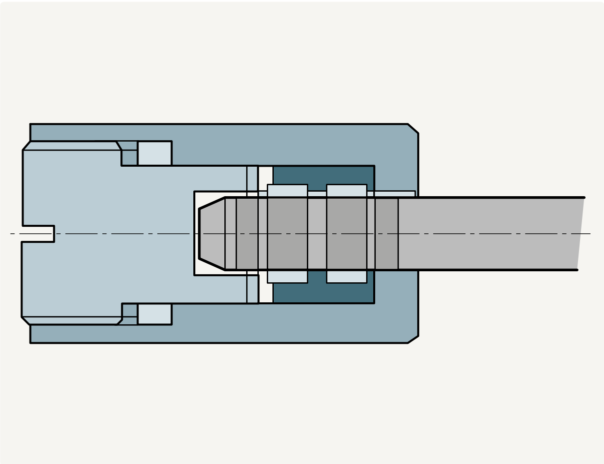


Fig. 24 – Axial rotor bearing with magnetic bearing

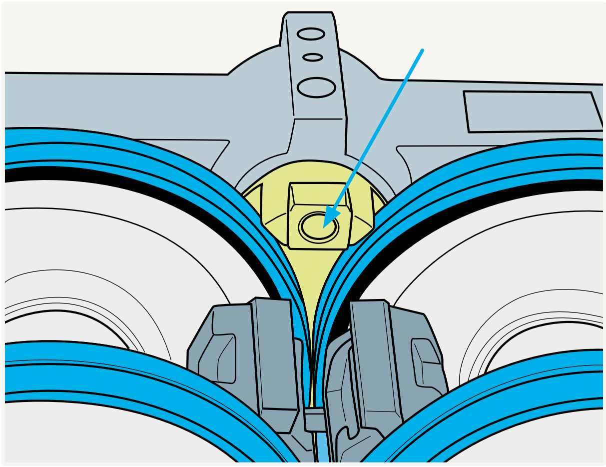


Fig. 25 – Positioning the magnetic bearing

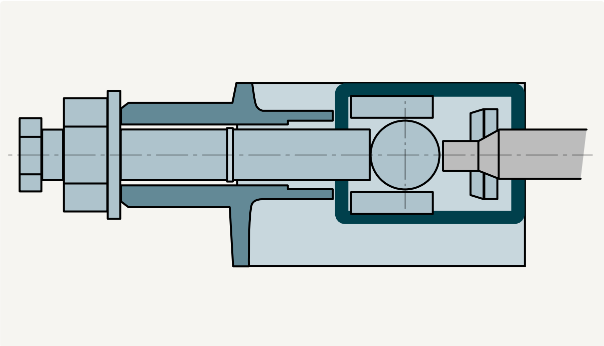


Fig. 26 – Axial rotor bearing with EC bearing

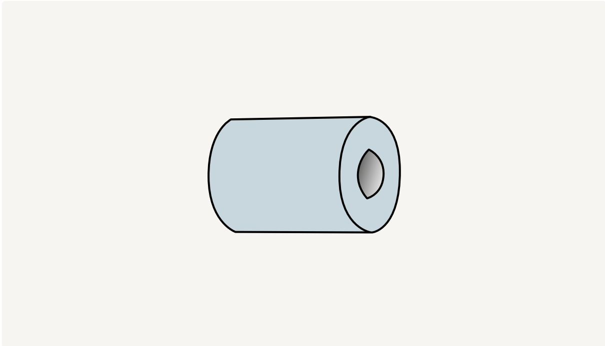


Fig. 27 – Sealed grease cup of the EC bearing

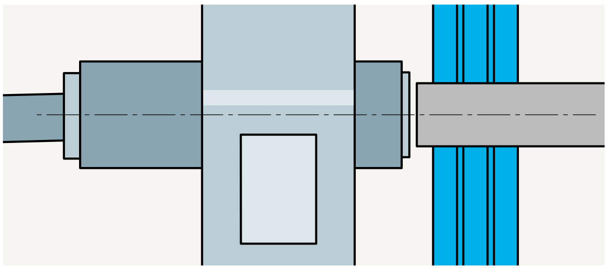


Fig. 28 – Axial rotor bearing with AERObearing

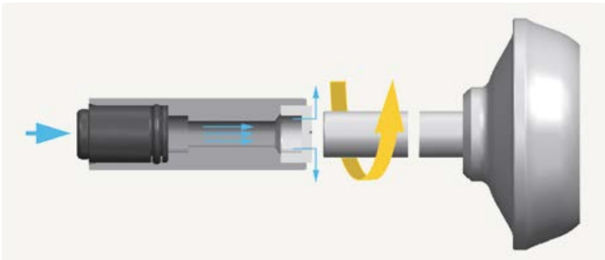


Fig. 29 – Airflow with the AERObearing; air pressure 6 bar

2.3.10. Yarn take-off

The yarn is taken from the rotor by the delivery shaft and pressure roller (a in Fig. 30), diverted virtually at right angles in the process by draw-off nozzle (b) projecting into the rotor and guided out by draw-off tube (c) immediately following this. However, as has already been said, the draw-off nozzle is far more than a mere guide device. At take-off the yarn continuously rolls off on the surface of the draw-off nozzle due to the rotation of the rotor. This rolling-off temporarily inserts additional twist into the yarn (contrary to the direction of twist of the yarn), thus creating the false-twist effect required for spinning stability, which can be up to 60 % of the set yarn twist (see section „5.2. Genuine and false twist“). The greater the false-twist effect, the higher the spinning tension.

While rolling off on the surface of the nozzle, the yarn is repeatedly raised briefly in rapid succession, depending on the surface structure. This high-frequency vibration – together with the false-twist effect – promotes twist propagation into the rotor groove. The more pronounced the structure of the nozzle surface, the more vigorously the yarn vibrates, thus supporting twist propagation and the false-twist effect extending into the rotor all the more. As a result of this, the greater the false-twist effect, the lower the genuine yarn twist that can be selected and the bulkier and softer the yarns that can be spun. The draw-off nozzles are held firmly in the rotor cover by either a screw or magnetic lock. Draw-off nozzles can be replaced very easily and in some cases without using tools. Since draw-off nozzles are now usually made of high-quality ceramics, service lives of several years can be achieved under normal spinning conditions.

Section „4.4.3. Range of application of draw-off nozzles and draw-off tubes“ deals in detail with the ranges of application of the different nozzle surfaces, the positioning of the draw-off nozzle relative to the thread collecting groove of the rotor and the influence of the different thread draw-off tubes on yarn quality, yarn structure and spinning stability.

2.4. Package formation

Rotor spinning machines produce packages ready for sale, which can be used immediately in downstream processing without any detour via the winder. Waxing devices and quality monitoring sensors at each spinning position and cylindrical package formats from 2° to 4°20′ (USA 3°51′) ensure that the most suitable cross-wound packages can be provided for any stage of downstream processing – knitting, weaving, yarn dyeing or doubling.

Almost all rotor spinning machines nowadays produce packages with a traverse of 150 mm (6″), which results in the following package formats, depending on the winding unit of the different types of machine:

- cylindrical packages: max. diameter 350 mm; max. package weight up to 6 kg;
- conical packages (2° - 4°51′): max. diameter 280 mm; package weight depends on package density.

The high package weights reduce handling costs in the spinning mill and downstream processing as well as capital costs for empty tubes.

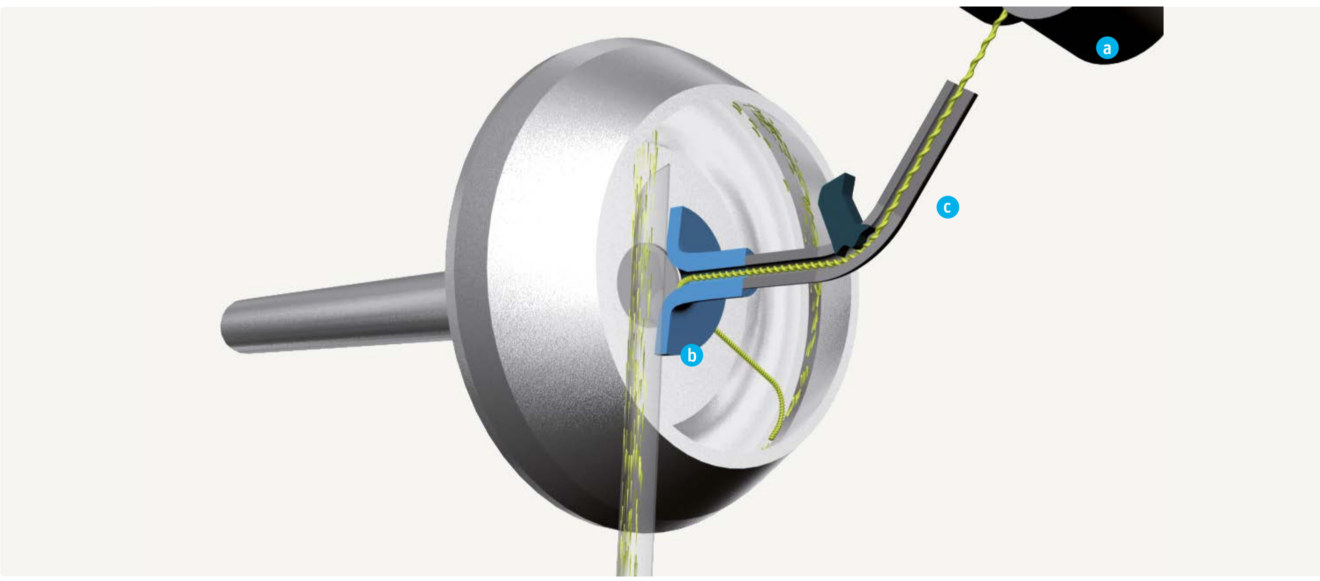


Fig. 30 – Yarn take-off with take-off rollers (a), draw-off nozzle (b) and yarn draw-off tube (c)

Two main advantages are cited for cross-wound packages from the rotor spinning machine as compared with those from the winder:

- the number of piecings in the rotor spinning package is only 2 - 3 % of the number in the winder package since, in rotor spinning, a continuously spun yarn is wound up as it is produced, whereas the winder package is made up of yarn from small cops with a mass of 60 - 120 g, joined together by corresponding splices;
- winding is carried out at speeds of up to 350 m/min, as compared with 1 400 m/min in the winder; this gives a better package build, and the yarn lengths on the individual packages can be kept more uniform; admittedly, however, a larger balloon is generated when unwinding yarns from rotor spinning packages.

The following requirements must be fulfilled by packages of yarn from modem rotor spinning machines:

- package density as uniform as possible from one package to another;
- the same yarn length on all packages; this will be achieved exactly with individual length-measuring devices;
- adaptable winding density attainable by means of adjustable yarn tension and above all by a variable angle of intersection of the windings in the package;
- packages free of patterning zones;
- yarn waxing where necessary;
- formation of an accessible yarn reserve on the tube so that, during unwinding, the thread end can be knotted to the start of the yarn on the next package to be unwound before the package runs out; this enables stoppages to be avoided at package change in further processing.

2.4.1. Winding, stop motion and quality control

The spun yarn is taken off the rotor by means of the take-off rollers, which draw the finished yarn out of the spinning box through the draw-off nozzle and the draw-off tube. While the full spinning tension in the yarn is in effect below the take-off rollers winding onto cylindrical or conical cross-wound packages above the take-off rollers is performed with considerably reduced winding tension. This winding tension is infinitely adjustable. The lower the winding tension, the softer the packages (e.g. for dyeing packages); the higher the tension, the more compact the package, but at the risk of reducing yarn elongation.

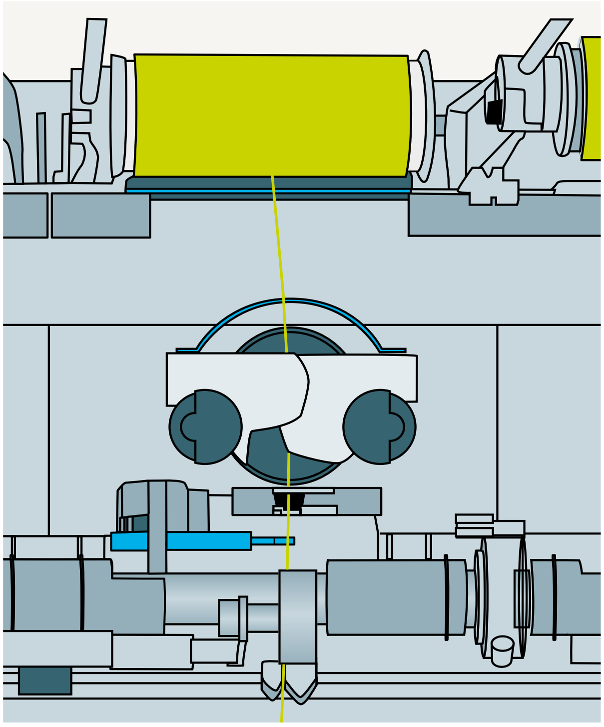


Fig. 31 – Winding head with package

The yarn is wound onto a tube which is clamped between the package holders (Fig. 31). Cylindrical packages and 2° conical packages are driven by the one-part winding roller. In the case of 3°50′ and 4°20′ conical package formats, allowance must be made for the different peripheral speeds on both sides of the winding roller.

2.4.2. Compensation of winding tension

The traversing motion of the yarn depending on stroke and winding helix requires compensation of the winding tension for homogeneous package density. A thread guide is arranged to effect crosswise laying of the yarn in the package by means of its to-and-fro movement. A compensation bow (Fig. 32, a) and the yarn tension bar (Fig. 32, b) are needed to even out path-length variations which arise because the length of yarn between the take-off rollers and the right- or left-hand edge of the package is greater than the length between those rollers and the middle of the package. Path-length compensation by means of compensation bow and yarn tension bar only is, however, adequate for winding cylindrical and conical packages with up to 2° taper.

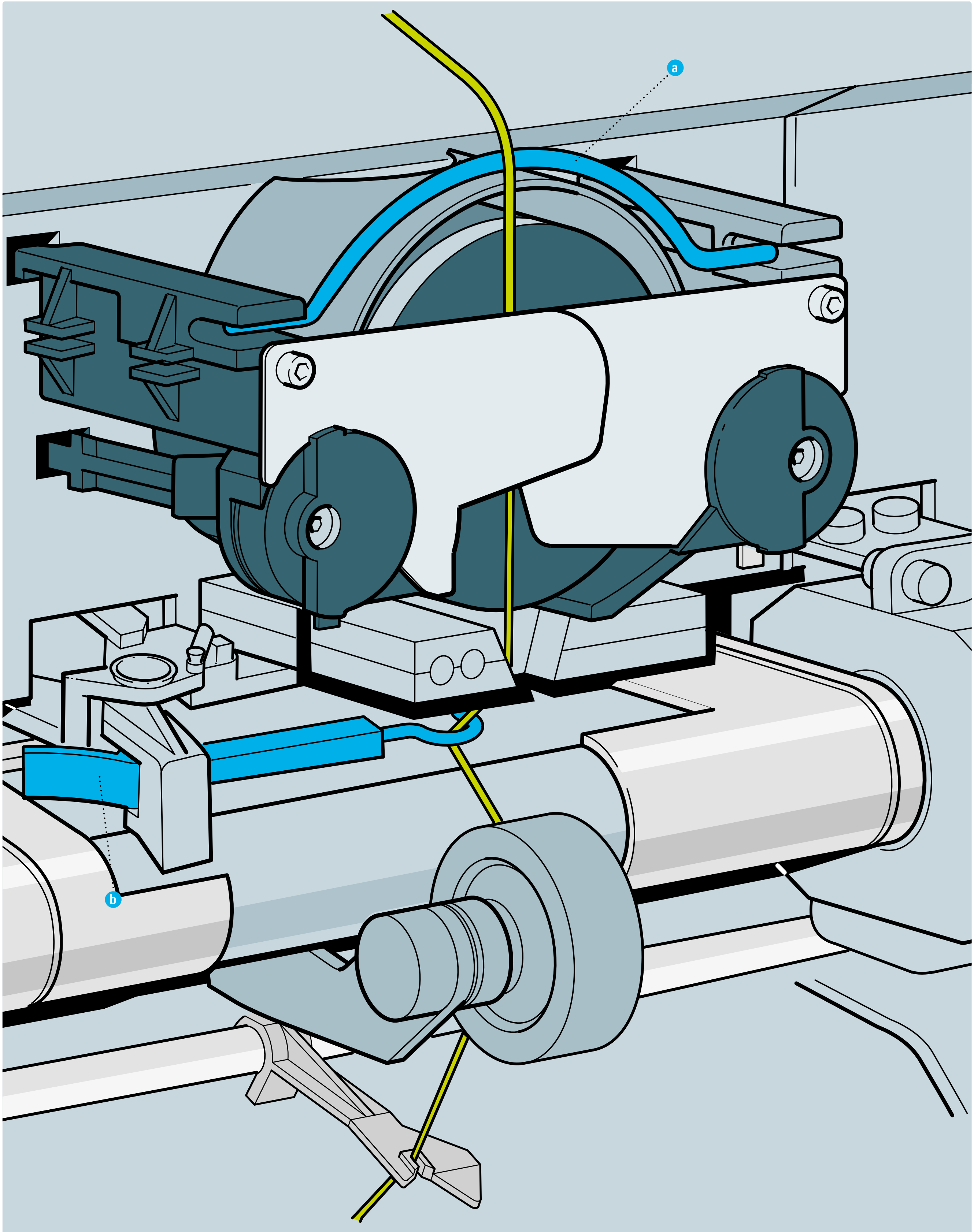


Fig. 32 – Compensation of winding tension with compensation bar (a) and yarn tension bar (b)

Compensation bow and yarn tension bar no longer suffice for tension compensation when producing packages with a taper of 3°51′ or 4°20′.
A three-part differential winding cylinder is therefore used, for example, for the package drive (Fig. 33), with which the differences in speed from small to large package diameter are compensated via the wheel and disc differential gear.

2.4.3. Winding helix and delivery speed

A traversing yarn guide rod equipped with slotted yarn guides determines the angle of intersection (winding helix) of the yarn. The traversing motion is created by a traverse gear in the headstock. Each machine side has its own traverse gear, operating in opposite directions on the two sides. The maximum permitted delivery speed depends on the winding helix but also on the tube shape and the number of rotors per machine.
The yarn winding angle mainly affects the package density and the unwinding performance of the package. It therefore has to be matched to requirements with the utmost precision by adjusting the traverse per unit time of the thread guide. The angle can usually be varied between 30° and 40°. The larger the angle, the lower the density and hence the greater the softness of the package (Where the latest generation of high-pressure dyeing equipment is available, dyeing can also be carried out with harder packages).

As already mentioned, the density (γ) of the package depends not only upon the winding angle but also on:
- the (adjustable) winding tension;
- the (adjustable) contact pressure of the package on the winding roll; and
- the yarn count.

A finer yarn always gives a higher package density, which can be calculated according to the well-known physics equations:
density (γ) = mass/volume,
γ = yarn net mass (g)/ yarn volume (cm^3)
Standard values for package density for yarns made from cotton and cotton-like fibers:
- packages for package dyeing: γ = 0.33 - 0.38 g/cm^3;
- hard packages: γ = 0.38 - 0.42 g/cm^3.

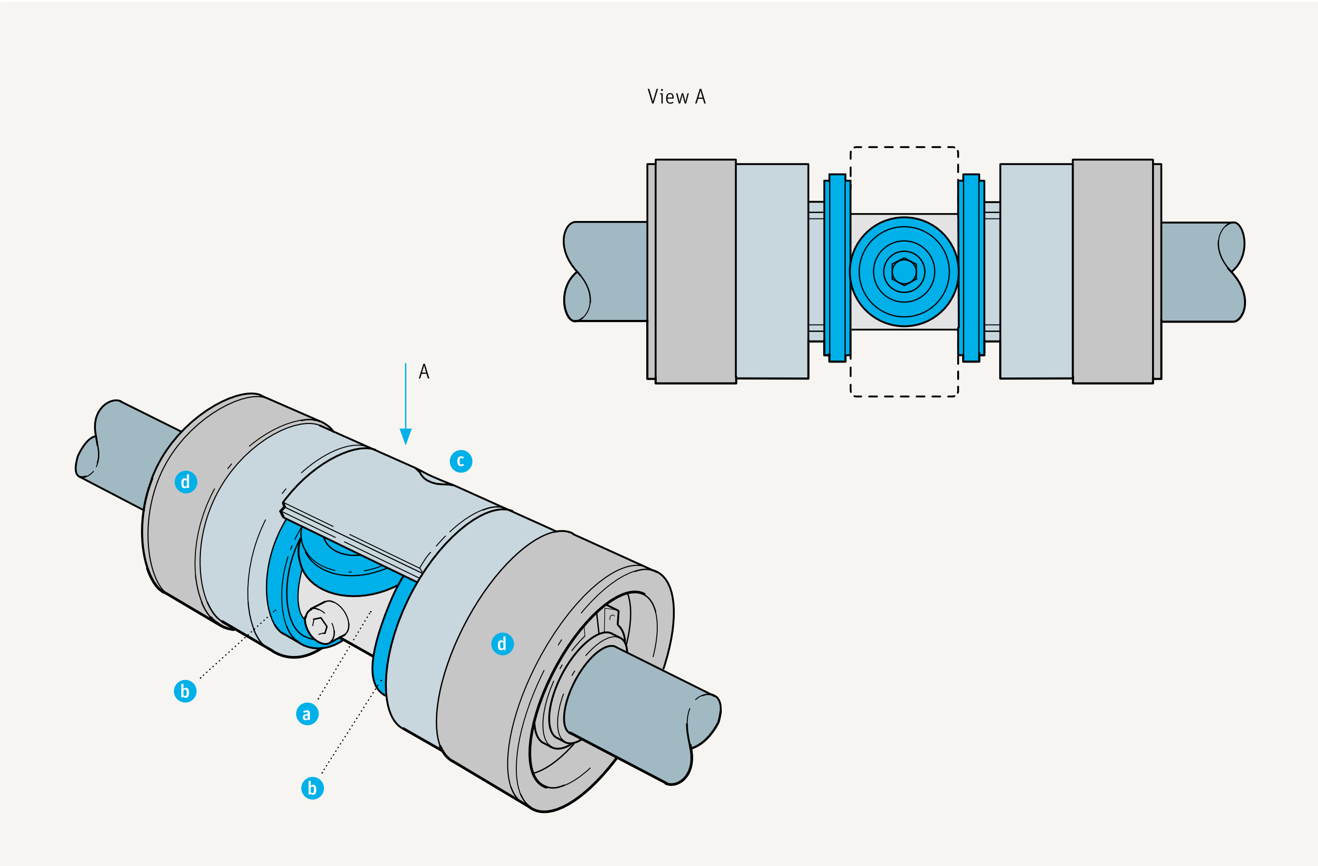


Fig. 33 – Three-part winding cylinder with powered middle section (a), two powered side sections (b), wheel and disc differential gear (c) and friction coatings (d) for driving the package

2.4.4. Anti-patterning device

Normally, the yarn windings are distributed irregularly over the whole surface of the package. However, it can happen that the turns of a new layer are deposited exactly on top of the turns of the preceding layer, and this process repeats itself for several successive layers (turn on turn on turn, etc.). This generates uniformly intersecting (rhomboidal) ridges, so-called pattern windings or pattern zones. They reduce the take-up capacity of the package and make unwinding difficult, and are therefore to be avoided at all costs. Their occurrence is determined by mathematical relationships between the traverse frequency and rate of revolution of the package, mainly by ratios of 1:1, 1:2, 1:3, etc. An anti-patterning device minimizes pattern winding (frequent parallel layers) on the package. Pattern windings emerge at certain package diameters depending on stroke and winding helix (see Table 1). The anti-patterning device continuously varies the motion speed of the traverse gear. Thus, the winding helix is changed continuously, preventing the build-up of patterns to a large extent.

STROKE [mm]	WINDING HELIX				
	30°	32°	34°	37°	40°
152	(384)*	(360)*	337	308	283
148**	(375)*	350	329	301	276
145**	(368)*	344	323	295	271
142**	(361)*	337	316	289	266
138	350	328	307	281	258

* Pattern winding already out of the maximum permitted package diameter of 350 mm.
**Standard stroke boxes (see section „2.4.5. Edge displacement at package shoulders")

Table 1 – Pattern windings 1:1 at package diameter in mm

2.4.5. Edge displacement at package shoulders

At the reversal points of the traverse, i.e., at the edges of the package, a short pause occurs in the movement of the thread guide owing to the deceleration and subsequent reverse acceleration required here. More yarn is wound up at these points than at other points along the package length. This leads to considerable accumulations of yarn with the following consequences:

- excessively hard and compact package edges;
- ‚slippers' at the package edges (laterally displaced layers of yarn, disturbing in downstream processing);
- differences in dye take-up between the center and edge of the package in dyeing packages.

To avoid the repeated placement of yarn at the same part of the package edge, a shift of the reversal point is added to the traverse motion (Fig. 34). This shift can be set from 0 - 5 mm in the case of conventional gears. Infinitely adjustable gears with variable traverse extension (Fig. 35 and Fig. 36) provide an extended range of adjustment of 0 - 30 mm and thus particular advantages in the production of soft dyeing packages with the required low package density in the package edge zone.

2.4.6. Length measurement

If packages are doffed after they have reached a certain diameter (the old method used in the winding room), they will have differing yarn lengths because of varying yarn tension. These packages run out at different times in downstream processing, where many packages are unwound simultaneously, e.g., in the warping machine. The need to re-creel causes considerable effort and loss of yarn. Accordingly, attempts have been made over many years to provide constant and uniform yarn lengths in packages. This is possible by means of special measuring

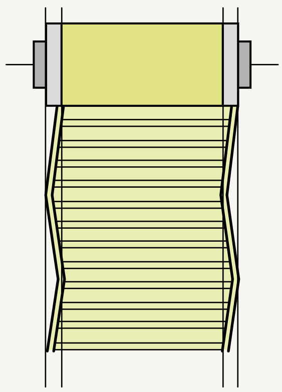


Fig. 34 – Conventional stroke displacement

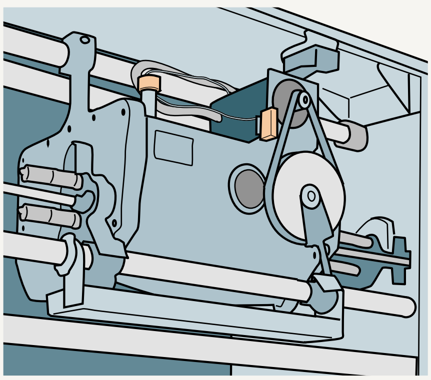


Fig. 35 – Gear for variable stroke displacement

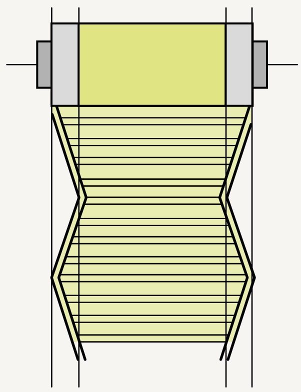


Fig. 36 – Variable stroke displacement

devices in the rotor spinning machine. At each spinning position they register the exact length wound and stop the spinning position when a predetermined yarn length is reached. Length variability within ±0.5 % is technical standard.

2.4.7. Yarn waxing device

In the production of knitted goods in particular, where the yarn is bent sharply around the needles, rough yarns can cause disturbances, broken threads, and a high degree of wear. In order to improve running performance, knitting yarns have always been waxed. The rotor spinning machine enables this to be done directly at the spinning position.

Mill results have shown that a maximum reduction of the coefficient of friction of between 40 and 50 % is achieved by means of the usual wax application of between 0.5 and 3 g/kg of yarn. Type and quality of the wax are decisive for optimum waxing application. Wax differs in hardness, melting point and penetration and needs to be selected according to raw material, yarn type and knitting requirements. Waxing devices also differ in the size of the wax blocks used. In addition to longer running times, larger wax blocks entail significantly reduced effort for replacing the wax blocks. In this connection, it should be noted that over-application is just as detrimental as under-lubrication, since both result in a high coefficient of friction.
The waxing device (see Fig. 37 and Fig. 32) is arranged between the take-off rollers and the package so that small particles of lubricant can settle on the yarn as it passes over a body of wax. These particles are rubbed off as the

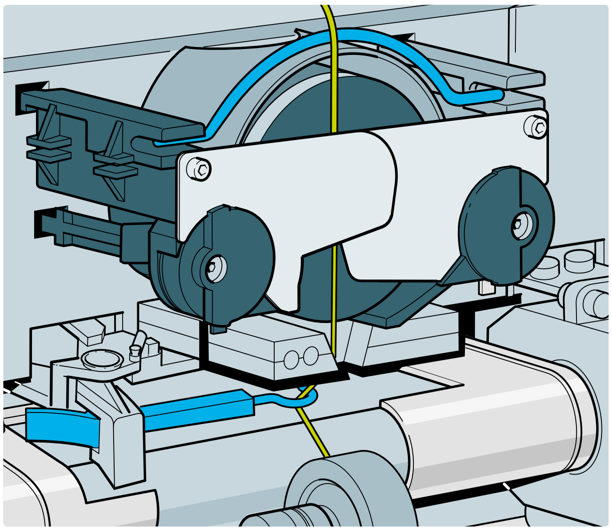


Fig. 37 – Waxing device with large wax blocks

yarn is sharply bent at the needles of the knitting machine, and they then ensure good running properties. The wax block is pushed automatically by a spring into an optimum position to counteract wear. The rotating wax block is stopped in the event of ends down.
The waxing device always requires yarn compensation devices such as compensation bows or yarn tension bars. Different kinds of covers at or below the waxing device prevent loose wax particles from falling into the spinning cans and thus contaminating the sliver.

2.5. Drives

Of the various drives in an automated ring spinning machine, those for the rotors, the opening rollers and spinning vacuum account for the majority of energy consumption. Fig. 38 shows the proportion of energy consumed by the main drives of a rotor spinning machine.

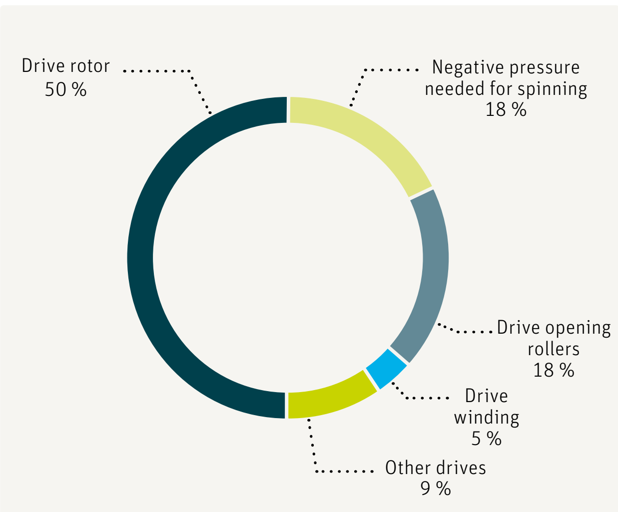


Fig. 38 – Breakdown of energy consumption for the various drives of a rotor spinning machine

The rotors and opening rollers are usually driven by tangential belts, with a growing trend toward synchronous drives. Individual drives provide advantages in flexibility, but entail high costs and very complex controls. Major aspects when considering drives are smooth running, the cost factor and energy consumption.

The settings for draft (ratio $n_{feedcylinder}$/ $n_{deliverycylinder}$), yarn twist (ratio $n_{rotorspeed}$ /$n_{deliverycylinder}$) and winding tension (ratio $n_{deliverycylinder}$/$n_{windingshaft}$) are made via the drives for the feed cylinder, the take-off rollers and the winding shaft. The interaction of the drives for draft, twist and winding tension is shown schematically in Fig. 39. Settings are made either via infinitely adjustable inverter drives or conventionally via change gears.

The use of infinitely adjustable inverter drives reduces both operator effort when changing setting parameters and machine downtimes, since gear wheels no longer have to be changed with this concept. The settings for draft, yarn twist and tension can be individually entered directly at the machine control panel, as can the values for rotor and opening roller speed (optional in some cases) with inverter drives.

The package conveyor belts (one conveyor belt on each side of the machine) are driven from the tailstock. The package conveyor belt starts automatically when a preset number of completed packages have been placed on the belt. The conveyor belt transports the packages to the end of the machine, where the packages are ready for removal. When all packages have been removed the package conveyor belt drive is switched off. Various concepts are offered for package doffing (refer to section „3.2.3. Package transport between the rotor spinning machine and subsequent zones“).

Empty tubes are transported (to the operating robot) by narrow conveyor belts arranged in pairs (Fig. 40), which are driven by a separate motor. Each side of the machine is equipped with a pair of belts operating independently of each other. The package handling system of the tube magazine places an empty tube on each of the pair of conveyor belts. As soon as the spinning robot requests an empty tube, the conveyor belt starts and delivers the empty tube to the robot‘s empty tube holder.

The drives for the trash conveyor belt (one on each side of the machine) are designed so that the belts are moved alternately forward and backward (Fig. 41). The reversal point is controlled by a sensor. Suction units which extract the trash removed from the spinning box and transport it to the central filter are located at the reversal points.

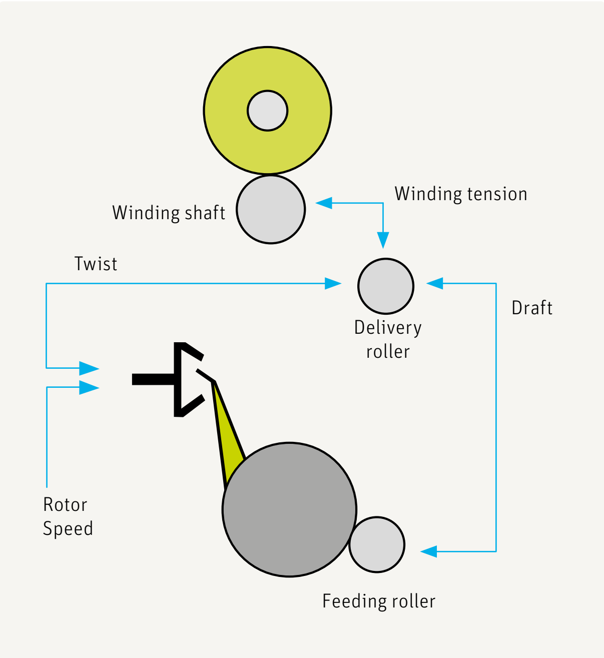


Fig. 39 – Infinitely adjustable inverter drives for draft, twist and winding tension

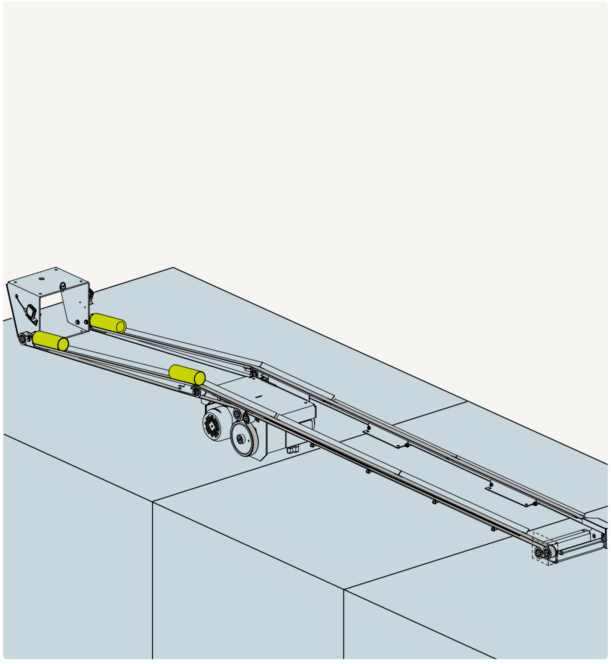


Fig. 40 – Supplying empty tubes via conveyor belts

Fig. 42 – Negative pressure drive

Power for all control units is supplied by an externally driven motor via a generator. The motor and generator are in the headstock. The flywheel mass of the three-phase motor generates enough power to bridge short-term power failures lasting a few seconds, without causing the machine to shut down.

2.6. Suction systems

The spinning process requires negative pressure at each spinning position for the piecing process and for waste removal from the waste conveyor belt. The negative pressure for the machine is generated by a motor-driven suction fan located at the tailstock of the machine. The negative pressure for the robot is supplied by a separate fan at the tailstock (Fig. 42).

2.6.1. Suction system machine

The main fan (Fig. 42, 1) sucks the air from each spinning position through negative pressure duct (2) and filter housing (3), thus creating a negative pressure of approx. 60 - 85 hPa at the rotor housing of the spinning box. Trash, dust and fiber fragments carried by the air current are collected by a filter layer (4) in the filter housing. The layer of fibers, trash and dust is held on the filter by the current of air. However, as the filter becomes increasingly full, the negative pressure inevitably weakens. If the negative pressure then falls below the adjustable limit value (alarm level), the current of air is automatically diverted briefly through a bypass (5). The layer of material on the filter is now no longer held and drops onto the base of the filter housing (6). The negative pressure is thus restored in full.

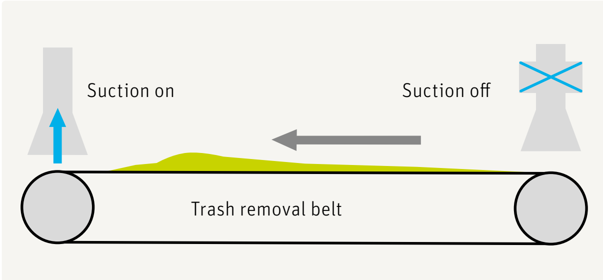


Fig. 41 – Trash removal belt with suction units

Another option for offsetting the decline in negative pressure for spinning with increasing filter coating is to keep the negative pressure constant, i.e. fan speed and thus the negative pressure are continuously increased as the filter coating increases. Negative pressure for spinning is continuously monitored by sensors and adjusted according to filter loading. However, power consumption also increases with rising fan output. There are therefore also limits here, and when these are reached the filter coating must be removed manually. The burden on operating personnel is also relieved considerably with this concept by extending the intervals between manual emptying of filters. In addition to negative pressure for spinning, the fan generates the suction required to dispose of the trash removed from the spinning box. The trash resulting from extraction from the spinning box is deposited on a trash conveyor belt and fed to the filter by suction nozzles at the left-hand and right-hand ends of the machine. The suction nozzles are controlled in such a way that only the suction nozzle toward which the conveyor belt is moving is operating. If the belt changes its direction of movement, the currently active suction nozzle is closed and the suction nozzle on the opposite side of the machine is switched on.

2.6.2. Suction system robot

The necessary negative pressure for the spinning robot is generated by an additional fan (Fig. 42, 7) mounted in the tailstock. Extraction duct (8) for the spinning robot is positioned between the robot's inner guide rails. The extraction duct has an opening at each spinning position, which can be kept closed by flaps. When the robot approaches the spinning position the flaps are opened and the negative pressure is available to the robot. The „waste removal" function is controlled by the machine control system. To open the filter boxes and while cleaning the filter boxes, the machine control system disables the positioning of the robots.

2.7. Operating and monitoring

The central machine operator panel (Fig. 43) is the central interface between user and machine. This operator panel is used for much more than the mere input and output of data. Machine settings are changed, characteristic values for integrated quality control systems are specified, the machine and the package transport system are started or stopped, the running strategy for the operating robots is specified, causes of errors in the event of machine problems or failures are displayed and both current and cumulative machine, production, performance and quality data are provided via this display. Analyses of stationary or deactivated spinning positions, i.e. spinning positions with too many ends down or quality stops, provide foremen or mechanics with working data for immediate trouble-shooting action on the machine under surveillance.

On machines with frequency-controlled inverter drives, spinning parameters are set and changed by entering the relevant values directly at the operator panel instead of the time-consuming and labor-intensive changing of gear wheels and step pulleys with the associated machine shutdowns. A further advantage is that setting values can be entered or changed while the machine is running! This considerably reduces machine downtimes for batch and count changes.

Data input and data queries are performed (on modern systems) via a touch screen panel (Fig. 43), and the user is guided through the program by menu assistance. At the same time the touch screen displays the data in alphanumeric and/or graphic form. In simpler systems data input and data queries are performed via a keyboard; data output is via a printer or monitor.

Access authorization in the mill can be organized via different access codes (mill management, maintenance/service personnel, operating personnel).

Various menus are available to the user for input and queries of machine, production and quality data, in a wide range of languages, of course (Fig. 43).

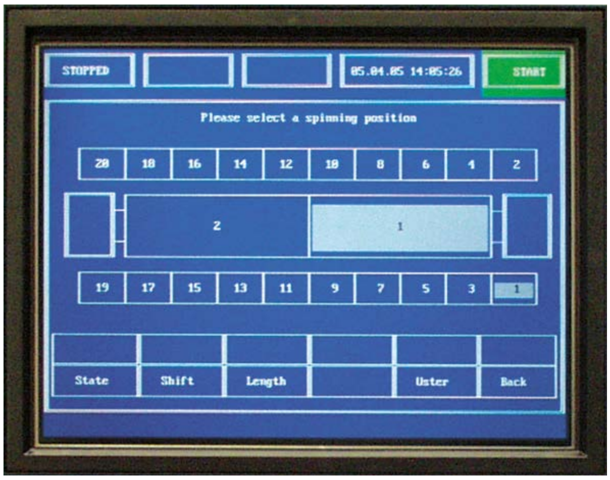


Fig. 43 – Machine operator panel in the form of a touch screen panel

On the basis of the current production and quality data from each machine, operating or maintenance personnel can immediately take the necessary action if production or quality faults are displayed. If the machines are connected to a higher-level data collection system, comprehensive data are available to mill management for efficient production and quality monitoring (refer to section „2.9. Production monitoring").

The robot operating panel (Fig. 44) is the interface to the user in the same way as the central operator panel for the machine control system. All settings and queries relating to the robot can be made via push buttons. Setting and optimizing piecings (length, mass and tenacity) are especially important here for operating personnel.

Fig. 44 – Robot operating panel

The display of the number of piecing attempts per piecing process and robot efficiency figures for piecings after ends down or quality stops and for piecing on empty tubes are key statistics for optimizing settings and can also indicate whether overall spinning conditions (raw material quality, yarn parameters, spinning elements, rpm and speeds) are correctly coordinated.

2.8. Quality control systems

The fact that rotor-spun yarns contain significantly fewer yarn defects than ring-spun yarns has made a major contribution to the success of the rotor spinning system. A comparison of Uster Statistics shows that the numbers of thick places, thin places and neps are significantly below the level of ring-spun yarns, even at delivery speeds that are up to 10 times higher. And the finer the yarn counts, the greater the differences. The reasons for this are back-doubling in the rotor (which balances variations in mass) (refer to section „5.1.2. Fiber collection in the rotor groove (back-doubling)“) and fiber guidance and monitoring without a cylinder drafting system. Furthermore, a package of rotor-spun yarn contains only a fraction of the yarn joints (piecings) compared with a cross-wound package of ring-spun yarn. A 4 - 5 kg cross-wound package in the rotor spinning mill contains no more than 3 - 5 spinning-related piecings at normal ends down rates. However, a 3 kg cross-wound package of ring-spun yarn produced on the winder already contains some 30 - 40 piecings due to system-related cop joints plus a certain number of additional piecings due to cleared yarn defects. This very soon adds up to more than 50 piecings (splices or knots per package).

This was also a major reason why rotor-spun yarns could for many years be processed further without cleaning. However, today‘s quality standards no longer permit this; quality requirements for rotor-spun yarns have increased considerably. For example, manufacturers of branded denim products (jeans, shirts, etc.) stipulate precise specifications for yarn and fabric quality which are so strictly formulated that only quality-tested yarns can be considered for processing.

Quality control systems have therefore very soon become integral components of high-performance rotor spinning machines. While contract spinning mills were the first to cite quality-tested yarns as a product advantage, in the meantime increasing numbers of vertically integrated mills are also starting to used quality-tested and cleaned yarns in downstream processing, especially for high-quality woven or knitted fabrics.

Leading global suppliers of quality control systems (e.g., Uster Technology with the Uster Quantum Clearer2® and Barco with the BarcoProfile) employ different measuring systems in some cases, but offer a largely comparable range of performance:

- detecting, counting and clearing disturbing yarn defects in accordance with adjustable clearing limits;
- counting uncleared (non-disturbing) yarn defects in defect classes;
- detecting and eliminating extraneous substances;
- measuring the main physical textile yarn attributes: yarn irregularity, imperfections and Classimat values (not yarn tenacity and elongation).

Quality data from each spinning position for all running batches are available to operating personnel on request at any time. Necessary interventions in the event of variances can be made immediately if required, and thus without any loss of time.

2.8.1. Quality control systems as integral components of rotor spinning machines

Uster Quantum Clearer2® (Fig. 45) and BarcoProfile® (Fig. 46) quality control systems are usually integral components of the rotor spinning machine. The system is adjusted and operated via the central operator control panel, as are the retrieval and display of all the relevant quality data.
The Uster Quantum Clearer® is optionally available with a capacitive or optical measuring head for quality control. Extraneous substances are detected by an optical sensor integrated in the capacitive or optical measuring head. BarcoProfile is based solely on the optical measuring principle, both for quality control and for detecting extraneous substances. The sensor for detecting extraneous substances is mounted separately on the yarn draw-off tube, and not in the measuring head. The advantage is that this sensor can be operated and retrofitted irrespective of the make of clearer module and also without a yarn clearer module.
Each spinning position on the rotor spinning machine is equipped with a capacitive or optical measuring head, which is directly connected to a central analyzing unit and the machine's control system. If a defect that exceeds the preset clearing limit is detected in the measuring zone of the measuring head, the spinning position is switched off immediately. The defective piece of yarn is wound off the package and extracted before spinning recommences at the spinning position.

2.8.2. Comparison of measuring methods

Whereas the weight per unit of length, i.e. the mass of the fiber material in the measuring slot, is recorded using the capacitive measuring principle, the signal in the optical measuring principle corresponds to the external contour, i.e. the yarn diameter. The properties of and differences between the principles are explained in Table 2 and Table 3.

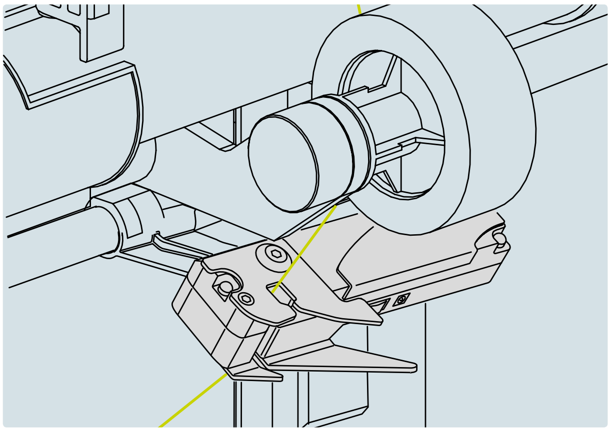


Fig. 45 – Uster Quantum Clearer yarn clearer

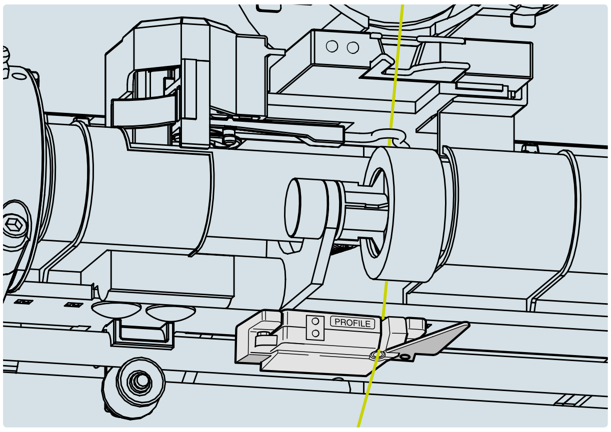


Fig. 46 – Barco Profile yarn clearer

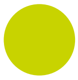
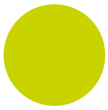
Yarn		**Capacitive principle**	**Optical principle**
Regular yarn		0 % base value	0 % base value
Thick place with double cross-section		Increase of cross-section: +100 %	Increase of diameter: +42 %
Thin place with half cross-section		Decrease of diameter: -50 %	Decrease of diameter: -29 %

Table 2 – Sensitivity of the measuring principle

	Capacitive principle	**Optical principle**
Property • Yarn	Corresponds to the mass of the yarn, or number of fibers	Corresponds to the diameter of the yarn, the visual impression
Influence • Fiber	Yarn, con tains electrical conductive fibers cannot be processed	All fibers
• Colored	No	Dark yarns possibly require other settings
• Fiber	No	No
• Humidity	Variations in the humidity can have an influence	No influence; very dry yarns exhibit a higher hairiness – larger diameter – unjustified stops

Table 3 – Properties of the measuring principle

2.9. Production monitoring

Rotor spinning mills with 40, 50 or even more machines in a single spinning installation are by no means rare. These machines are often processing a wide range of different yarns. This inevitably increases the demands on efficient production and quality monitoring. In contrast to this, however, personnel numbers have steadily decreased in modern, thoroughly rationalized spinning mills (higher numbers of machines allocated to operating and maintenance personnel, leaner administration, etc.).

The higher the number of machines and the more complex the logistics in a spinning mill in terms of raw material and product diversity, the more important is comprehensive production monitoring (independent of personnel). This in turn is only assured if machine, production and quality data are available at all times, up-to-date and complete. Omissions in this context have serious effects: every undetected malfunction in the production process results in reduced machine efficiency, loss of output and thus directly in higher production costs. If not identified immediately, the production of defective yarn at the high output rates of modern rotor spinning machines results very quickly in enormous quantities of unusable or severely devalued yarn. If the faulty yarn is delivered and the defect only identified in the finished fabric, this results in additional compensation claims for the finished goods.

Systems for monitoring production have been on the market for some years and are offered by both machinery manufacturers and other suppliers. They usually consist of a central process computer with the relevant peripherals (printer and monitor) for data output. Each rotor spinning machine, or any other machine in the spinning mill equipped with the required sensors, is directly linked with the process computer via cable (see Fig. 47). All signals from the machine and the spinning positions are scanned, stored and processed at very short intervals. In contrast to the production machine, the storage capacity of the central computer permits long-term analysis of production and quality data.

All essential machine production and quality data are available in tabular and graphic form. These include speeds, efficiency, stoppages and their causes, and many other data.

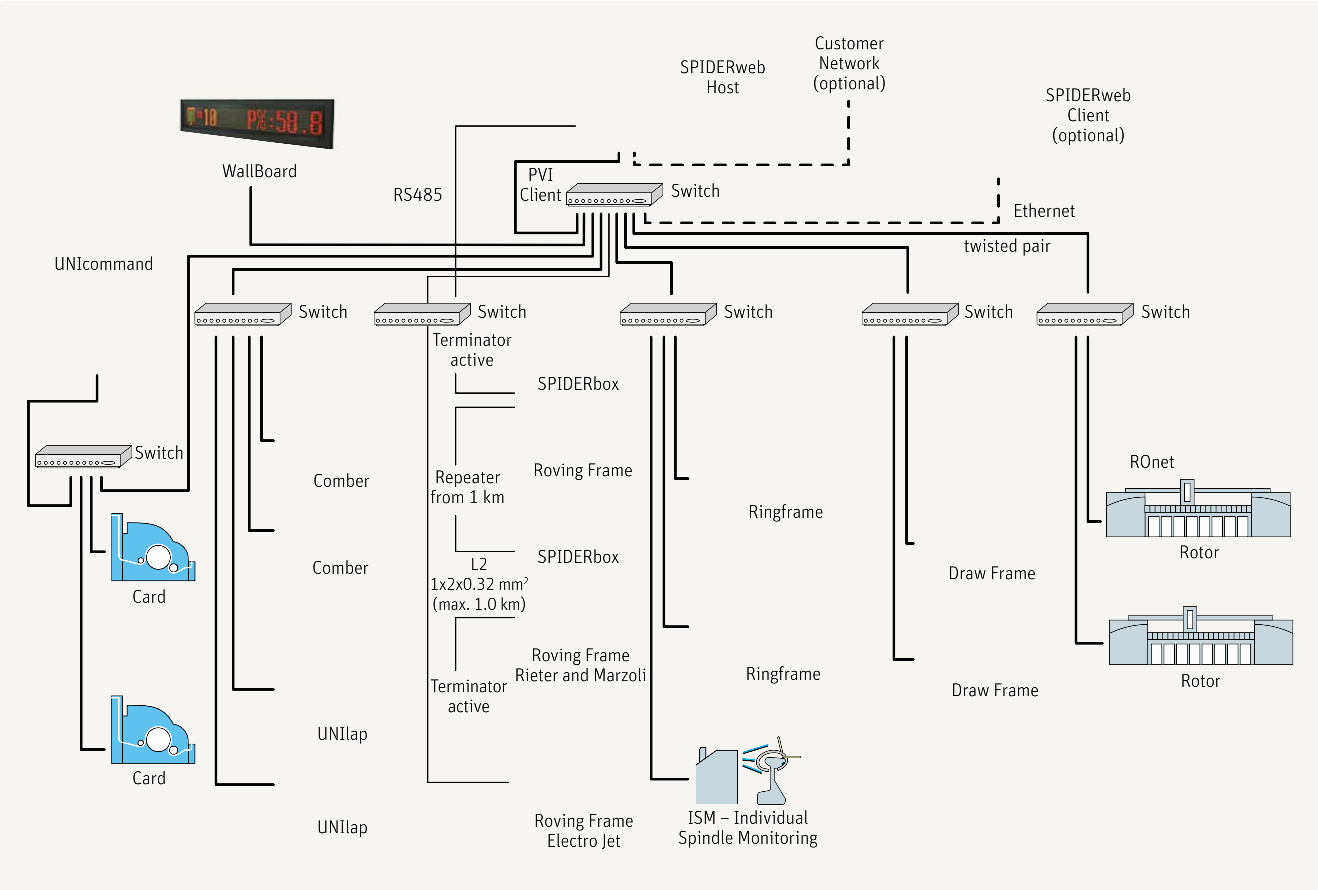


Fig. 47 – System diagram of production monitoring; central computer with peripherals and connected production machines

Printed reports are available both for individual machines and for groups of machines, organized according to the above-mentioned criteria. Reports are printed out automatically at the end of the shift or on request. Machines or spinning positions that fail to achieve the specified reference efficiency or exceed certain preset criteria (ends down, quality stops, etc.) are listed separately.

Mill management can use this information to analyze output, productivity and quality as a basis for decision-making on the deployment of personnel and technical aspects of production, such as changes in machine allocation when order bottlenecks arise, adjustments to machine settings in response to sudden changes in raw material quality and the relevant action in spinning preparation operations, etc.

Information is available to the Material Planning Department, for example for purchasing raw material (selecting raw material quality on the basis of cost/benefit criteria), planning material flow in accordance with productivity in the spinning mill, specifying spinning parameters (rotor speeds, yarn twist, etc.) according to the required yarn quality and monitoring order processing (number of kg produced, number of packages completed, etc).

Data on those machines that fail to achieve the required efficiency or exceed a certain ends down rate or a certain number of quality-related stops are available at all times to foremen or shift foremen. The foreman or mechanic can therefore concentrate solely on machines and spinning positions that are not running satisfactorily, and take the appropriate action without delay.

Maintenance personnel receive reports on spinning positions that are at a standstill, running unsatisfactorily or out of action, inadequate robot efficiency, etc., and can then immediately take the action they consider necessary. Periodic maintenance for machines and robots can be planned, performed and monitored on the basis of the operating hours of the rotor spinning machines.

3. MACHINE AND TRANSPORT AUTOMATION

The development and introduction of systems for automating operating functions on production machines and the transport of material between production machines is always called for when pressure to reduce costs and improve the quality and flexibility of production operations is especially severe. This is also especially the case for the textile industry, and in particular for spinning. It is therefore hardly surprising that machine and transport automation have been integral parts of the spinning process for some years.
Automation in rotor spinning in particular is very far advanced – at least in comparison to other spinning processes – not only in respect of machine automation as such (i.e. rotor cleaning, repairing ends down, transporting empty tubes, package change), but also as regards process-linking automation of material transport from the card through the draw frame(s) to the rotor spinning machine up to fully automated package removal or palletizing at the machine itself. Systems for automated material transport between card and draw frame and between the individual draw frame passages will not be dealt with here. You will find details of this in the relevant publications in this series of textbooks.

3.1. Machine automation in rotor spinning

Systems for automating the operation of rotor spinning machines have been integral parts of high-performance rotor spinning machines for some years. Automated systems have been developed for all manual operations in several stages:
- automatic gripping and introduction of the sliver end from a new can into the spinning box (implemented only in certain cases to date);
- automatic cleaning of rotor, draw-off nozzle and draw-off tube after ends down, quality stops or package changes;
- automatic piecing (start-up) after ends down, quality stops or package changes;
- automatic removal of full packages upon reaching the preset yarn length, and replacement with empty tubes;
- automatic feeding of empty tubes to the operating robot for package change;
- programmable batch phase-out/batch change;
- automatic deposit of removed packages at the end of the machine;
- automatic or semi-automatic filter cleaning.

Machine automation reduces manual operations to a minimum and replaces them by monitoring tasks and intervention in the event of malfunction. However, the importance of automation is by no means confined to economies in operating personnel and labor costs. Automation also has a major influence on product quality, i.e. yarn quality, for example through automated piecing after ends down:
- Manual piecing is no longer possible at high rotor speeds (> 100 000 rpm).
- Manual piecings have an average tenacity of no more than 40 %, whereas automated piecings have a yarn tenacity of up to 100 %.
- Since electronic yarn clearers are standard equipment on rotor spinning machines nowadays, it is only worth clearing yarn defects as long as they are not replaced by a piecing of inferior quality (thick and of lower strength) than the cleared defect, as a result of being produced manually. Only piecing systems featuring controlled fiber feeding and synchronized yarn take-off can produce piecings that are virtually invisible in the yarn and the end product and thus permit fine clearer settings.
- Consistent piecing quality is essential for economical downstream processing of rotor-spun yarns, and this can only be assured by piecings produced with process control and reproducible setting parameters.
- Last but not least, thorough cleaning of the rotor groove inevitably takes place on automated machines after each end down or package change, thus reducing the risk of a creeping decline in yarn quality.

Machine automation is represented in practice by two different concepts:
- Integrated automation, in which all operating functions (rotor cleaning, repairing ends down, package change) are combined (integrated) in a single robot (Fig. 48). Package changing and the subsequent re-start of the spinning position occur as a single process.
- Automation by means of units operating separately, with the operating functions of spinning start-up (after ends down or package changes) being performed by a piecing robot, and the transport of starter bobbins (instead of empty tubes) and package change by a second robot. There is no system-imposed link between robots which operate separately and the use of starter bobbins, but the greater technical complexity this concept entails in connection with the pre-wound starter bobbin (additional starter bobbin unit, starter bobbin transport, etc.) is system-imposed. This is probably also the reason why manufacturers which previously supplied robots operating separately have switched to the integrated automation system on their machines.

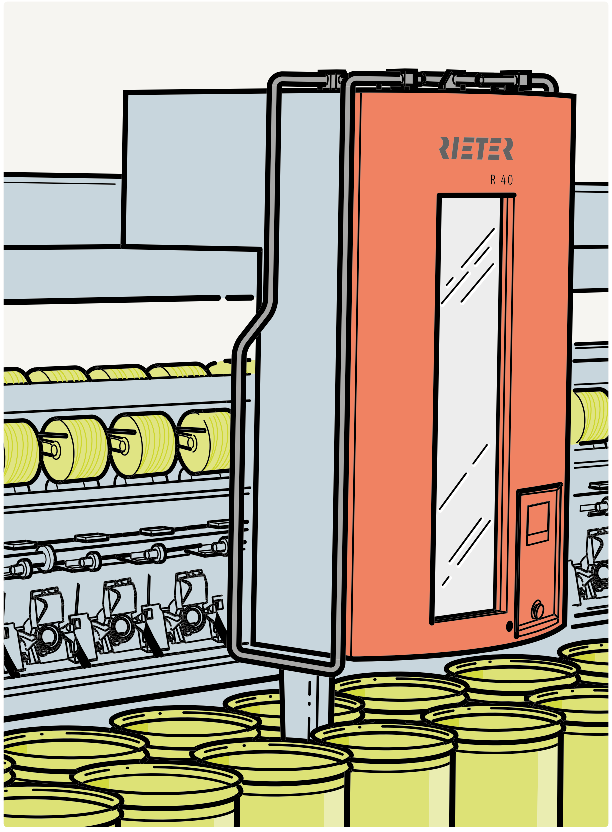


Fig. 48 – Operating robot on a modern high-performance rotor spinning machine

Operating robots are powered and controlled either mechanically / electronically or pneumatically / electronically. Robots of modular design significantly simplify maintenance. The modular structure of pneumatically controlled operating robots permits synchronized functional processes in package change and the subsequent re-start of spinning. The entire piecing process after ends down or quality stops is completed after less than 25 seconds. The operating robots travel at a speed of some 0.4 m/sec.

3.1.1. Application options for operating robots

Rotor spinning machines can be equipped with up to 4 operating robots (up to 2 on each side of the machine). Their travel strategy is usually coordinated in such a way that the robots move to and fro within a certain working range, successively attending to all spinning positions in the direction of travel where intervention is required. The travel strategy can be optimized in accordance with the operating status of the machine.

3.1.1.1. Machines with a single operating robot

The use of only one robot per machine is economically justifiable only for very short machines, if at all. When starting spinning on a machine or during an accumulation of ends down or package changes it then takes a very long time for all spinning positions to be attended to. If the robot has to be serviced, ends down cannot be repaired and packages cannot be changed. The reduction in efficiency due to long downtimes usually exceeds the advantages of lower capital costs for a second robot.

3.1.1.2. Machines with two operating robots

Two operating robots (on for each side of the machine) are usually adequate for serving the spinning positions efficiently on the machine lengths of 240 to 280 spinning positions that are customary nowadays. Each robot serves one side of the machine, and when one robot is being serviced the second robot can be programmed also to serve the other side of the machine (Fig. 49). In this case the robot transfers from one side of the machine to the other via a loop on the headstock. The downtime due to stationary spinning positions is therefore reduced by half. Using 4 robots on machines of this length results in a significant improvement in efficiency only in extreme spinning conditions – e.g. a combination of coarse yarn counts, small package formats and high delivery speeds – and only then justifies the higher capital costs of the two additional robots.

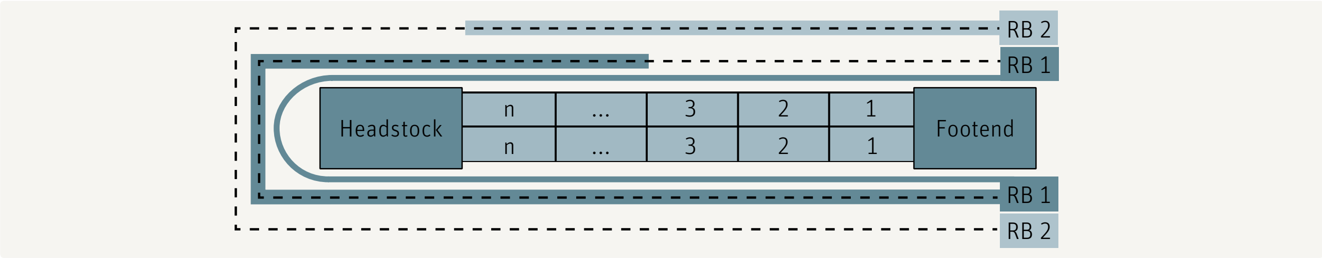


Fig. 49 – Travel strategy with one operating robot on each side of the machine; each robot can also serve the other side

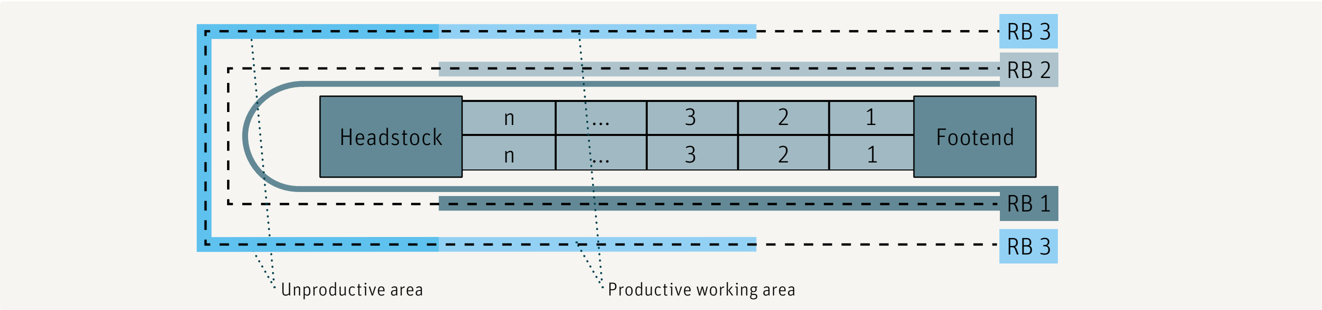


Fig. 50 – Travel strategy with 3 operating robots. One robot on each side of the machine, robot RB 3 serves each side alternately

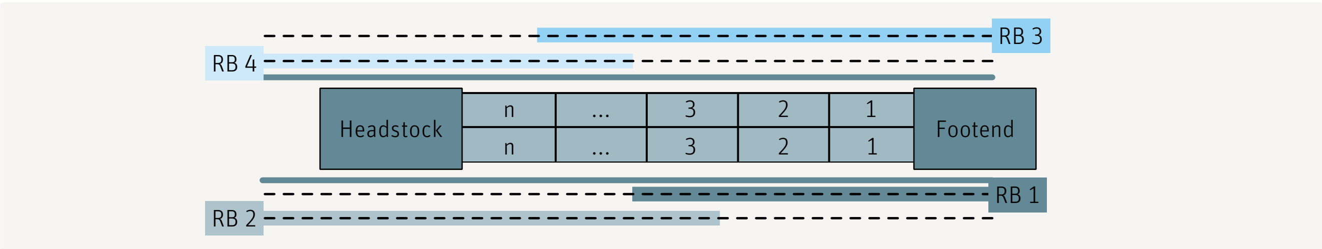


Fig. 52 – Travel strategy with 2 robots on each side of the machine

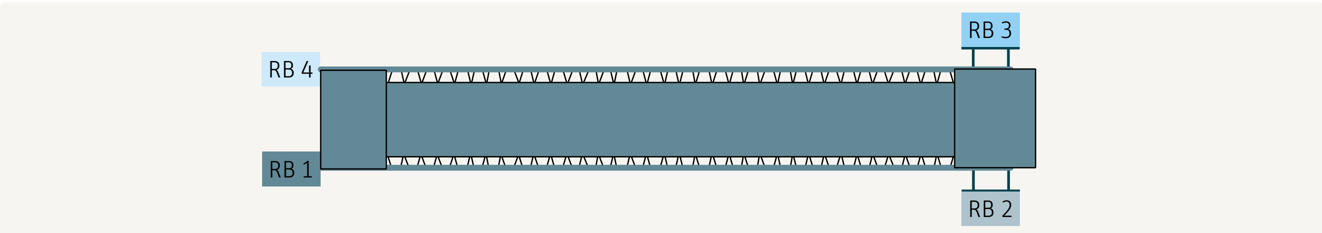


Fig. 53 – Rotor spinning machine with service stations for 4 robots

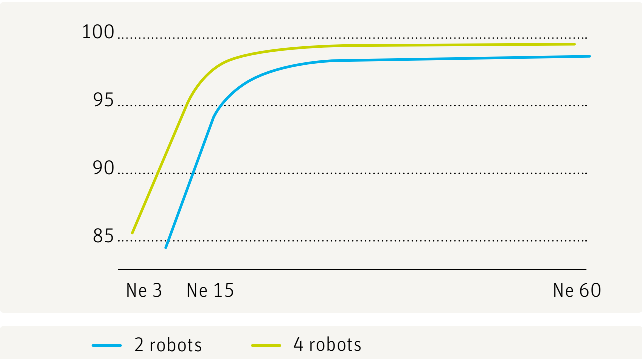


Fig. 51 – Machine efficiency with 2 and 4 robots

Another possibility for optimizing travel strategy is useful when using 2 and 4 robots. The robots can be controlled in such a way that a robot changes its direction of travel if no spinning positions in the original direction of travel require the robot‘s services. All commands for robot control are entered via the machine control panel.

3.1.1.3. Machines with three operating robots

The use of 3 robots per machine is theoretically possible (Fig. 50). Two robots (RB 1 and RB 2) each serve one side of the machine, while the 3rd robot (RB 3) supports the other two robots by operating alternately on one side of the machine and then on the other. However, the long distances traveled by the 3rd robot via a loop from one side of the machine to the other – amounting to more than one-fourth of its working range – mean that only a very limited improvement in efficiency can be achieved. A major drawback of this concept is that the third robot seriously disrupts work at the end of the machine, such as the removal of full packages, due to its frequent movements back and forth around the loop on the tailstock. The concept with 3 robots per machine has not become established in mill operations to date.

3.1.1.4. Machines with four operating robots

Four operating robots (2 on each side of the machine) are essential for extra long rotor spinning machines with up to 500 spinning positions, so that maximum machine efficiency can be achieved even with small package formats, high delivery speeds or high ends down rates. The higher the material throughput, i.e. the more frequently packages need to be changed, the greater the gain in efficiency through the use of 4 robots (see Fig. 51).

Two robots each serve one side of the machine. Each robot traverses a certain length of a machine side. The travel zones overlap in the middle of the machine (Fig. 52). The central robot control system ensures that the two robots do not collide. A loop at the end of the machine and thus the use of a robot on the other side of the machine are no longer necessary. If a robot is being serviced, the other robot serves the entire side of the machine during this period. A service station – as shown in Fig. 53 – is provided for each robot at the headstock or tailstock; this is outside the range of travel and thus does not restrict the radius of action of the active robot.
The robots can be programmed in such a way that both robots serve one or more sections jointly. This is always useful if, for example, large numbers of packages need to be changed on a section. The robots can also be controlled in such a way that a robot changes direction if no spinning positions in the original direction of travel require the robot‘s services. All commands for robot control are entered via the machine control panel.

3.1.2. Automatic piecing

After an end down or package change the interrupted spinning process at the spinning position in question has to be re-started. In terms of spinning technology this entails overlapping a thread end that has been fed back with the fiber ring in the rotor groove. The quality of such a piecing is just as important as the quality of the yarn itself, since both determine its market value to a great extent. The quality of a piecing is defined essentially by:
- the tenacity of the piecing expressed as a percentage of yarn tenacity;
- the variation in tenacity between the piecings (CV% of piecing tenacity);
- the thickness of the piecing (diameter or mass);
- the length of the piecing;
- the repeat accuracy of the piecing.

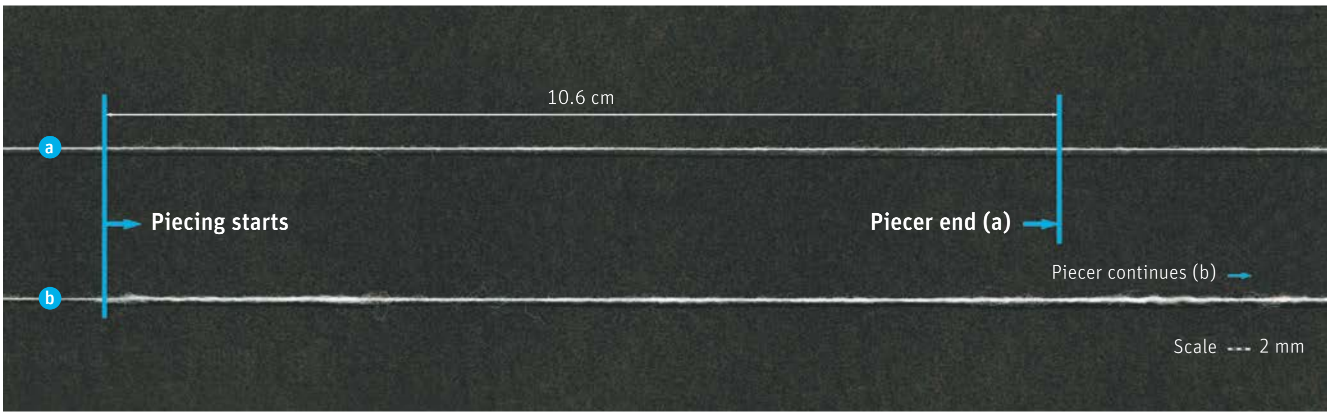


Fig. 54 – Piecing quality (Ne 30, Twist multiplier α_e = 4.6, 100 % cotton)
a) piecing quality with processor-controlled robotic systems
b) piecing quality with mechanically controlled operating robots

Every piecing with too much mass is regarded as disturbing in the final fabric and results in its devaluation; the longer the thick place, the more disturbing its appearance. Piecings that are too thick often display especially low tenacity as a result of having too little twist. This in turn causes problems in downstream processing. A high-quality yarn can suffer a drastic reduction in value due to defective piecings.

Piecings with high tenacity and virtually yarn-like appearance can only be produced by processor-controlled robotic systems, since the timing of the individual functional steps has to occur in the millisecond range. The piecings produced by means of controlled fiber feed and synchronized thread take-off are virtually invisible, both in the yarn and in the end product. The improvement in piecing quality when using processor-controlled operating robots instead of mechanically / electrically controlled robots is clearly apparent in Fig. 54. Repeat accuracy is provided by precise control of rotor speed and fiber flow. Piecing systems operating at high rotor speeds ensure that only piecings with high tenacity withstand the high spinning tension refer to section „3.1.2.3. Piecing speed and piecing quality".

The piecing process after ends down or quality stops (refer to section „3.1.2.1. Automatic piecing after ends down and quality stops") and the piecing process after package change (refer to section „3.1.2.2. Automatic piecing after package change") differ in principle in certain functional steps.

3.1.2.1. Automatic piecing after ends down and quality stops

After an end down or quality stop, sliver feed to the spinning position is discontinued immediately (signal from yarn monitor disconnects feed cylinder) in order to prevent the rotor from being overloaded with fiber material. The package is lifted off the winding cylinder to prevent damage to the layers of thread. The operating robot is called up via the machine control system.

Spinning positions that have been stopped due to quality alarm or maintenance and reported to the machine control system are not re-started when the cause of the fault has been remedied manually. Spinning positions that are stationary due to the absence of sliver are detected by the robot by means of sensors and are not served until a new sliver has been fed in.

After the robot has been positioned precisely, the piecing process starts with the end of the sliver waiting between the feed trough and the feed table being moved briefly into the opening roller zone in order to comb out short and damaged fibers. Immediately after this the sliver is withdrawn again in order to prevent renewed damage of the fibers in the end of the sliver.

As the next step the inside wall of the rotor and the rotor groove are thoroughly cleaned pneumatically by means of a precise current of air, and if necessary the rotor groove is additionally cleaned by means of scrapers. The deposits removed in this way are blown out and extracted by means of compressed air.

The thread end is taken off the package and fed back into the rotor housing through the draw-off tube (Fig. 55 – step A). At the same time the sliver feed is started and the fibers are fed under control (depending on rotor speed) into the rotor. In the rotor groove the end of the thread is joined to the fibers fed in. The rotation of the rotor inserts twist into the overlapping zone and the fibers fed subsequently into the rotor. Synchronized thread take-off from the rotor then commences (step B). How long the thread remains in the rotor and how much twist is thus to be inserted in the piecing zone can be determined by the timing of the thread take-off.

After the piecing has been formed, the rotor is accelerated to full spinning speed and the piecing process is thus concluded. Each piecing is examined electronically with regard to mass (capacitive) or diameter (optical) before it is wound onto the package (step c). If a piecing exceeds the preset limits the spinning process is interrupted again (sliver feeding is discontinued) and the piecing process is repeated.

The success rate of piecings produced automatically is almost 100 %, with a success rate between 80 and 90 % for the first piecing cycle, while the remaining spinning positions can usually be re-started in a second piecing process (the number of piecing attempts can be set between 1 and 3). Unsuccessful piecing attempts are on the order of no more than 1 % and are indicated by a signal lamp on the spinning position.

3.1.2.2. Automatic piecing after package change

In contrast to piecing after ends down or quality stops, no thread is available from a package in the package holder for piecing after package changes. This means that an „extraneous thread" has to be used for piecing at the spinning position in order to re-start the spinning process.

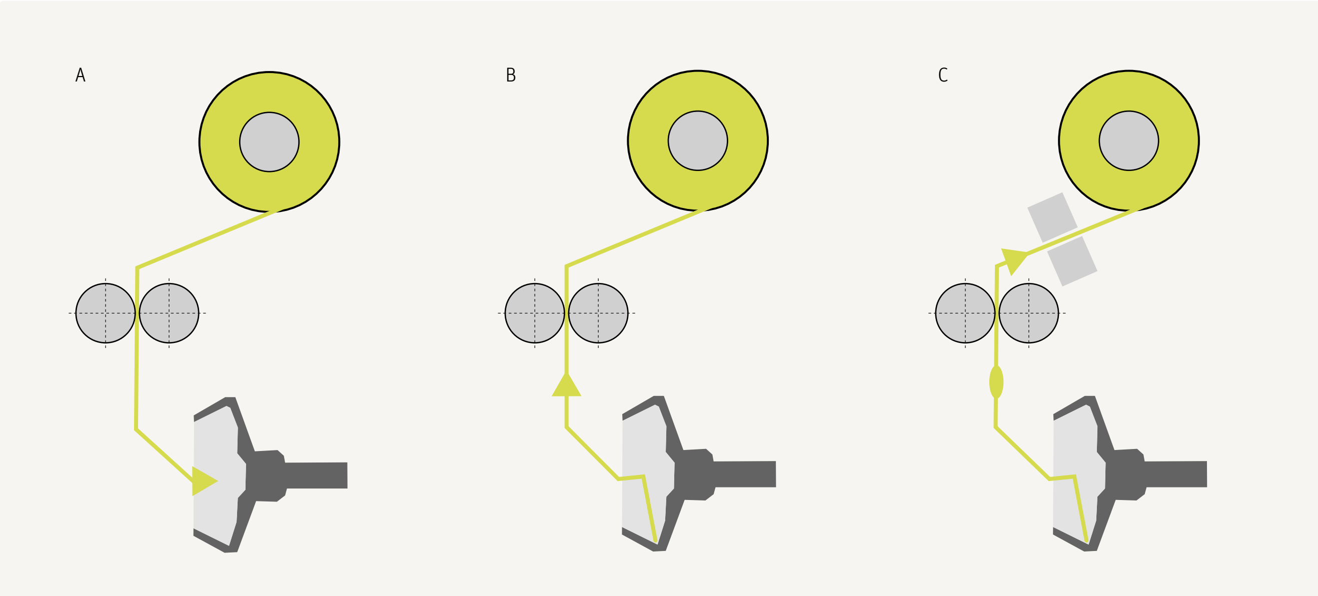


Fig. 55 – Automatic piecing after an end down or quality stop
A The end of the thread is taken off the package and inserted in the rotor at the same time as starting fiber feed
B The piecing is formed under processor control and thread take-off is started
C The piecing is examined electronically and then wound onto the package

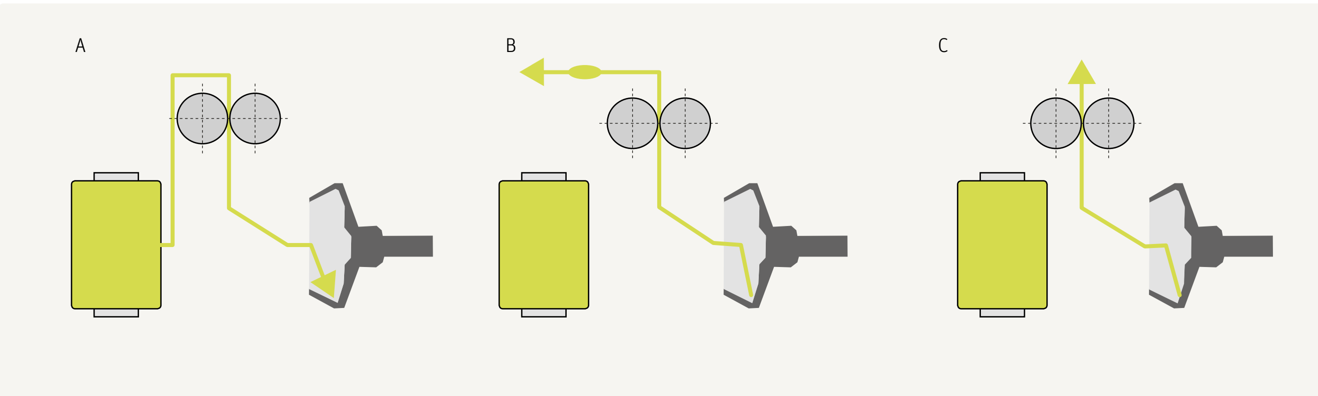


Fig. 56 – Automatic piecing after package change:
A Piecing thread from a package carried in the operating robot is fed into the rotor and a piecing is produced
B Piecing thread and piecing are completely extracted via the robot
C Only the original yarn is transferred by the robot to the empty tube and wound up there

When piecing on an empty tube, the thread from a package carried by the robot is used for this purpose. After the full package has been replaced with an empty tube and the rotor cleaned, the thread from the supply package is fed back into the rotor, fiber feed to the rotor is started and the piecing is formed (Fig. 56 – step A). A particular advantage of this system is that the piecing thread and the piecing are extracted by the rotor and fed to the filter (step B). The new original yarn, which also briefly passes into the robot's extraction device, is transferred by the robot to the empty tube (step C) through the formation of a fixed thread reserve (the first layer of yarn is covered by the following layers, the end of the thread remains free).

The great advantage of piecing onto empty tubes is that:

- A „piecing-friendly“ yarn can be selected for piecing, e.g. especially strong, not too fine, etc., since the piecing thread (complete with the piecing) is cut off and extracted, and does not reach the package.
- Piecing mass and tenacity can be adjusted so that high piecing tenacity and thus a high piecing success rate are achieved. The length and mass of the piecing are of no concern, since the piecing is extracted. The piecing success rate after package change is in many cases 100 %.
- It ensures that only original yarn is wound onto the newly started package and thus no problems can arise in downstream processing with starter yarn and starter piecings.

Piecing with a starter packages: the alternative method for re-starting the spinning process after package change is to place a pre-wound starter package (with 20 - 50 meters of original yarn) in the tube holder and piece with the end of the yarn on this package. In this case piecing after package change is identical to piecing after an end down or quality stop (see above). The starter packages required for this piecing concept are produced on a starter winding station installed at the drive end and transferred via a transfer station to the automatic doffer, which docks onto this transfer station. The number of starter packages carried determines the number of package changes possible in one pass. When all the starter packages have been used, the doffer returns to the transfer station to collect new starter packages. When spinning conditions necessitate very frequent package changes (small packages, e.g. dyeing packages, short running times with coarse yarns) an additional starter shuttle can also be used to supply the automatic doffer with starter packages „on the spot“ while it is in operation.

However, the use of starter packages is not unchallenged, for various reasons:

- Original yarn must be used for the starter packages. For this purpose several packages must either be produced before the machine starts up (which takes time) or reserve packages from earlier final spinning operations must be used.
- The technical effort expended in producing starter packages is relatively substantial (service, maintenance). A starter winding station, a starter transfer station and in some cases a starter shuttle are required.
- The yarn on the starter package is wound in the opposite direction to the spun yarn. In the case of sensitive end products / dyeing methods the differences in direction can be visible.
- A serious drawback is that by virtue of the system every package contains an additional piecing compared to packages produced by piecing onto an empty tube. In the coarse count yarn range, e.g. with denim yarns, the number of starter piecings can exceed the number of spinning-related piecings (after ends down or quality stops).
- Even if technically ingenious piecing systems can produce high-quality piecings, the emphasis must be placed on keeping the number of piecings per package as small as possible. A „poorly“ produced piecing, whatever the reason, is a potential weak point in the yarn.

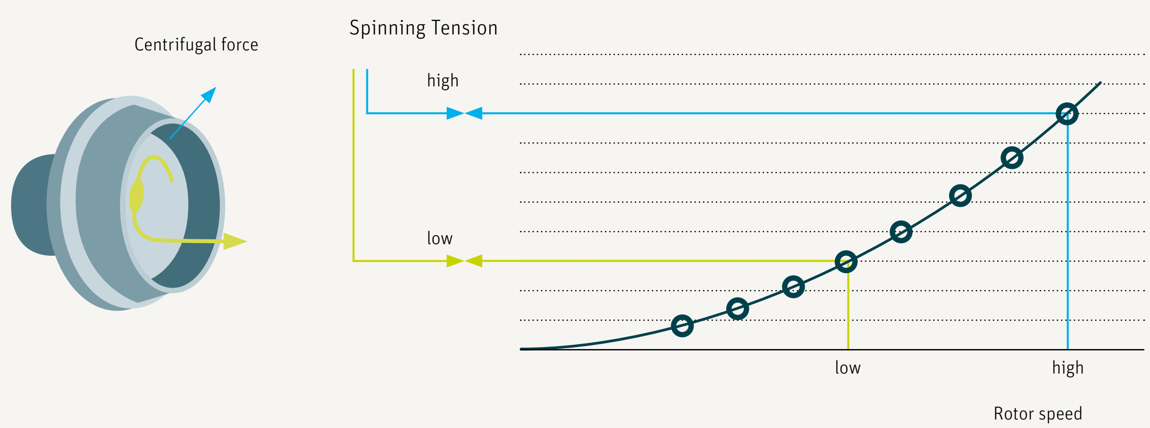


Fig. 57 – Influence of piecing speed on spinning tension and thus on piecing tenacity

3.1.2.3. Piecing speed and piecing quality

Piecing systems that perform the piecing process at high rotor speeds, i.e. at 80 % to 100 % of the normal spinning speed, ensure by virtue of the high spinning tension during yarn take-off that only strong piecings withstand the piecing process (Fig. 57). Piecing-up rotor speed during piecing is dictated by the raw material and yarn structure. The lower the piecing-up speed and thus the spinning tension, the greater the risk that weak piecings will also survive the piecing process and thus reach the package. A piecing that has only just survived the piecing process can prove very costly in downstream processing. The „integrated" strength test imposed by high piecing-up speeds is therefore of advantage, since no monitoring system yet exists at the spinning position to examine piecing strength. However, quality control systems on a capacitive or optical basis do provide specific monitoring channels for examining piecing mass. If a piecing exceeds the (adjustable) limits for fiber mass or fiber thickness, the spinning process is immediately interrupted again. The robot draws the length of yarn with the excessively thick piecing off the package and extracts it. The piecing process is then repeated.

If high piecing-up speeds are the criterion for strong piecings, piecing at constant speeds is the precondition for high piecing uniformity in terms of thickness and length (Fig. 58). This is in contrast to systems on which the piecing process is performed while the rotor accelerates (Fig. 59). Since the rotor shaft is driven by friction via the tangential belt, it is impossible to avoid variations in speed between spinning positions, i.e. between piecing processes, due to variations in slippage between the tangential belt and the shaft, especially during acceleration of the rotor. These variations inevitably have a direct impact on mass and length, in the worst case also on piecing strength.

Fig. 60 shows the results of a series of measurements in which the tenacity and elongation of automated piecings are presented in comparison with the corresponding yarn values, expressed in percentages. With the exception of individual measurements, the fluctuation range of the piecings is almost the same as the values for the normal yarn. What is more, even the piecings with the lowest tenacity are well above the minimum piecing tenacity level of 60 % required for downstream processing (compared to the average yarn tenacity).

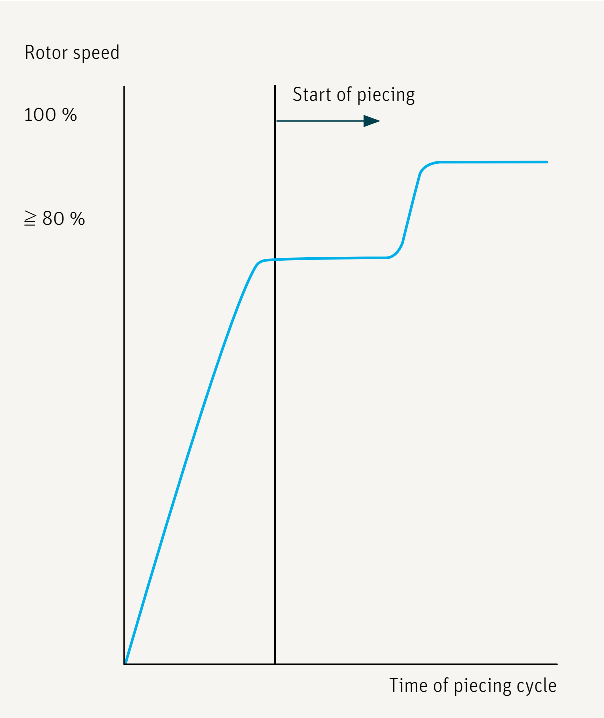


Fig. 58 – Automatic piecing at constant, high rotor speed

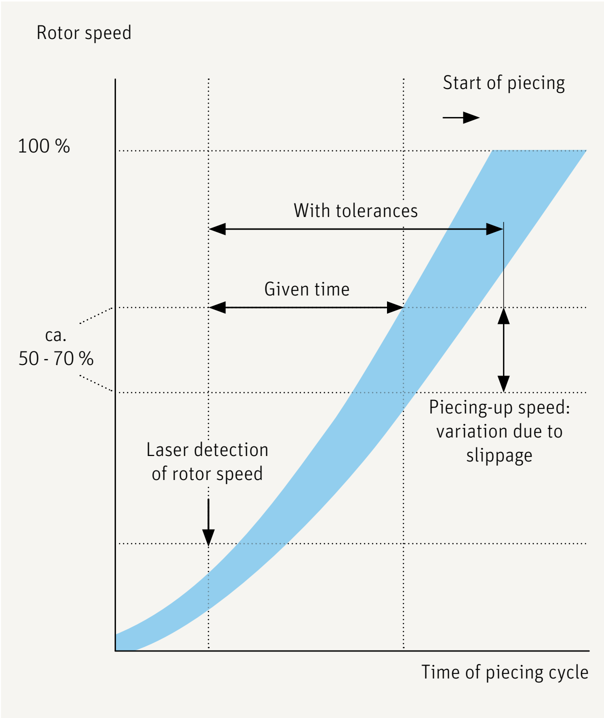


Fig. 59 – Automatic piecing during rotor acceleration

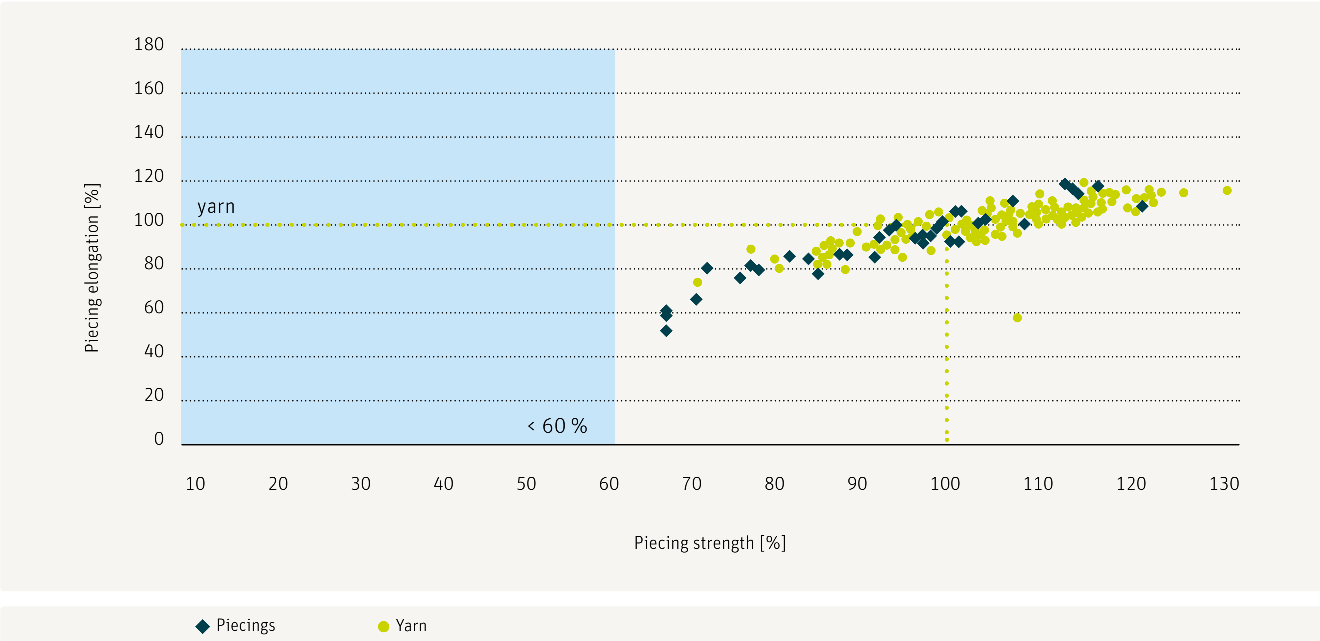


Fig. 60 – Tenacity and elongation of piecings compared to the corresponding yarn values

3.1.3. Semi-automatic piecing system on manually operated machines

The variations in mass, length and tenacity of piecings produced manually even by skilled operating personnel are so wide that they no longer satisfy international quality standards by far. This means that as a consequence of the inadequate piecing quality alone an otherwise high-quality yarn is not accepted and used in downstream processing.

This is why so-called semi-automatic piecing processes, which have significantly narrowed the gap in piecing quality relative to automatic piecings, have been developed for manually operated machines in recent years. Piecing after ends down essentially consists of the following operating steps (Fig. 61):

The only remaining manual operations are pulling the end of the thread off the package, cutting it to length accordingly and inserting it into the previously cleaned rotor through the draw-off tube.
Starting sliver feed to form the fiber ring in the rotor, subsequent yarn take-off from the rotor and start-up of the package are actuated under electronic control at the push of a button. A further special feature is that the fibers first combed out of the end of the sliver, some of which are damaged, are extracted when sliver feed commences, and fiber flow is only then diverted into the rotor.

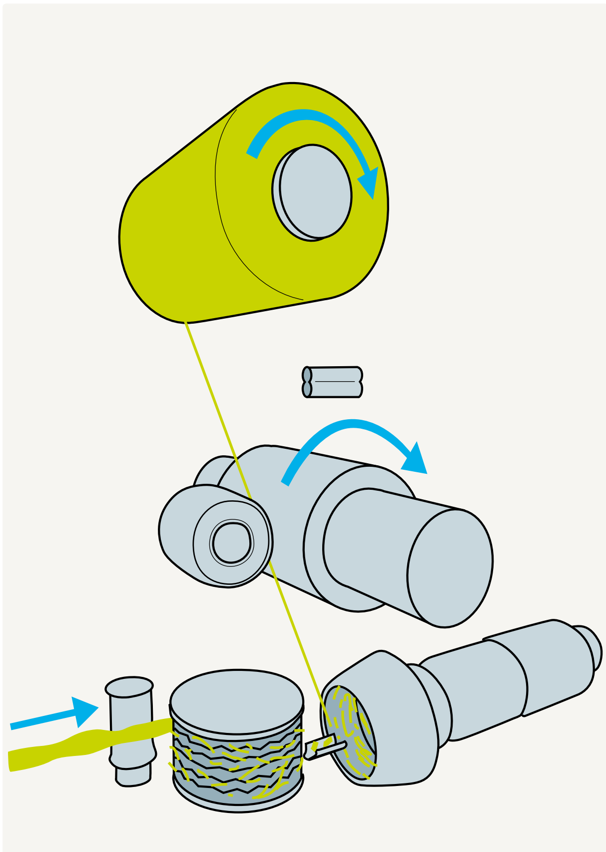


Fig. 61 – AMIspin semi-automatic piecing system

3.1.4. Automatic package change

Package change on automated rotor spinning machines is actuated when the preset length of yarn or package diameter is reached. Electronic length measurement is so accurate that variations in yarn length from package to package are maintained in a very narrow tolerance range, usually of +/- 0.5 %. Mechanical diameter cutout is less accurate, since package diameter and thus the yarn length wound up can vary due to differing winding conditions at the individual spinning positions (differences in thread tension, slippage, etc.).

Automatic package change has been solved by different conceptual approaches. Whereas in one system removal of the full package and spinning start-up on an empty tube are performed in a single operation (integrated automation), in another case removal of the full package and subsequent spinning start-up are performed in two separate operations by two robots working independently. Spinning is started on an empty tube, but using a starter package pre-wound at the end of the machine. Although all manufacturers of automated rotor spinning systems now offer the integrated automation system, a large number of machines, also newer ones, are in operation worldwide with operating robots working independently. Both systems will therefore be described in more detail.

3.1.4.1. Package change and spinning start-up on empty tubes in a single operation (integrated automation)

When the package has reached the preset yarn length, the spinning position is switched off by the electronic length measurement device. At the same time the operating robot is called up via the machine control system. If additional delta lengths are being used, the package continues to run after reaching the reference length until the robot approaches the spinning position on its control run (advantage: no stationary spinning positions due to full packages). Only then is the spinning position switched off and the change process immediately initiated. The full package is placed on the package conveyor belt in the center of the machine by a robot arm, and at the same time spinning is started on an empty tube (refer to section „3.1.2.2. Automatic piecing after package change").

3.1.4.2. Package change and spinning start-up with starter packages in two separate operations

If the „package change" and „spinning start-up after package change" operations are performed by two robots working independently, these two operations can also only be performed consecutively and not synchronized, i.e. simultaneously.

The operating robot called up via the machine control unit for package change (automatic doffer) places the full package on the package conveyor belt in the center of the machine and replaces it by one of the pre-wound starter tubes it has brought with it.

The spinning position remains stationary until the requested operating robot for piecing (automatic piecer) has served the spinning position and initiates spinning start-up at the spinning position by re-introducing the end of the thread on the starter package into the rotor and starting sliver feed.

In this concept the spinning position being served has to wait both for the automatic doffer and then again for the automatic piecer; i.e. it is affected by two waiting times, compared with one waiting time with integrated automation.

As already explained elsewhere, machinery manufacturers which previously used operating robots working independently also offer automation featuring integrated operating robots on their new models.

3.1.4.3. Yarn end placement

The yarn end placement feature ensures the reliable positioning of the yarn end on the outside surface of the full package. In downstream processing the yarn end can easily be found and removed from the package by the operators. This results in significant cost savings of up to 40 % for package handling in downstream processing.

Yarn end placement is performed prior to the replacement of the full package by an empty tube. The robot unwinds a certain length of yarn from the full package, which still remains in the package holder. The yarn removed is then wound back onto the package, with one layer around the left-hand side of the tube and placement of the yarn onto the package surface.

3.1.5. Batch change

Depending on the utilization of the rotor spinning machine, batch change can be performed individually.

3.1.5.1. Batch change at individual spinning positions

For certain batch sizes it can happen that only a few more packages are needed to complete the batch. These packages can be completed on individual spinning positions while the batch is phased out.

Although the rotor spinning machine operates in „package change for the complete machine“ status, individual spinning positions can be brought back into operation. This requires the input of yarn length (at the touch screen machine panel) for the selected spinning position(s) and initiation of spinning restart at the spinning box.

3.1.5.2. Batch change on one side of the machine

On machines that piece onto empty tubes, different batches (e.g. different raw materials) can be produced both on individual sections and on each side of the machine.

Batch change on only one side of the machine requires selection of the corresponding mode of operation at the robot. The robot replaces each full package by an empty tube, but leaving the spinning position stationary. After all packages have been replaced, spinning can be re-started by the robot with new stock.

3.1.5.3. Batch change on the machine as a whole

Batch change on the entire machine requires the appropriate mode of operation to be selected at the touch screen machine panel. After all spinning positions have been stopped – either in the case of full packages or immediately, regardless of package size – the robot replaces all packages by empty tubes. The machine can be restarted with either new stock, new spinning elements and/or new settings via the machine panel by selecting the corresponding mode of operation.

3.1.6. Supplying empty tubes

The tube loading system (Fig. 62) with empty tube magazine (a) and tube handling system (b) is standard equipment on rotor spinning machines where spinning is re-started on empty tubes after package change. The system supplies the robots with the empty tubes required for package change.

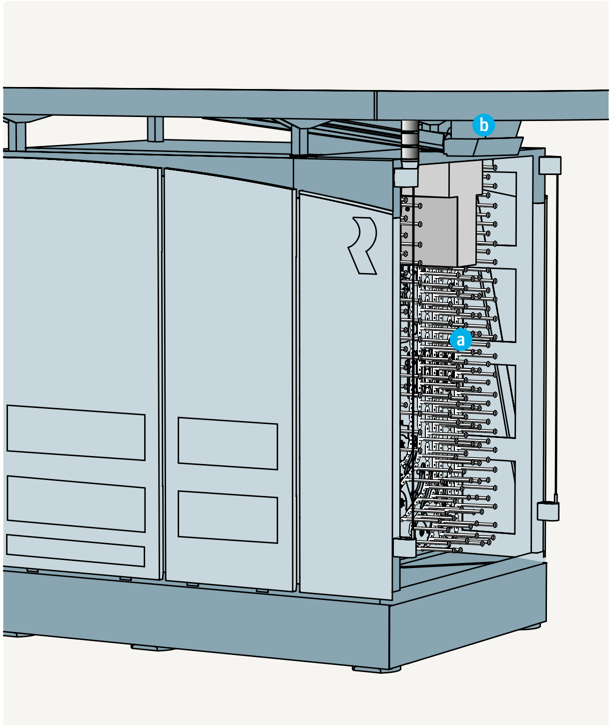


Fig. 62 – Empty tube magazine (a) with tube handling system (b) on the end frame of a rotor spinning machine

The tube handling system mounted on the front of the headstock accepts an empty tube from the tube magazine and places it on a pair of conveyor belts on the left-hand and right-hand side of the machine. At the request of the robot the empty tube is fed to the robot by means of the conveyor belts. This occurs whenever the robot performs a package change. The new empty tube replaces the tube carried by the robot and used for the current package change. The robot accepts the new empty tube from the conveyor belts and is thus already prepared again for the next package change.

3.1.7. Automatic sliver piecing after can change

Also the sliver piecing has been automated in a few cases. The prerequisite are a rectangular can and a special auxiliary device on the operating robots. When a can is pushed out on the draw frame the end of the sliver must be positioned precisely at the front of the can lip. A suction arm on the operating robot grips the end of the sliver from the newly fed can and guides it between the intake roller and the feed table into the spinning box. Automated sliver piecing actually is not used frequently, as the investment cost for such devices are relatively high.

3.2. Transport automation in the rotor spinning mill

In modern spinning mills the cost of transporting materials has become the largest component of direct labor costs. Systems automating can and package transport have therefore been developed and supplied for some years. However, savings on labor costs are only sufficient to amortize these systems partially over an economically justifiable period of time. Other cost-relevant reasons for using these systems are therefore:

- preventing damage to slivers and yarn which is often unavoidable during manual transport of these packages;
- increasing output through more uniform utilization of machine capacity and reduction of downtime (cans that have to be changed or packages that have to be removed from the machine conveyor belt no longer depend on the availability of personnel);
- reducing movements of material (both of the raw material and of spinning cans and yarn packages) and thus reducing or eliminating storage areas;
- no confusion between different feed materials (sliver counts);
- and finally cost benefits due to improved overview of material flow and simplified planning and control of material throughput.

All the necessary systems are now available for process-linking automation in rotor spinning mills, i.e. for material transport (empty and full spinning cans and cross-wound packages) between the individual process stages. These systems are supplied in different versions and various degrees of automation. Nevertheless, in contrast to machine automation, which is standard equipment on high-performance spinning machines, transport automation has not established itself to the same extent. The reasons for this are many and varied, and certainly also very different in significance from mill to mill. However, there is no question that the use of semi-automatic or fully automated transport systems can make a contribution toward ensuring competitiveness, especially in countries with high labor costs.

On the basis of experience in a large number of spinning mills that have switched to automated transport systems it can be seen that the following conditions must be created and the following principles observed and adhered to for the successful implementation of this kind of project.

In the planning phase the management of the spinning mill must be convinced that the decision in favor of an automated transport system is correct and must also encourage acceptance of it by personnel. Mill management must already analyze operating processes at the planning stage and prepare the appropriate reorganization of operations. The more thorough the preparation phase, the easier its introduction and the greater its success will be.

Optimum adaptation to existing processes is achieved by the careful choice of interfaces between (any planned) manual and automated sub-processes. The possibility of step-by-step commissioning or staggered implementation should be examined.

The transition from purely manually operated to semi-automatic or fully automated systems has far-reaching consequences. The changes in work content are considerable. Manual transport activities are replaced by monitoring, trouble-shooting and maintenance activities. Personnel with higher or completely different qualifications must be provided for this purpose. Intensive training of this personnel is an essential precondition for successful, trouble-free operation of the system!

The new jobs usually extend over several of the previous process stages; machine allocation and thus working areas are usually larger. Operating and management personnel also need to be trained accordingly with this in mind.

3.2.1. The importance of can format for automated can change

It is customary in rotor spinning mills to use round cans, which are arranged in two rows, one behind the other, on the rotor spinning machines. Replacing a round can which has run empty in the back row entails considerable mechanical and control effort for a can changing system. The systems developed for such concepts have therefore not established themselves to date.
In the context of transport automation the rectangular can has been launched on the market and has enabled can change on the rotor spinning machine to be automated (Fig. 63). Rectangular cans enable the available space to be allocated clearly in terms of the spinning can and the spinning position (only one can stands under each position). This layout of spinning can and spinning position in relation to the gauge was one of the essential preconditions for simple, automated can change on the rotor spinning machine.

Another advantage of rectangular cans is that the surface under the rotor spinning machine can be utilized much more efficiently. The volume and thus the contents of the rectangular cans are thus up to 65 % larger than round cans. This results in longer running times per can and fewer stoppages at the spinning positions for can changes.

The can filling and can changing mechanisms required for rectangular cans on the draw frames have been successfully used for some years. While limitations on delivery speeds had to be accepted with the first generation of these draw frames, delivery speeds of up to 1 000 m/min can now be achieved without any difficulty. At the delivery end of the draw frame a can trolley (can buffer) contains empty cans ready for filling and also accepts filled cans. A shuttle pulls empty cans one at a time from the can trolley under the turntable. After the can has been filled, the shuttle pulls the full can into the empty position on the can trolley and removes the next empty can from it for filling.

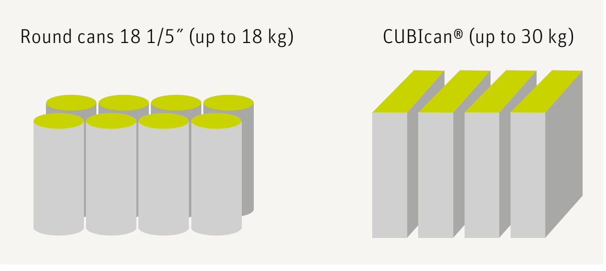


Fig. 63 – Can formats in the rotor spinning mill.
Rectangular cans for economical transport automation

3.2.2. Can transport between the draw frame and the rotor spinning machine

The full cans are transported from the draw frame to the rotor spinning machine and the empty cans in the reverse direction by process-controlled, unmanned transport vehicles (see Fig. 64). These vehicles are also responsible for automatic can change on the rotor spinning machine. The transport vehicles are steered either inductively via wires embedded in the floor or optically via colored strips. The control effort required for complex travel concepts of this kind is high, but they enable highly flexible systems to be implemented that are ideally adapted to changes in loading. By contrast, vehicles running on rails are confined to fixed routes. These systems are considerably less complex, but are also much less flexible.

A working cycle commences with the unmanned transport vehicle collecting an appropriate number of filled cans from the can trolley at the draw frame and thus starting its monitoring run. One space always remains free in the transport vehicle in order to accept the empty can at the first can change, which is then replaced by a full can. The next empty can then takes the place of the full can, and so on.

The machine control of the spinning machine calculates the can running time on the basis of the delivery speed of the sliver, the downtimes and the sliver length. When the can has run empty a new (full) feed can is requested via the central machine control.

The empty can is pulled out of its position under the machine onto the empty space in the transport vehicle by means of a suction device on the transport vehicle. The

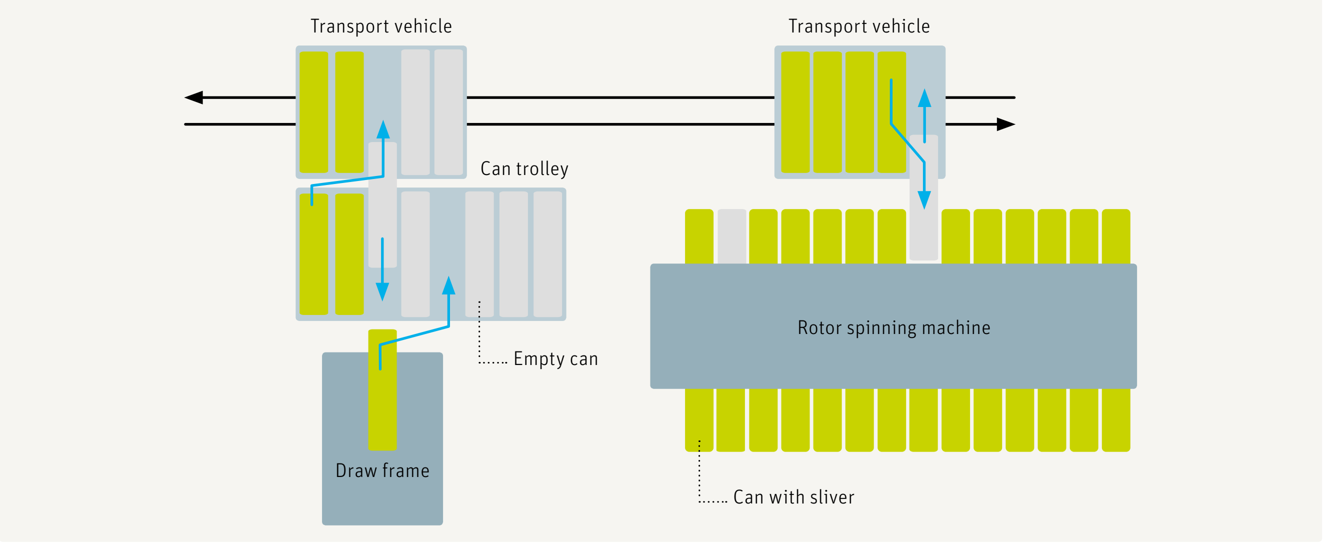


Fig. 64 – Concept for automatic can transport between draw frame and rotor spinning machine

transport vehicle then positions itself, offset by one spinning position gauge, in front of the gap and pushes a full can under the machine. The end of the sliver, already positioned precisely on the lip of the can in the draw frame, is taken manually or by the suction arm of the operating robot and introduced into the spinning position. After all full cans have been placed in position the transport vehicle travels back to the can trolley on the draw frame with the empty cans, where the empty cans are again replaced with full cans. An operating cycle is thus completed and the transport vehicle prepared for the next monitoring run.

The number of transport vehicles depends not only on the size of the mill, i.e. the number of machines, but also on the material throughput (coarse or fine count yarns) and the variety of products. Transport volume per transport vehicle, taking the above factors into account, amounts to between 500 and 1 100 kg/h. Experience in practice shows that 3 - 5 different assortments can be run simultaneously.

It is also possible to divide the spinning mill into different zones, e.g. a cotton and a man-made fiber zone, and to allocate the transport vehicles accordingly. The control software of the transport system then ensures that both zones remain strictly separated in the use of the cans, transport vehicles and can stores on the draw frame. This reliably prevents contamination of either raw material by extraneous fibers.

Although rectangular cans have been developed primarily for fully automated transport systems, they can also be conveyed manually by means of special transport trolleys. The advantage over round cans is that operating personnel on the spinning machine can check the filling level of rectangular cans much better (since all cans are visible) and can ensure timely replacement of the cans. Manual utilization of rectangular cans offers the possibility of integrating these in an automated transport system at any time.

3.2.3. Package transport between the rotor spinning machine and subsequent zones

With automatic package change the cross-wound packages replaced by the robot are placed on package conveyor belts (one each for the right-hand and left-hand sides of the machine). When a preset number of finished packages has been placed on the conveyor belt, the package conveyor belt is automatically started and the packages are transported to the end of the machine. Various concepts are available for package removal itself. The previously customary manual package removal at the end of the machine has been complemented increasingly by systems with different degrees of automation.

The packages delivered to the end of the machine are placed automatically or manually in containers, on pallets or creel trolleys at the machine itself and taken away, or alternatively the packages are transported on overhead conveyors or conveyor belts (Fig. 65) to the subsequent process stages for immediate further processing or to the material store. In the material store they can be deposited in containers or boxes for packaging, palletized for onward dispatch or, depending on transport logistics, direct supply to weaving, warping or knitting operations.

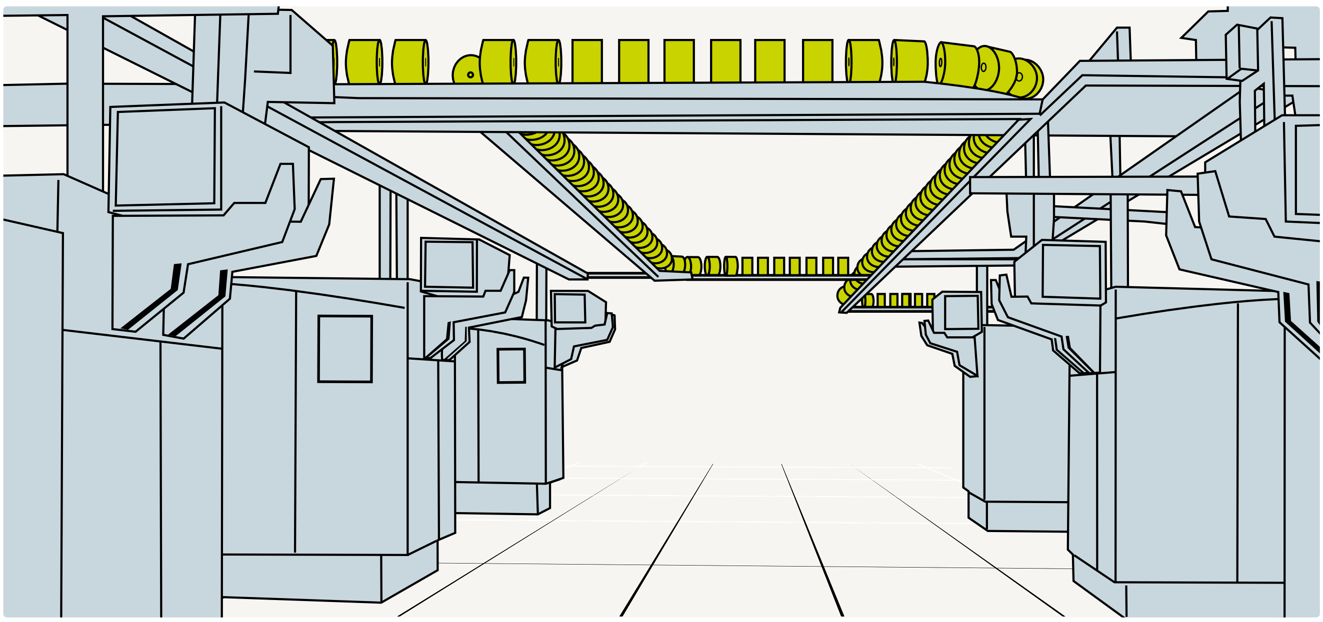


Fig. 65 – Automatic doffing and transport of packages to the palletizing unit

Manufacturers of rotor spinning machines either offer their own systems for automatic doffing and/or provide appropriate interfaces that enable users to connect third party suppliers‘ doffing systems.

In practice the concept of resorting to specialist suppliers‘ doffing systems is becoming increasingly established. The user, i.e. the spinning mill management, is therefore able to choose the appropriate system for his operating conditions from a wider range. Connecting third party systems calls for close cooperation between the machine manufacturer and the supplier of these systems, especially for the initial installation.

Contract spinning mills and textile companies where yarn manufacturing and processing are in different locations prefer to use systems with automatic doffing on the rotor spinning machine and direct deposit on pallets (Fig. 66). These systems are now developed to such an extent that the removal of packages from the machine, their deposit on the pallet, the positioning of intermediate liners and the film-wrapping of the full pallets are performed automatically. Package size, package shape and deposit pattern can be programmed.

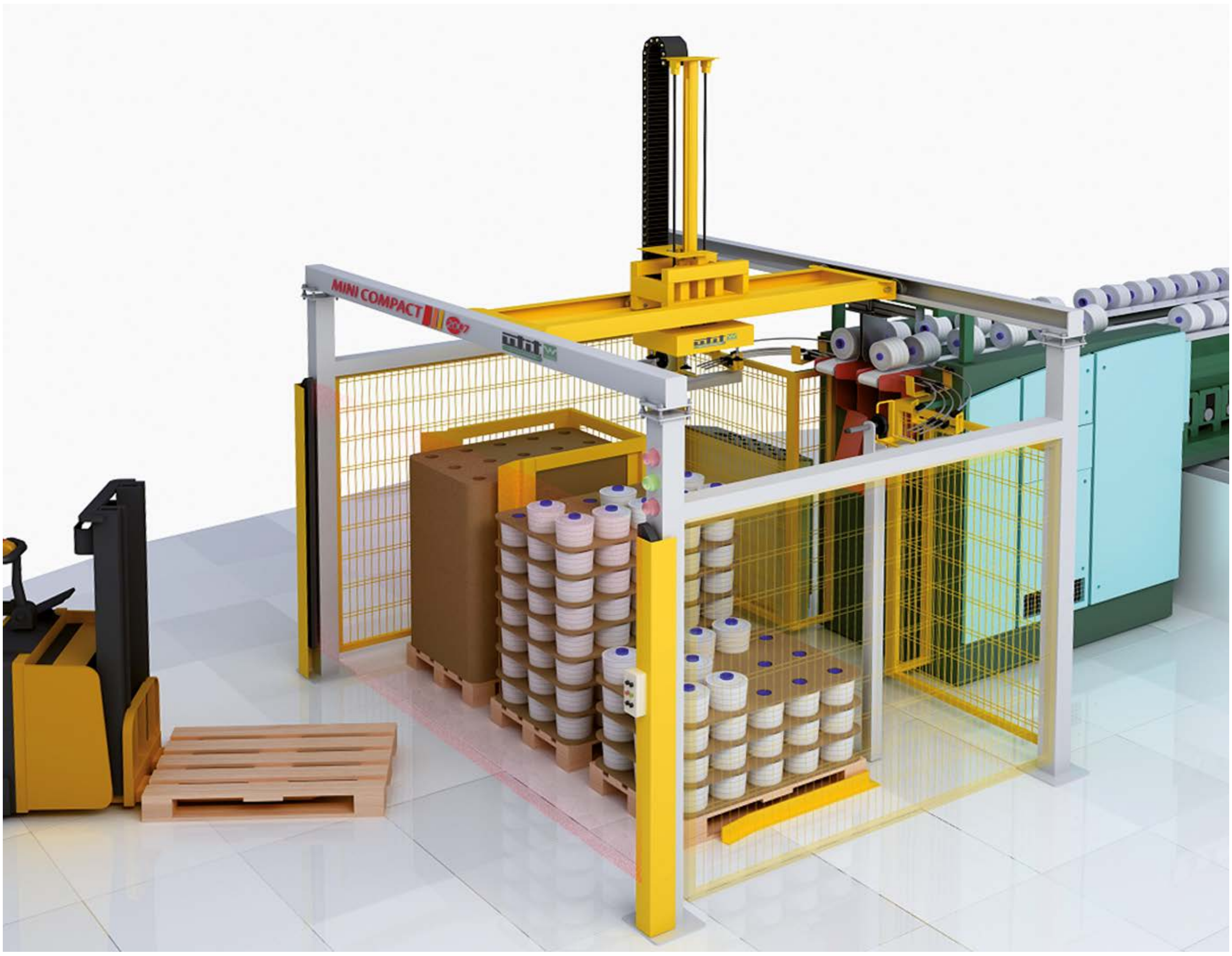


Fig. 66 – Automatic palletizing unit with protective grid on the rotor spinning machine

4. APPLICATIONS ENGINEERING

4.1. Raw material selection

Rotor spinning technology offers considerable flexibility as regards raw material selection. Rotor spinning machines are capable of processing successfully fiber lengths between 10 and 60 mm in virtually all natural and man-made fibers. Rotor spinning thus offers a range of application that no other spinning process, with the exception of ring spinning, can even approach. The following section will explain which raw materials and raw material properties are especially suitable for the rotor spinning process, and how the different characteristic values and properties of the fibers affect the quality of the yarn and end product and the spinning process.
Fig. 67 shows the individual raw materials as a proportion of the total volume of rotor-spun yarns. Even recycled cotton waste and noil are processed successfully on rotor spinning machines. In mill operations the rotor spinning process has earned the reputation of being especially „cotton-friendly“. This is also the reason why predominantly carded rotor-spun yarns of 100 % cotton or blends of cotton and man-made fibers are currently produced worldwide. Table 4 shows the preferred cotton qualities for the rotor spinning process.

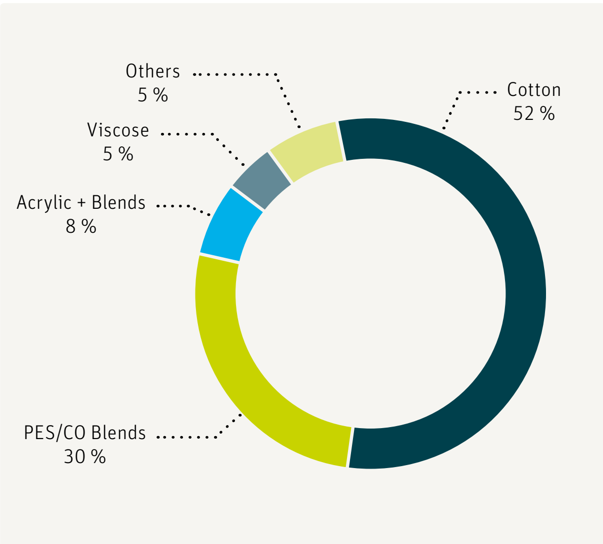


Fig. 67 – Share of fiber materials in the total volume of rotor-spun yarns

A special application is the manufacture of combed rotor-spun yarns. Although this application has not established itself on a broad basis – due to the manufacturing costs for the additional combing passage – the results that can be achieved by using combed feed sliver in mill applications are entirely convincing. These advantages have an impact both on yarn quality (higher tenacity, better regularity, fewer imperfections), on running properties on the rotor spinning machine and on downstream processing (fewer stoppages, less fiber fly generated in weaving and knitting), and thus also on the quality of the end product (e.g. softer hand in knitted fabrics).

In addition to cotton, man-made fibers and/or their blends are successfully processed on rotor spinning machines – and have been since this spinning process was launched. Especially yarns made from polyester fibers and their blends with cotton (in rare cases in blends with wool, bast fibers and angora), are used in a wide range of end products. The reasons for this remarkable development are in particular:

- the outstanding physical and chemical properties of polyester fibers for use in clothing;
- the low production costs for manufacturing polyester fibers and the resulting economical raw material costs;
- and the limited availability of cotton in light of growing global fiber consumption; the annual increase in fiber consumption of some 3 % is now accounted for almost entirely by man-made fibers, and here mostly by polyester fibers.

Viscose fibers, also known as rayon in the US and Asia, account for an appropriate proportion of the total volume of rotor-spun yarns, either pure or in blends with cotton and polyester. However, viscose fibers are heavily exposed to variations in fashion, so that their share of total yarn volume can vary from virtually zero up to 10 %, depending on fashion trends.
Table 5 a) shows the man-made fibers and their blends which can be considered for rotor spinning, including a list of fiber criteria (Table 5 b)) that have to be borne in mind when processing them on rotor spinning machines.

Cotton (CO)		
100 % virgin cotton • short and medium staple • carded and combed	Cotton waste ≤ 7/8″ • secondary material, e.g. reclaimed by recycling	Comber noil • rotor-friendly material because already cleaned
• blends of two or more of these components		

Table 4 – Specification of cotton grades which can be considered for the rotor spinning process

Man-made fibers (MMF)		
natural polymer, cellulosic MMF	**synthetic polymer, synthetic MMF**	**Bio polymer**
• Viscose (CV) / rayon (term in Asia, USA) • Modal (modified viscose) • Micromodal (fiber < 1.1 dtex) • Lyocell (CLY) • Tencel	• Polyester (PES) • Polyacrylic (PAN) and PAN high bulk • Polyamide (PA)[1)] • PA-Aramide (Nomes, Kevlar)[1)] • Polypropylene (PP)[1)] • Polyvinyl chloride (PVC)[1)]	• Nature works (PLA)[2)]
Blends		
• blends of man-made fibers (mostly PES/CV and PAN/CV) • blends of cotton and man-made fibers (mostly CO/PES and CO/CV)		

1) These types of fiber are only processed in exceptional cases
2) Bio polymer fibers only at the experimental stage

Table 5 a) – Man-made fibers used in the rotor spinning process

Fiber specification	
Microfibers	fiber fineness < 1.1 dtex more fibers in cross section = higher yarn strength
High-tenacity fibers	fibers with higher tenacity (approx. +5 .. 10 %)
Low-pilling fibers	reduced fiber tenacity (-15 .. 25 %) red. yarn strength red. rotor speed
Shiny fibers	higher fiber/fiber friction higher cohesion slightly higher drafting strength
Semi-dull or dull fibers	reduced lifetime of spinning elements slightly reduced drafting strength
Flame-retardant fibers	chlorine fibers danger of corrosion
Extruded-/tuft dyed fibers	more aggressive than raw white fibers reduced opening roller and rotor speeds

Table 5 b) – Fiber properties which have to be recognized when processed on rotor spinning machines

Other natural raw materials	
Animal raw materials[3] • Angora wool • Sheep's wool (sheared or teased, max. 60 mm) • Wool noil (tow)	Bast fibers[4] • Jute • Linen • Ramie
• Usually in blends with cotton, viscose or polyester, but not in blends with each other	

[3] The use of wool calls for intensive cleaning (burrs, lanolin, organic impurities). The residual fat content of the wool must not exceed 0.5 %
[4] All bast fibers require intensive cleaning (coarse fibers and dust!) and fibrillation (various solubilizing processes)

Table 6 – Other sustainable raw materials

Since both wool and bast fibers display low inherent strength, these fibers are usually processed in blends with man-made fibers or cotton, which act as stabilizing fibers.

The raw materials listed in Table 6 are rarely processed on rotor spinning machines. Special process expertise is required for processing them and the raw materials listed under 1) 2) in Table 5 and under 3) 4) in Table 6; this has been developed by the spinning mills in question, often in cooperation with the machinery manufacturer or with textile institutions. This starts already with the selection of raw materials and the pre-treatment that is necessary in most cases. Processing in the spinning mill usually calls for specifically adapted machine speeds, delivery speeds and setting parameters, especially at nip and fiber transfer points, and in most cases necessitates an appropriate modification of the spinning climate, in terms of both temperature and humidity. In certain cases special spinning elements are adapted by yarn manufacturers on their own initiative, and these take into account the gentle treatment usually required for these fibers.

We will therefore not deal in greater detail with these special applications, since in most cases the fiber- and process-specific features are not revealed, i.e. are regarded as the intellectual property of the individual spinning mills.

4.2. Fiber properties

In any spinning system, fiber properties exert a decisive influence on the processing of the fibers and the resulting yarn. These influences are reinforced in the case of rotor spinning, so that several remarks are appropriate here with regard to the raw material and its preparation. Priority of fiber properties in each spinning system see Table 7.

100 % cotton yarns			
Priority	**Rotor**	**Ring**	**Air-jet**
1	Fineness	Length	Length
2	Strength	Strength	Cleanliness*
3	Length	Fineness	Fineness
4	Cleanliness*		Strength

*see section "4.3. Preparation of raw material"

Table 7 – Priority of fiber properties for rotor-spun and ring-spun yarns

4.2.1. Fiber count

In rotor spinning fiber count and thus the number of fibers in the yarn cross-section probably have the greatest influence on yarn and spinning results. Fiber count (Micronaire or dtex) defines the spinning limit, i.e. the ratio of fiber count to yarn count from which stable spinning behavior is assured. Due to the markedly different yarn structure of rotor-spun and ring-spun yarn, resulting in less pronounced parallelization of the fibers in rotor-spun yarn, the material utilization of fiber tenacity and thus also yarn tenacity (with the same fiber count and thus the same number of fibers in the yarn cross-section) is some 15 - 25 % lower than in ring-spun yarn. In order to compensate for these system-related differences, i.e. in order to ensure stable spinning conditions and also achieve good yarn tenacity, rotor-spun yarns must be spun with a higher number of fibers (at least 90 - 110 (120)) in the yarn cross-section. The relationship between the fiber count of cotton and man-made fibers and the resulting spinning limit is shown in Table 8.
The spinning limit (Nm/Ne/tex) can be calculated as follows:

$$\textit{spinning limit tex (Y)} = \frac{dtex\,(F) \times n_F}{10} = \frac{Mic \times n_F}{25.4}$$

$$\textit{spinning limit Nm (Y)} = \frac{10\,000}{dtex\,(F) \times n_F} = \frac{25\,400}{Mic \times n_F}$$

$$\textit{spinning limit Ne (Y)} = \frac{5\,917}{tex\,(F) \times n_F} = \frac{15\,030}{Mic \times n_F}$$

n_F = number of fibres given for the spinning limit in the table 8 (90 to 110 fibres)

Derived from this, the number of fibers in the yarn cross-section (n_F) is calculated as follows:

$$\textit{number of fibers } n_F = \frac{tex\,(Y) \times 10}{dtex\,(F)} = \frac{5\,917}{Ne\,(Y) \times dtex\,(F)} = \frac{10\,000}{Nm\,(Y) \times dtex\,(F)}$$

$$\textit{number of fibers } n_F = \frac{tex\,(Y) \times 25.4}{Mic} = \frac{15\,030}{Ne\,(Y) \times Mic} = \frac{25\,400}{Nm\,(Y) \times Mic}$$

n_F = number of fibers in the yarn cross-section
Mic = Micronaire
Y = yarn
F = fiber

Spinning limit, 100 % carded cotton (110 fibers/yarn cross-section[1])		
Micronaire	**dtex cotton**	**Spinning limit Nm/Ne/tex**
3.2	1.26	72/43/14
3.5	1.38	66/40/15
4.0	1.58	57/34/17
4.2	1.65	55/32/18
4.5[2]	1.77	47/28/21
5.0[2]	1.97	42/25/24

Spinning limit, MMF and blends (90 fibers/yarn cross-section)		
dtex	**den**	**Spinning limit Nm/Ne/tex**
0.6	0.7	185/110/5.4[3]
0.9	1.1	123/73/8[3]
1.1	1.2	101/60/10
1.3	1.5	85/50/12
1.7	1.9	65/39/15
2.2	2.4	50/30/20

[1] When using combed fibers the spinning limit is 90 - 100 fibers/yarn cross-section
[2] Coarser fibers (with counts ≥ Mic 4.5) are mostly short to very short fibers; in this case the spinning limit is at least 120 fibers in the yarn cross-section)
[3] Yarn counts cannot be produced economically on rotor spinning machines

Table 8 – Spinning limit for cotton and man-made fiber yarns as a function of fiber count

In blends the arithmetic mean fiber count (dtex or Micronaire) is calculated according to the percentage content of the individual components:

Example:
67 % polyester 1.3 dtex/33 % cotton 4.2 Micronaire = 1.65 dtex (dtex cotton = Micronaire x 0.394)
∅ fiber count = 100/{[67/1.3] + [33/1.65]} = 100 / [52 + 20] = 1.4 dtex

The cottons used for rotor-spun yarns are mostly in the count range of 3.5 to 4.6 Micronaire, although in some applications very fine cottons from 2.8 Micronaire (for very fine yarns) up to very coarse yarns up to 5.0 Micronaire (in the coarse yarn range) are used. Care is required especially with very fine fibers – < 3.0 Micronaire – since in this count range the danger of immature fibers increases. In this context a fundamental comment on the Micronaire value: when using the Micronaire value it should be borne in mind that this value does not always correspond to the current count, since it is influenced by the maturity of the fiber. It has been established that for certain Micronaire values the current count corresponding to the maturity varies, and can thus also influence the spinning limit. Accurate fiber count values are obtained by measuring fiber count in mtex or dtex. However, since the Micronaire value is still mostly used in practice, the following statements are also based on this value.

Through careful selection of correspondingly fine and well matured types of fiber, carded cotton yarns up to Ne 60/Nm 100/tex 10 can now also be spun industrially, i.e. with stable spinning conditions and good yarn values, using the rotor spinning system.

Man-made fiber manufacturers recognized the importance of finer fibers for rotor spinning very early, and have offered increasingly fine fiber counts on the market. Whereas fibers were offered with 1.5 den as the finest count at the beginning of the nineteen-eighties, only a few years later fibers with 1.2 den and within a few more years fibers with counts of < 1.0 den, so-called microfibers, were already available. The availability of these very fine fibers has enabled yarn manufacturers to produce increasingly fine yarns with increasingly high yarn quality. By using microfibers, man-made fibers with counts of up to Ne 60/Nm 100/tex 10 can also be spun on rotor spinning machines.

If finer fibers are also used for coarser yarns, i.e. the number of fibers in the yarn cross-section is increased, this has a positive influence not only on the yarn characteristics; in particular, yarn twist can be significantly reduced, which in turn substantially improves the hand of the yarns in the end products. These advantages have been exploited by those yarn manufacturers who prefer to manufacture yarns for end products where wearing comfort plays a major role. This applies in particular, for example, to T-shirts (in which rotor-spun yarns are now dominant both in the US and also in Europe), but also to leisurewear and lightweight men‘s and women‘s outerwear. Fig. 68 clearly shows the influence of fiber count, i.e. the number of fibers in the yarn cross-section, on yarn tenacity.

Yarn counts of yarns produced from wool and bast fibers, even if they are spun in blends with cotton or man-made fibers, depend largely on the available (and also widely varying) fiber counts. However, since the fibers of these raw materials are usually coarser than those of cotton or man-made fibers, the finally spun yarn counts are usually in the coarser count range ≤ Ne 12/Nm 20/tex 50. Yarns in counts up to Ne 24/Nm 40/tex 25 are produced only with very fine wool grades or angora wool, usually in blends with cotton or PES (the figures given are only approximate values).

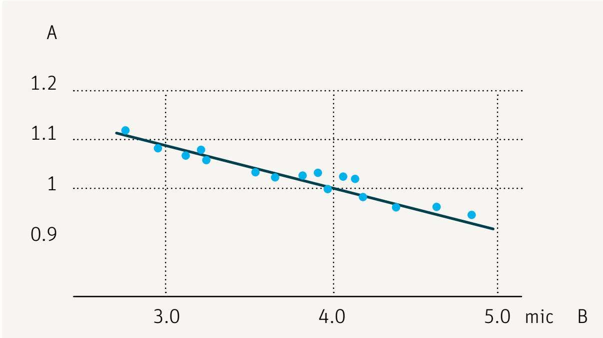


Fig. 68 – Relationship between fiber count (B) and yarn tenacity (A)

4.2.2. Fiber length

The influence of fiber length on the processing properties and the quality of the yarns produced is less significant in rotor spinning than in ring spinning, but should nevertheless not be underestimated. Fig. 69 shows the influence of different fiber lengths on yarn tenacity and yarn irregularity.

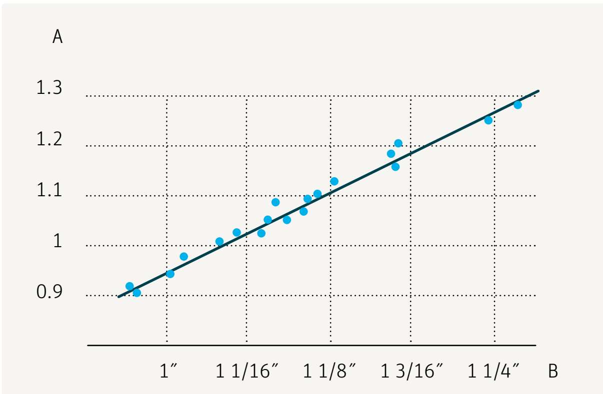


Fig. 69 – Relationship between staple length in inches (B) and yarn tenacity (A)

Table 9 shows the relationship between staple lengths and the yarn counts produced from them. It should be noted here, however, that this relationship is not governed solely by staple length, but that fiber count plays a role inasmuch as shorter fibers are often quite coarse, but longer fibers are available in finer counts.

100 % cotton / recycled cotton waste / comber noil					
Cotton class	**Staple length**		**Yarn count**		
	inches	**mm**	**Ne**	**Nm**	**tex**
short	29/32″ - 15/16″	23.0 - 23.8	< 10	< 17	> 59
	31/32″	24.6″	< 12	< 20	> 49
	1″	25.40	≤ 16	≤ 27	≥ 37
medium[1)]	1 1/32″ - 1 3/32″	26.2 - 27.9	≤ 40	≤ 68	≥ 14.8
	1 1/8″ - 1 5/32″	28.3 - 29.4	< 60	< 100	> 10
long	> 1 5/32″	> 30	no applications in rotor spinning		
waste (recycled fibers)	≤ 7/8″	≤ 22.2 mm	3 - 10	5 - 17	200 - 59
comber noil	[2)]	[2)]	≤ 20	≤ 34	≥ 50

[1)] Fibers in the medium cotton class are also processed in combed form on rotor spinning machines.
[2)] The yarn count being spun depends on the quality of the combed cotton and the noil extraction rate on the comber. In mill practice 100 % noils are spun up to Nm 34/Ne 20/tex 50.

Table 9 – Yarn counts for cotton yarns as a function of staple length

This table also shows clearly that cotton and cotton waste with a high short fiber content (< 1″/25.4 mm) can be processed successfully using the rotor spinning principle. Cotton waste is therefore in demand as a raw material for certain ranges of application. However, it should be borne in mind that yarn quality declines alongside staple length; this affects yarn tenacity and yarn purity (imperfections) in particular. Yarns produced from shorter fibers usually also have to be spun with higher twist multiplyers. However, physical textile properties such as tenacity and regularity play only a subordinate role in the end products usually produced from these yarns, such as sheets, which are subsequently napped, while the high number of fiber ends has an especially favorable impact on the napping effect of the final fabrics (short fibers result in a high number, whereas longer fibers result in a lower number of fiber ends for the same yarn length).
If the rotor diameter is too small for the intended fiber length, twist integration in the rotor groove is considerably disturbed. However, the tolerance range is larger than is often described in the literature. As a rule of thumb, fiber length (mm) should not significantly exceed rotor diameter (mm). However, in mill practice fibers with a staple length of 40 mm, for example, are successfully spun in large quantities on rotors with a diameter of 30/32 mm.
Finally, it must be reiterated that in rotor spinning fiber length is not the dominant fiber characteristic it is in ring spinning; in the rotor spinning machine, this role is assumed by fiber count.

Table 10 shows the yarn counts of man-made fiber yarns as a function of fiber length.

The influence of staple length compared to fiber count is also of secondary importance for man-made fibers. The graduation of yarn count in accordance with fiber length results from the fact that, in contrast to cotton, shorter fibers are supplied in finer counts and longer fibers in coarser counts.

Man-made fibers (MMF)				
Fiber length		**Yarn count**		
inches	**mm**	**Ne**	**Nm**	**tex**
1.18 - 1.4	30 - 36	24 - 50	40 - 84	25 - 12.0
1.5 - 1.58	38 - 40	20 - 30	34 - 50	29.4 - 20
1.9 - 2.05	48 - 52	8.3 - 18	14 - 30	71.5 - 33.3
≤ 2.36	≤ 60	≤ 8.3	≤ 14	≤ 71.5

Table 10 – Yarn counts of man-made fiber yarns as a function of staple length

4.2.3. Fiber tenacity and fiber elongation

The higher the required yarn tenacity the higher the inherent strength of the fibers used must be. However, in order to achieve stable spinning conditions a sufficiently high number of fibers must be available in the yarn cross-section in addition to adequate fiber tenacity (see „4.2.1. Fiber count“). Yarn blends of cotton and polyester are increasingly being used to manufacture rotor-spun yarns featuring particularly high tenacity and where the end product permits this. It is apparent from the fiber tenacity values of different types of fiber shown in Table 11 that PES fibers display approx. twice the tenacity of cotton fibers. The higher tenacity of these yarns results both in more stable delivery behavior in weaving preparation and on weaving and knitting machines and also in higher fabric strength (weaves, knits) and thus improved properties in use.
However, when considering fiber properties, fiber tenacity should not be viewed in isolation. Fiber elongation is at least as important. Only the product of fiber tenacity and fiber elongation, i.e. the work capacity, enables a meaningful statement to be made regarding the further processing behavior of the fibers and yarns in the spinning process.

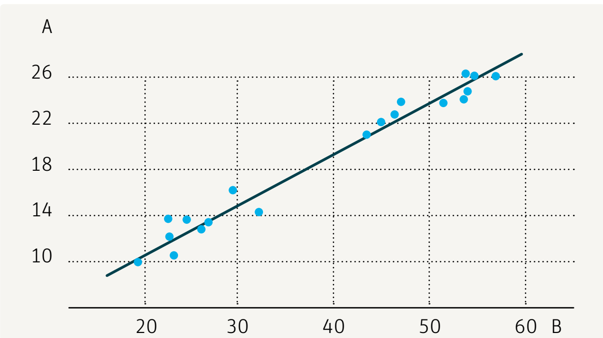


Fig. 70 – Relationship between fiber tenacity (B) and yarn tenacity (A) in cN/tex

The material utilization of fiber tenacity in the rotor yarn is between 40 and 60 %, depending on yarn count, and is thus some 15 - 25 % less than that of ring-spun yarns. Fig. 70 shows the linear relationship between fiber tenacity (B) and yarn tenacity (A) in cN/tex.

Fiber	Breaking strength (cN/tex)
Cotton	15 - 40
Cellulosic MMF	
Viscose/rayon	23 - 30
Modal	32 - 38
Lyocell/Tencel	39 - 50
Synthetic MMF	
Polyester[1)]	50 - 71
Polyacrylic	24 - 35
Polyamide	40 - 70

Table 11 – Breaking strength (cN/tex) of natural and man-made fibers

4.3. Preparation of raw material

Whereas synthetic and cellulosic man-made fibers are usually „clean“, i.e. free of trash and extraneous material (with the exception of coarse fibers and packaging residues), raw cotton always contains a certain amount of organic and inorganic trash, dust, and vegetable and extraneous particles. The majority of disturbing impurities can be eliminated by efficient cleaning of the cotton with the appropriate number of cleaning positions in spinning preparation and careful carding (see The Rieter Manual of Spinning, Volume 2 – Blowroom & Carding). Modern blowrooms are capable of removing up to 97 % of the trash contained in raw cotton (trash content of the carded sliver compared to the raw cotton fed to it). However, depending on the method of harvesting and the „cleaning propensity“ of the cottons used, certain disturbing extraneous materials can survive the cleaning and carding process. These are mainly:

- fine and very fine dust (especially critical when adhering tenaciously to the fibers);
- extraneous fibers (especially bale packaging material);
- vegetable residues (seed coats, leaves, cotton plant stems);
- larger trash particles when the cotton has not been adequately cleaned.

While trash removal on the rotor spinning machine is capable of effectively removing larger trash and extraneous particles, dust and other very light extraneous material can reach the rotor in the air current and be deposited there in the rotor groove.
Coarser particles (mainly seed coat fragments) stay caught in the rotor groove. They can prevent yarn formation at this point, and this in turn can result in ends down, mainly when spinning finer yarn counts. On the other hand, fiber agglomeration at the particle results in a thick place at the agglomeration point, and immediately thereafter a thin place where the agglomerated fibers are absent in the groove. The resulting defect (thick/thin place) is absolutely periodic and leads to a moiré effect if the affected yarn is worked into a fabric.
Small dust particles lead to slow but persistent filling-up of the collection groove in the rotor. If this is originally narrow, it becomes steadily more open and wider as it fills up. The fiber bundle, which was extremely condensed in the narrow groove to produce a compact yarn, becomes steadily less compressed; the yarn thus becomes gradually more open and bulky. The yarn character and quality thus change gradually and unnoticed over a long period. The same effect is observed in spinning synthetic fibers if the spin finish can accumulate in the rotor.

Clean raw material is therefore a precondition for spinning yarn on the rotor spinning machine. Rieter Ingolstadt recommends that the following residual trash content should not be exceeded in the feed sliver:
- up to Nm 10 / Ne 6 / 100 tex : 0.3 %;
- up to Nm 34 / Ne 20 / 30 tex : 0.2 %;
- up to Nm 50 / Ne 30 / 20 tex : 0.15 %;
- above Nm 50 / Ne 30 / 20 tex : 0.1 %.

These requirements imply that the "cleanest possible" cotton should be sought out at the purchasing stage and furthermore that good preparation equipment, giving a high cleaning and dust-removal effect, is of great benefit for the rotor spinning process. In addition, several machine manufacturers have fitted their machines with trash-removal devices.

4.3.1. Disturbing materials in the cotton

In addition to trash, dust and vegetable residues, cottons are unfortunately being contaminated increasingly with other impurities, which in some cases can cause significant processing or quality problems.

4.3.1.1. Organic and inorganic impurities

On the one hand, these are residues of cotton packaging (jute, polypropylene, etc.) that get into the fiber material due to careless removal during bale feeding. However, more and more impurities, e.g. remains of plastic sacks and other refuse, are already getting into the fibrous material during harvesting in the cotton fields. These impurities and packaging residues are reduced in size by the various opening units in the blowroom and carding room to such an extent that it may no longer be possible to remove them. These impurities either result in ends down on the spinning machine, which is the lesser evil, or they are spun into the yarn, with much more serious consequences. Extraneous fibers (e.g. jute in the case of cotton) usually display a different dyeing behavior from the original fibers. However, since the extraneous fibers are also usually distributed over long lengths of yarn, this leads to a drastic reduction in the value of the fabric produced. Increasing numbers of monitoring systems are therefore being used on rotor spinning machines to detect and eliminate these impurities.

4.3.1.2. Yarn remnants

Recycled weaves, knits or fiber residues are processed on rotor spinning machines, since they are especially suitable for this application. However, the crucial precondition for successful spinning of these very low-cost raw materials is the opening of the materials used down to the individual fibers. Appropriate machines are supplied by various manufacturers. Disintegration takes place in principle in several stages, starting with cutting up and then tearing up the fabric or yarn residues down to the individual fibers. If the necessary care is not devoted to this process, even the smallest remnants of fabric or yarn result in ends down if they reach the rotor. In the case of very coarse yarns the remnants of fabric or yarn may not cause ends down, but be incorporated in the yarn and then inevitably appear as a thick place in the yarn.

4.3.1.3. Quartz sand and mineral dust

Quartz sand and mineral dust are present mainly in cotton from the latitudes of the desert regions (e.g. West Texas cotton). They exert an abrasive effect, like sandpaper, and cause rapid wear on spinning elements, such as opening rollers, rotors, and navels. If mineral dust is present, this effect is reinforced.

4.3.1.4. Honeydew

Honeydew forms tenaciously adhering sticky deposits on spinning elements and thus makes spinning more difficult while causing deterioration in yarn characteristics and an increase in ends down. However, if the use of cottons contaminated in this way is unavoidable, the speed of the spinning machines must be reduced and the room climate adjusted accordingly. In particular, relative humidity should not exceed 45 to 50 % RH in order to limit the formation of sticky deposits on thread guiding components. It is also necessary to clean all thread guiding components thoroughly after the passage of the contaminated cotton (wash)! Wherever possible, the use of cottons containing honeydew should therefore be avoided.

4.3.2. Processing problems with man-made fibers

In the case of man-made fibers (MMF), particular attention must be paid during processing in the spinning mill not only to the coarse fibers referred to earlier, but especially to the spin finish and the titanium dioxide used as a delustring agent on some types of fiber.

4.3.2.1. Spin finish (MMF)

Quality and quantity of the spin finish of MMF are of considerable importance for spinning performance, shedding and yarn quality. This also is one of the main reasons for speed limitations in high-speed rotor spinning. Rotor spinning needs fibers with less finish application compared to ring-spun types. While the amount of spin finish for ring-spun yarn varies between 0.18 % and 0.20 %, fibers suitable for rotor spinning require only 0.12 % to 0.14 %. Finish application above that level or insufficient adhesion may result in troublesome deposits at the spinning elements and these in turn may cause ends down.
The strain on the fibers in the spinning unit – due to opening roller action, fiber transport, etc. – requires low-friction finishes which prevent electrostatic charging of the fibers, reduce fiber/metal friction and avoid dust formation.

4.3.2.2. Delustrants (MMF)

If luster and smoothness of MMF are to be suppressed in round fibers, this can only be done chemically. Titanium dioxide (TiO_2) is used for this purpose. However, this delustring agent is extremely aggressive, similar to mineral dust, and results in premature wear of all fiber guiding components on the machine, and in particular the spinning elements on final spinning machines (rotor, ring, Air-jet). While delustred fibers (titanium dioxide content ≥ 0.4 %) should not be processed in principle, partially delustred fibers with a titanium dioxide content ≤ 0.15 % can be used in blends with natural and/or man-made fibers which have not been delustred. The machine manufacturer‘s processing recommendations must be followed without fail. As a rule no warranty is given for the service life of the spinning elements if there is any departure from these recommendations.

4.3.3. The processing stages

In rotor spinning, not only the characteristics of the raw material are important; the manner in which this material is prepared on the mill‘s preparatory equipment is also significant. The machines to be selected and the processing lines must be adapted to the type of raw material. Currently, the processing lines shown in Fig. 71 are most commonly used.

A third draw frame passage is not even necessary when cotton is blended with synthetic fibers in sliver form, because the back-doubling in the rotor leads to a high degree of fiber/fiber transverse doubling (refer to section „4.3.3.3. Draw frames“)

4.3.3.1. Blowroom

Since rotor spinning reacts less critically to short fibers than ring or Air-jet spinning, the main task of blowroom machinery is the efficient removal of trash and dust. The blowroom line can therefore be kept very short, but calls for very effective cleaning and opening units (see The Rieter Manual of Spinning, Volume 2 – Blowroom & Carding, 1. The blowroom).

4.3.3.2. Cards

The card usually has to reduce the dirt content to less than 0.1 - 0.2 % and also to remove part of the dust. The card is already capable of removing dust adhering to the fibers because significant fiber/metal friction arises here, and the dust is rubbed off. With regard to dust removal, the blowroom, carding room and draw frames are each expected to remove about one-third of the dust. Web crushing at the delivery of the card often brings about a significant improvement in the cleaning effect for cotton with medium to high dirt content. (see The Rieter Manual of Spinning, Volume 2 – Blowroom & Carding, 2. The card).

When the carded sliver is processed directly on the rotor spinning machine (Fig. 71) the card must be equipped with a leveling device or a card with a draw frame module used (refer to section „4.3.3.3. Draw frames“ and The Rieter Manual of Spinning, Volume 3 – Spinning Preparation, 2. The draw frame).

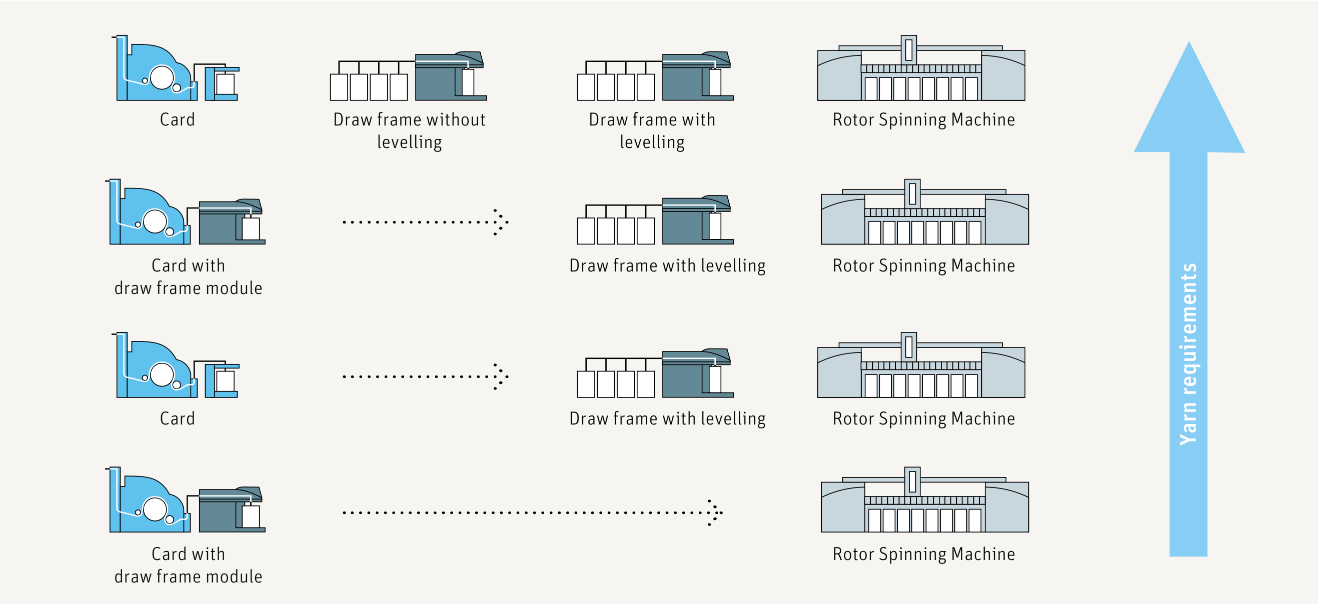


Fig. 71 – Rotor spinning systems with different sliver preparation depending on yarn quality requirements

4.3.3.3. Draw frames

The draw frame is of crucial importance for the quality of the yarn and thus ultimately also for the quality of woven and knitted fabrics. Defects which are not leveled out on the draw frame reappear undiminished in the yarn.
An essential task of modern draw frames is to deliver defect-free draw frame slivers of maximum regularity to the rotor spinning machine. This is assured nowadays by highly effective leveling devices on the draw frame (especially through the open control loop leveling principle) (mill readings, see Table 12).

Raw material	m/min	CV% (1m)	CV% (3m)	CV% (5m)
Cotton carded	1 000	0.41	0.21	0.15
Cotton carded	700	0.32	0.19	0.10
Viscose	650	0.41	0.18	0.06
Polyester	600	0.41	0.25	0.12

Table 12 – Mill readings for sliver irregularity CV% for sliver lengths of 1 m - 3 m - 5 m (open control loop leveling principle)

Modern high-performance draw frames are currently equipped with highly efficient extraction systems which reliable remove a substantial proportion of the dust still present in the fiber material. Dust, fiber fragments and trash are effectively separated from the fibers by fiber/fiber friction during the drafting process in the draw frame and can thus very easily be removed by the extraction system.
In contrast to ring spinning, where in principle 2 draw frame passages, when processing blends even 3 draw frame passages are used, rotor spinning operates with one or no more than two draw frame passages (even with blends). In rotor spinning the effect of fiber hooks is of secondary importance on the one hand, and additional blending takes place in the rotor due to back-doubling on the other. Only 2 draw frame passages are therefore used, even when manufacturing blended yarns, without loss of quality. Directly leveled carded sliver can also be fed to the rotor spinning machine in certain applications.
Fig. 71 compares rotor spinning systems with different sliver preparation, which are used depending on the required yarn quality.

Two draw frame passages (leveling in the 2nd passage):

- for rotor-spun yarns in the fine count range (finer than Nm 34 / Ne 20 / 30 tex) and high demands on yarn count constancy (e.g. for single jersey); the 2nd passage also serves for additional de-dusting;
- for rotor-spun blends with draw frame sliver and stock blending in the medium and fine count range;
- for rotor-spun denim yarns (branded goods) with high standards in terms of tenacity, elongation and yarn purity.

One draw frame passage (with leveling):

- for rotor-spun yarns in the medium and coarse count range without very high demands on yarn quality;
- for rotor-spun denim yarns (low-price products) without particular quality specifications by garment manufacturers;

- for rotor-spun yarns with a high short-fiber content, where a second draw frame passage can even result in a deterioration in sliver regularity („floating“ clumps of short fibers in the drafting zone);
- combed rotor-spun yarns (only one leveled draw frame passage after the comber, also for ring-spun yarns!). Excellent parallelization is already achieved in the combed sliver due to combing and the high doubling number up to and including the comber. With each additional draw frame passage sliver cohesion would decline so steeply that false drafts are inevitable in downstream processing.

Direct processing of carded sliver (leveled card):

- for rotor-spun yarns in the count range coarser than Nm 20 / Ne 12 / 50 tex without particular demands on yarn quality;
- for rotor-spun yarns with a very high short-fiber content (e.g. cotton waste, recycled weaves or knits).

Special case: card with draw frame module (with leveling):

- Range of application as for one draw frame passage with leveling. Exception: combed rotor-spun or ring-spun yarns, since doubling cannot be dispensed with in this application.

4.3.3.4. Combing

Although the processing of combed cotton on rotor spinning machines has not yet become widely established to date, the results which can be achieved are noteworthy. Since the advantages for rotor spinning lie mainly in the elimination of seed trash, fiber neps and seed coats which interfere with the spinning process, and the short-fiber content does not necessarily have to be reduced, noil extraction rates of between 10 and 14 % are adequate to ensure the desired residual trash content of ≤ 0.04 % for fine count yarns. The upgrading of available and affordable cotton by means of combing has the basic advantage that, independently of harvesting methods, environmental and ambient influences, the cotton properties (trash content, short fiber content) can be adapted selectively and reproducibly to the spinning conditions.
Processing combed slivers not only improves the machine‘s running behavior (fewer stoppages and higher efficiency), but also the quality of the yarn and the end product, as well as downstream processing properties.

4.4. Ranges of application of the spinning elements

With no other spinning process, with the exception of ring spinning, can such a wide range of different yarns be produced in the count range Ne 3 - 60 / Nm 5 - 100 / tex 200 - 10 as with the rotor spinning system. The spinning elements play a crucial role here, making a decisive contribution to the optimum adaptation of the quality, structure and volume of the yarns to the intended end product. In addition, the selection of spinning elements also helps to optimize the running behavior of the machine (ends down, quality stops) in relation to the raw material used.

The following section contains a summary of the spinning equipment available for a rotor spinning machine (see Fig. 72), its range of application and its influence on yarn, final product and spinning technology.

Fig. 72 – Spinning elements for rotor spinning machines, opening rollers (rear left), rotors (rear right), draw-off nozzles (front), channel plates (center)

4.4.1. Range of application of the opening roller

The opening roller‘s task is to open the carded or draw frame sliver fed to the spinning box into individual fibers and at the same time to separate the fibers from the trash. The shape, geometry and design of the opening roller are, alongside the rotor, of the greatest importance for faultless spinning results. Its function with regard to releasing individual fibers from the fiber sliver, its influence on trash removal and fiber transport to the fiber transfer point in the fiber guide channel is described in detail in section „2.3.2. Opening unit“.
The point and front flank of the clothing tooth in particular are exposed to wear. The wear is greater, the more aggressive the raw material used, for example when processing cotton containing mineral dust or man-made fibers containing delustring agents (titanium dioxide TiO_2). The service life of the opening roller clothing is significantly improved if the teeth are coated. In this case the clothing is either given a nickel coating or diamond powder with a grain size of several microns is embedded in the nickel layer for even better wear resistance. The service life of nickel-plated clothing is about twice that of steel clothing that has only been hardened, while diamond/nickel-treated clothing lasts about 4 times as long.
Worn opening roller clothing usually first becomes apparent when ends down increase and yarn irregularity and imperfections deteriorate with otherwise identical raw material and spinning conditions. As a rule of thumb, clothing can be described as worn when ends down rates double and yarn irregularity deteriorates by more than 1 CV_m%.
Clothing shape and opening roller speed must be coordinated with the raw materials being processed (see Fig. 73). Clothing differs mainly in tooth shape, the gradient of the front flank of the clothing tooth and tooth density (pitch) relative to clothing surface area:

- For carded and combed cottons and viscose, clothing with a large, i.e. more aggressive front flank, higher tooth density and sharper points (type B 174) is usually used.
- For critical cottons, also those containing a small amount of honeydew, the use of clothing type B 174 - 4.8 is recommended, which is characterized by a modified clothing shape and wider tooth spacing (4.8 mm instead of 2.5 mm as in B 174).
- Clothing shape S 21 is characterized mainly by a less sharply inclined and thus also less aggressive front flank, which is suitable for gentle processing of thermally more sensitive man-made fibers in particular, especially polyesters and their blends.
- Clothing with low tooth density and low tooth height, type S 43, is used in particular for man-made fibers with a tendency to lap due to high metal/fiber cohesion, such as polyacrylic. Especially gentle opening is possible with this clothing and at the same time the fibers are more readily released from the clothing.

Besides the clothing specification, opening roller speed has a decisive influence on spinning results, as regards both the running behavior of the rotor spinning machine and yarn quality. The ideal speed for a given raw material and a given yarn is preferably defined by a series of trials at several opening roller speeds. The most suitable speed can be chosen on the basis of yarn quality. A series of trials of this kind can even provide a rough idea of running behavior. If 2 or 3 thread breaks already occur during a half-hour spinning trial on 10 spinning positions, this opening roller speed is unsuitable for stable spinning conditions, despite possibly good yarn values. Empirical values for basic settings are usually provided by machinery/component suppliers.

The following factors apply in principle when specifying the opening roller speed:

- A higher opening roller speed should be selected, the higher the material throughput per unit of time, for example with coarse yarns and/or high delivery speeds, or the more heavily contaminated the raw material and the more effective trash removal therefore has to be.
- The opening roller speed selected should be lower, the more sensitively the fibers react to mechanical and thermal stress and would be damaged at excessively high speeds.
- Certain raw materials, especially very fine and/or very long man-made fibers or fibers with high fiber/metal adhesion, have a tendency to lap in the opening roller clothing. In these cases especially careful definition of the opening roller speed is required, and this can ultimately only be specified by spinning trials.

Opening roller clothing, especially the teeth, is particularly susceptible to mechanical damage. If certain spinning positions display especially high ends down rates, or yarn quality deteriorates particularly severely at certain spinning positions, this is often attributable to broken or bent teeth, usually caused by incorrect handling when installing or replacing the opening roller. Maintenance and operating personnel must be specially instructed to handle opening rollers carefully and gently.

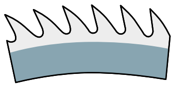
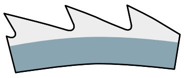
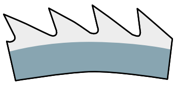
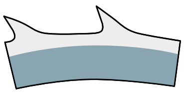
Tooth shape	Type	Recommendation
	B 174	• Preferably used for cotton and highly suitable for viscose • Good fiber separation • Favorable wear conditions
	B 174 - 4.8	• Same fiber characteristics as B 174 • Improved fiber transport due to tooth shape • Suitable for cotton with a small amount of honeydew
	S 21	• Suitable for polyester and polyacrylic • Also for poly/cotton blends
	S 43	• Suitable for polyacrylic • Gentle opening of the fiber beard and good separation of the fibers • No merry-go-round fibers

Fig. 73 – Tooth shapes of the opening roller clothing and their range of application

4.4.2. Range of application of the rotor

The rotor is the main spinning element of the rotor spinning machine. Yarn quality, yarn character, operating performance, productivity, etc., all depend chiefly on the rotor. The most important parameters of the rotor that exert influence are (see Fig. 74):

- the inclination of the rotor wall (a);
- the coefficient of friction between the fibers and the surface conditions of the rotor wall (b);
- the design and the positioning of the rotor groove (c);
- rotor groove diameter (d) and rotor speed.

On considering this broad range of influences, and taking account also of the weight of the influence exerted, it is readily apparent that there can be no such thing as a universal rotor. Out of the multiplicity of rotors on offer, the spinner has to select the one best suited to the raw material, yarn product, and spinning conditions. Rotors are replaceable elements in all rotor spinning machines.
The rotor, see Fig. 75, consists of rotor shaft (a) with wear protection in some cases, rotor cup (b) with rotor groove (C) and rotor wall (d). The wall inclination is necessary so that fibers emerging from the feed tube and passing to the wall can slide downward. Depending upon the material and area of use, the angle of the rotor wall to the vertical ranges between 12° and 50°. This angle is dependent upon the make but will in all cases be smaller, the higher the rotation speed for which the rotor is designed. At the internal periphery in the lower region of the rotor cup, there is usually a groove that varies in width. This groove serves to collect fibers.

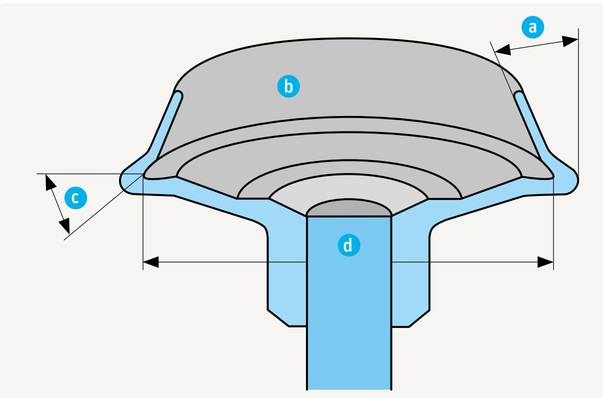


Fig. 74 – Important rotor parameters:
rotor wall (a), surface of the rotor wall (b), rotor groove (c) and groove diameter (d)

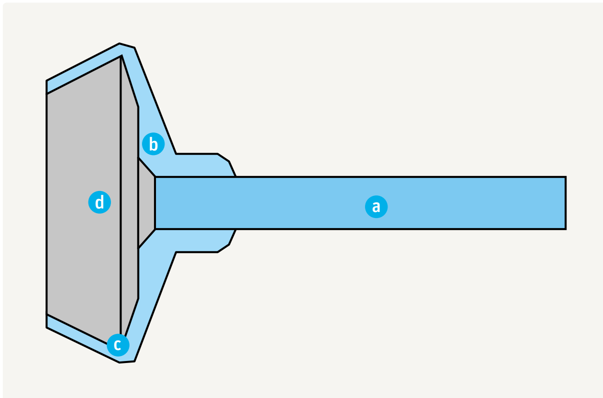


Fig. 75 – Structure and components of a spinning rotor:
rotor shaft (a), rotor groove (c), rotor cup (b) and rotor wall (d)

Rotors are made of steel and are in general surface-treated or coated to give them a longer useful life. The following means, which are customary and proven in mill practice, are available for protecting rotors against wear:

- diamond/nickel coating;
- boron treatment; or
- a combination of both processes.

The diamond coating usually consists of diamond dust embedded in a nickel layer and is the same as that used for protecting the opening rollers against wear. Boronized rotors and boronized rotors with an additional layer of diamond coating have twice the lifetime of a diamond-coated rotor. However, the surface structure of the rotor wall changes depending on the type of treatment (boron or diamond coating), and thus also its influence – which should not be underestimated – on both yarn quality and spinning stability and the tendency for deposits to form in the rotor groove. The best possible compromise between long service life of the rotor, good yarn values and stable spinning conditions is achieved with the combined boron/diamond coating. The rotor is a part subject to wear and must therefore be replaced periodically. Wear mainly affects the groove.

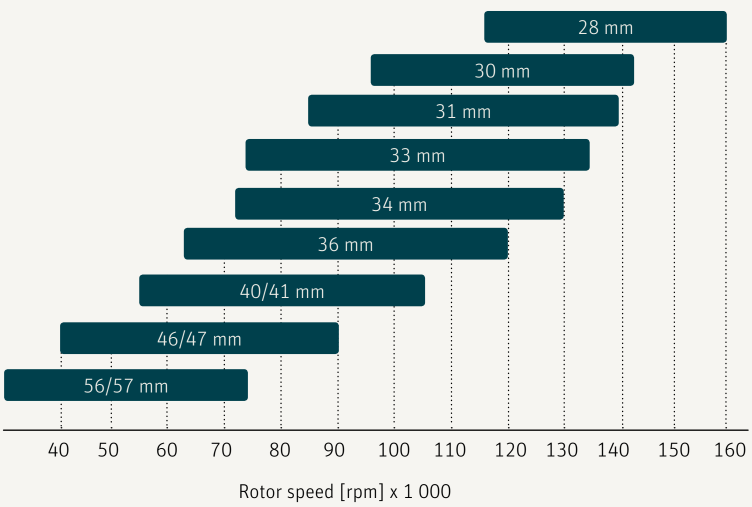
The configuration of the rotor groove determines whether the yarn is bulky or compact, hairy or lean, and whether the yarn quality is excellent or only adequate and the spinning stability low or high. The groove also affects the extent to which dust and dirt tend to accumulate in the rotor. Depending upon the raw material used, the desired yarn characteristics and yarn values, different groove designs are used in practice.

Wide grooves produce a soft, bulky yarn with rather low strength, while narrow grooves produce a compact, strong yarn with low hairiness. Wide grooves are therefore used in the production of yarns for knitted fabrics, homespun-type fabrics and coarse articles; narrow grooves are used for yarns required for the production of stronger fabrics with a smooth appearance. A fairly narrow groove is in most widespread use in classical short staple mills. The tendency to form moiré effects is also greater with the narrower groove, because fairly large dirt particles can jam in the groove.

A speed range in which the rotors in question produce optimum results, in terms of technology as well as spinning stability and energy consumption, is assigned to each rotor diameter. The speed ranges overlap between rotor diameters, with the energy consumption of the smaller rotor diameter being more favorable at the same rotor speed.

Fig. 76 shows the speed range and the highest possible rotor speed for the individual rotor diameters.

The smaller the rotor diameter, however, the higher the number of system-related wrapper fibers. The view generally held earlier and also valid at that time, that yarn twist must inevitably be increased when reducing the rotor diameter, is now no longer valid to the same extent. Optimized spinning elements, especially rotors and draw-off nozzles, as well as improvements in fiber guidance and spinning geometry mean that soft-twist knitting yarns can also be spun using small rotors (30 - 33 mm diameter). However, in these spinning operations spinning tension must not be too high, i.e. rotor speeds must be well below their maximum range.



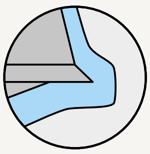
Diameter	–	**max. speed**
28 mm	–	160 000 rpm
30 mm	–	145 000 rpm
31 mm	–	140 000 rpm
33 mm	–	135 000 rpm
34 mm	–	130 000 rpm
36 mm	–	120 000 rpm
40 mm	–	105 000 rpm
46 mm	–	90 000 rpm
56 mm	–	75 000 rpm

Fig. 76 – Speed range and maximum rotor speed as a function of rotor diameter (in practice rotor speeds are used up to about 5 - 8 % below the maximum)

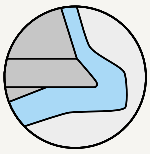
The rotor diameter should in any event be large enough to permit fiber formation in the groove without technological disadvantages. A certain amount of space is needed for the fiber mass, i.e., larger rotor diameters have to be used for coarser yarns and vice versa. A relationship – albeit not very close – also exists between fiber length and rotor diameter. As a rule of thumb, rotor diameter should not exceed 1.2 times staple length, otherwise fiber integration in the rotor groove is disturbed. In mill operations staple lengths of 38 or 40 mm are also spun successfully (albeit only in certain cases) on rotors in the 30 - 32 mm range.

Fig. 77 describes the configuration and the properties of the different rotor and groove shapes. In principle:

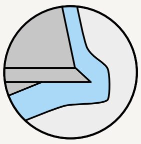
- Narrow groove angles and small groove radii (T and K rotors) are suitable for all raw materials and are used to manufacture smooth weaving yarns with good regularity and high yarn tenacity.
- Narrow groove angles with large groove radii (G rotors) are also suitable for all raw materials and are preferably used for bulky knitting yarns.
- Rotors with wide groove angles (U and DS rotors) are suitable for bulky knitting and denim yarns in cotton and its blends with man-made fibers. The different groove shapes and groove radii are chosen according to the type of denim yarn (weft or warp yarn, rope or beam dyeing, etc.).
- The TC rotor is outstandingly suitable for manufacturing high-quality denim yarns and at the same time is characterized by excellent running properties. Compared to the T rotor, groove angle and groove radius are larger, but the groove shape has been retained. Especially shifting-resistant yarns are produced when processing man-made fibers and viscose with the TC rotor.
- The GM rotor can be used very flexibly in the fine count cotton yarn sector, for both weaving and knitting. Compared to the G rotor, groove angle and groove radius are larger, but the groove shape has been retained.



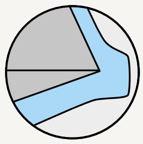
T-Rotor
• Universally applicable for all marerials
• Good yarn values
• For smooth weaving yarns



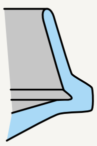
TC-Rotor
• For yarn counts coarser Ne 12
• Preferably for denim yarns
• Very good spinning stability
• Good resistance to fiber shifting



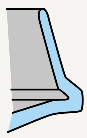
K-Rotor
• For smooth weaving yarns only
• For Cotton



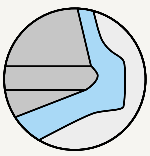
DS-Rotor
• For yarn counts coarser Ne 10
• Denim and knitting yarns
• For cotton and cotton blends



G-Rotor
• Universally applicable for all materials
• For bulky yarns
• Preferable for knitting



GM-Rotor
• Preferable for finer cotton yarns
• For weaving and knitting yarns



U-Rotor
• Yarn counts coarser Ne 10
• Denim and knitting yarns
• For cotton and cotton blends

TC-Rotor compared to T-Rotor:
• Groove shape remains the same, but
• wider groove and extended groove angel

GM-Rotor compared to G-Rotor:
• Groove remains the same, but
• improved yarn quality

Fig. 77 – Configuration and properties of available rotor/groove shapes

4.4.3. Range of application of draw-off nozzles and draw-off tubes

4.4.3.1. Draw-off nozzles

When it is removed from the rotor, the yarn is diverted virtually at right angles by the draw-off nozzle protruding into the rotor and guided out by the draw-off tube immediately following it. Meanwhile the yarn rolls continuously on the surface of the draw-off nozzle. During the rolling motion the yarn is repeatedly raised briefly in rapid succession from the nozzle surface – due to the design of the draw-off nozzle surface. This high-frequency vibration – together with the false-twist effect created by the unwinding motion – promotes twist propagation into the rotor groove. The greater the false-twist effect and the more intensive the creation of twist in the rotor groove, the lower the genuine yarn twist that can be selected and the bulkier and softer the yarns that can be spun. Spinning stability also improves with the increasing false-twist effect, of course.
In this context the positioning of the top edge of the nozzle relative to the rotor groove is also of some importance. Normally, the draw-off nozzle protrudes far enough into the rotor cup for ends extracted from the rotor groove to be diverted virtually at right angles at the draw-off nozzle. The position of the draw-off nozzle relative to the rotor groove can be changed by means of washers of differing thickness. The further the draw-off nozzle protrudes into the rotor, the larger the yarn‘s angle of wrap at take-off, the more false twist is created and the longer the binding zone in the rotor groove. In some cases this can help to increase yarn tenacity. If the washers are removed, the false twist effect is reduced, the binding zone becomes shorter and thus the positive impact on yarn tenacity is also reduced.

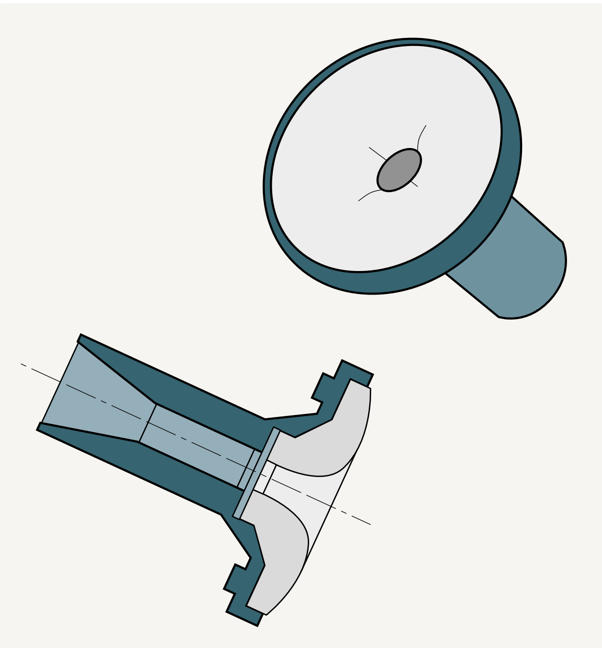


Fig. 78 – Draw-off nozzles with ceramic nozzle head and metal nozzle holder

Draw-off nozzles are made of either ceramics or steel. Draw-off nozzles usually consist of two parts, a wear-resistant ceramic nozzle head and a metal nozzle holder (Fig. 78). Ceramic or metal draw-off nozzles are also in use in which nozzle head and nozzle holder are produced in one piece. There are no technological differences, except that solid ceramic draw-off nozzles feature very low heat dissipation (ceramics are used as insulators in electrical installations) and can therefore hardly be considered for processing man-made fibers. By contrast, metal draw-off nozzles feature excellent heat dissipation, would therefore also be ideally suitable for processing man-made fibers, but due to short service lives are only used in certain cases for processing very temperature-sensitive man-made fibers, i.e. fibers with very low melt and softening point.

The use of appropriate types of ceramic and the combination of ceramic head and metal holder create conditions with regard to heat dissipation that enable most common man-made fibers and their blends to be processed successfully. The service life of ceramic nozzles can be several years, depending on raw material and material throughput, and they are the most long-lived spinning element compared with the service lives of opening rollers and rotors. Only the processing of cottons with a high mineral sand content and man-made fibers containing too much delustring agent (> 0.15 % TiO_2) can appreciably reduce the service life of a ceramic nozzle. If these restrictions are observed, the service life of a ceramic nozzle is between 10 000 hours (PES, CV, PAN) and 20 000 hours (CO), although in mill operations service lives of between 20 000 and 40 000 can certainly be achieved with these materials. Service lives with blends of cotton and man-made fibers are about in the middle of these ranges.

If the rotor groove makes a crucial contribution to yarn quality and bulk in technological terms, the structure and design of the nozzle surface exert a decisive influence on surface structure and hairiness.

Fig. 79 to Fig. 85 illustrate the different surface designs of draw-off nozzles (surface in contact with the yarn).

Fig. 79 – Smooth ceramic nozzle

Fig. 80 – Spiral nozzle

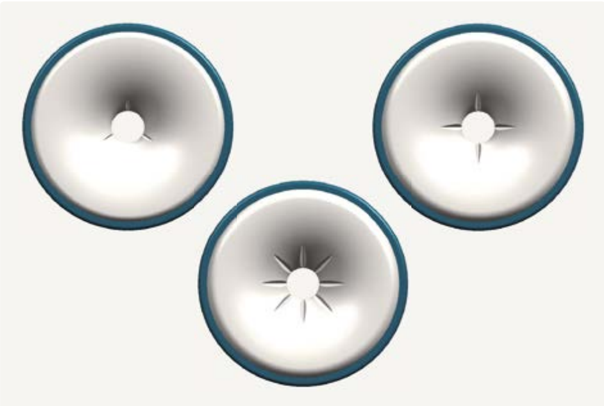


Fig. 81 – Ceramic nozzles with 3, 4 and 8 notches

Fig. 82 – Ceramic nozzle knurled with additional notches

Fig. 83 – Ceramic nozzle with small nozzle radius and 3 notches

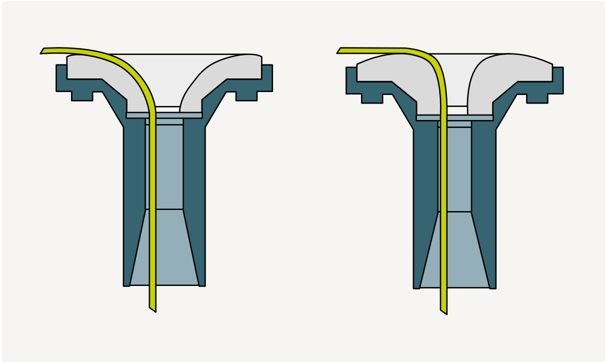


Fig. 84 – Ceramic draw-off nozzles with normal radius (left) and small radius (right)

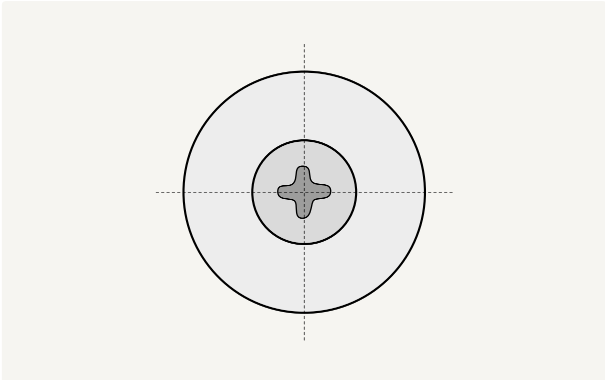


Fig. 85 – Eddy insert in nozzle throat (right)

Essentially, the following types of nozzle are used in manufacturing the wide range of rotor-spun yarns:

- Nozzles with a smooth surface (Fig. 79) are suitable for producing smooth warp yarns with low hairiness. This type of nozzle is rarely used, since very high yarn twist has to be imparted due to the low level of false twist created. Yarn values are not better than with other nozzle types in every case. The use of a TWISTstop draw-off tube (refer to section „4.4.3.2. Draw-off tubes with and without ceramic insert (TWISTstop)“) is recommended for stable running conditions.
- Nozzles with a spiral surface (Fig. 80) are ideally suitable for compact and fine warp yarns in 100 % cotton with low hairiness and good yarn values. High spinning stability.
- Nozzles with 3, 4, 6, 8 or more notches (Fig. 81) are universally applicable both for cotton and also for man-made fibers and their blends. The nozzle with 4 – mostly short – notches is the universal nozzle with the widest range of application: suitable for both warp and weft yarns (e.g. 4 notches) or knitting yarns (4 - 8 notches, depending on the required hairiness). Notched nozzles usually offer high spinning stability – the more notches, the higher the false-twist effect and the higher the spinning stability – but the higher also the yarn hairiness and the tendency to generate fly in downstream processing. Furthermore, the higher the number of notches, the more aggressive their effect and the greater their influence on yarn quality.
- Spiral or notched nozzle surfaces combined with an eddy insert in the nozzle throat (Fig. 85) are used solely – but very successfully – for very hairy, bulky and very soft-twist knitting yarns. The nozzles also offer very good spinning stability. However, yarn quality is not first priority with these nozzles!
- Externally knurled draw-off nozzles with additional notches in the nozzle radius (Fig. 82) and an eddy insert in the nozzle throat are recommended solely for manufacturing extremely hairy, very bulky, soft-twist yarns. „Yarn quality“ corresponds to the yarn structure.
- Nozzle surfaces with a small nozzle radius and 4 short notches (Fig. 83 and Fig. 84) feature a smaller contact surface compared with the standard nozzle radius and are therefore especially suitable for processing PES and its blends at speeds up to over 100 000 rpm. Rotor speeds are therefore up to 15 % higher than those for other draw-off nozzles.

4.4.3.2. Draw-off tubes with and without ceramic insert (TWISTstop)

The draw-off tube is positioned immediately behind the draw-off nozzle and is used to guide the yarn on its removal from the spinning box. In order to divert the yarn being withdrawn horizontally from the rotor to the take-up unit positioned vertically above it, the draw-off tube is bent at an angle of between 30° and 60°, depending on the type of spinning box. This diversion zone in the draw-off tube acts as a second twist accumulation element and supports the twist retention generated by the draw-off nozzle in the rotor. The greater the angle of the bend, i.e. the angle of wrap of this diversion zone, the greater the twist retention and the higher the spinning stability. This twist accumulation effect can be reinforced by fitting ceramic twist retention elements (TWISTstop or Torque stop – ceramic ribs arranged laterally) of differing intensity on the contact surface in the radius of the bend (Fig. 86).

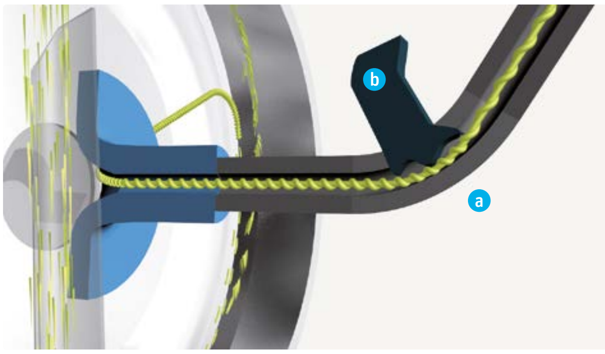


Fig. 86 – Thread draw-off tube (a) with interchangeable twist retention element (b)

The greater the angle of diversion and the higher the friction caused by the additional ceramic inserts, the greater the twist retention, the more intensive the twist propagation into the rotor groove and the higher the spinning stability. This favors the manufacture of especially soft-twisted knitting yarns, since the high twist retention enables low twist multiplyers to be set without adversely affecting spinning stability.

The twist accumulation elements are designed as clips and can be replaced very easily, as required. The design of the internal profile ranges from smooth to 3 lateral ribs in the radius of the bend.

The best spinning results as regards yarn quality, yarn structure and spinning stability are always achieved when the draw-off nozzle and draw-off tube are ideally coordinated with each other .

4.5. Components for manufacturing fancy yarns

Fancy yarns account for only a very small proportion of total yarn volume, but are repeatedly in considerable demand, depending on fashion trends. Yarn effects arise from selective, controlled changes in the yarn cross-section. As a rule, these involve slub-like thick places which can be varied in shape, length, increase in cross-section, sequence and the frequency of their occurrence. The standard drives for the feed and take-off cylinders are replaced by special, processor-controlled drives in order to enable fancy yarns to be produced on the rotor spinning machine.

The thick places produced with these fancy yarn devices (see Fig. 87 and Fig. 88) can, however, due to the back-doubling in the rotor and in contrast to ring-spun yarns, never be shorter than the rotor circumference! This limitation is unimportant for most types of effect. Specially developed spinning elements (opening rollers, draw-off nozzles) are used on the rotor spinning machine where shorter effects are essential, for example to imitate the short variations in cross-section typical of ring-spun yarns (refer to section „4.9.2. Fabrics made from rotor-spun yarns“.
One method that is rarely employed because the extent of the effect is very limited is to vary selectively the cross-section of the draw frame slivers. The high drafts on the rotor spinning machine enable only very long changes in cross-section to be produced in the yarn in this way.

4.6. Selection and influence of draft and yarn twist

The structure of a yarn is defined by
a) its count in Nm or Ne (weight per unit length) or in tex (length per unit weight) and
b) the amount of twist imparted to the yarn in T/m or T/″.

4.6.1. Draft

A yarn‘s count is the product of the degree of draft applied to a carded or draw frame sliver. This draft occurs on the rotor spinning machine between the feed roller (for sliver intake) and the delivery roller (for the yarn), and results from the speed ratio of the two drives. The draft can therefore be changed by altering either the sliver intake speed or the yarn take-off speed. However, since the take-off speed, i.e. delivery speed, is directly responsible for imparting twist to the yarn, and therefore must not be changed, the degree of draft can therefore only be changed by adjusting the sliver intake speed. The drafts used in mill practice are between 60 and 400-fold. Initially, however, much higher drafting occurs between the sliver feed and the fiber collecting groove, i.e. opening of the sliver down to the individual fibers. This corresponds to a maximum draft of up to 25 000-fold. The final yarn count is only formed from the individual fibers, i.e. fiber layers, in the collecting groove of the rotor. Only this ratio – yarn count to sliver count – corresponds to the degree of draft set at the machine control unit.

Rotor-spun denim yarn

Rotor denim yarn in ring-spun look

Fig. 87 – Fabric woven from rotor-spun denim yarn

Yarn effects

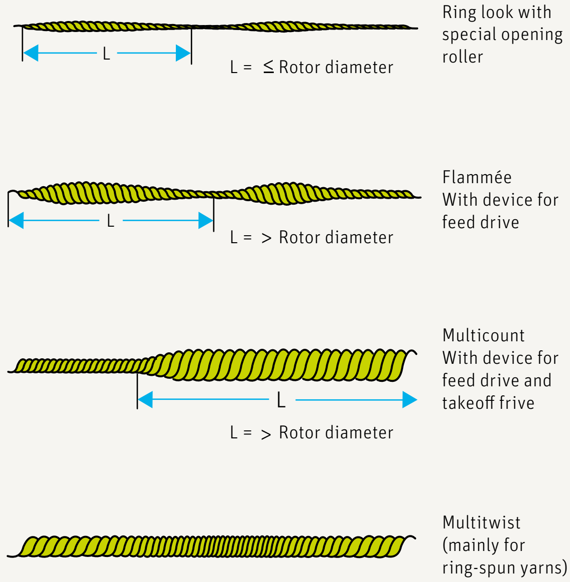


Fig. 88 – Yarn effects in rotor-spun and ring-spun yarns

The degree of draft is calculated as follows:

$$draft = \frac{Nm_{yarn}}{Nm_{sliver}} = \frac{Ne_{yarn}}{Ne_{sliver}} = \frac{100}{(tex_{yarn} / ktex_{sliver})}$$

or, transferred to the machine:

$$draft = \frac{V_{yarn\ delivery\ m/min}}{V_{sliver\ intake\ m/min}}$$

Yarn and sliver count are thus calculated as follows:

$Nm_{yarn} = Nm_{sliver} \ x\ draft$
$Ne_{yarn} = Ne_{sliver} \ x\ draft;$
$tex_{yarn} = 1\,000 \ x \ \frac{ktex_{sliver}}{draft}$

or
$Nm_{sliver} = Nm_{yarn}/draft$
$Ne_{sliver} = Ne_{yarn}/draft;$
$ktex_{sliver} = \frac{tex_{yarn} \ x\ draft}{1\,000}$

Drafts on the rotor spinning machine are much higher than in ring spinning, and also higher than in Air-jet spinning, although spinning is also performed directly from a feed sliver in this latter spinning process. However, considerably finer slivers (1 - max. 3 ktex) must be fed to the Air-jet spinning machine than to the rotor spinning machine, although fine slivers entail production drawbacks on the card and draw frame! The drafting range of up to 400-fold on the rotor spinning machine enables normal draw frame slivers in the range between 5 and 6 ktex (Ne 0.12 to 0.10) to be fed in, even when producing very fine rotor-spun yarns (see Fig. 89).

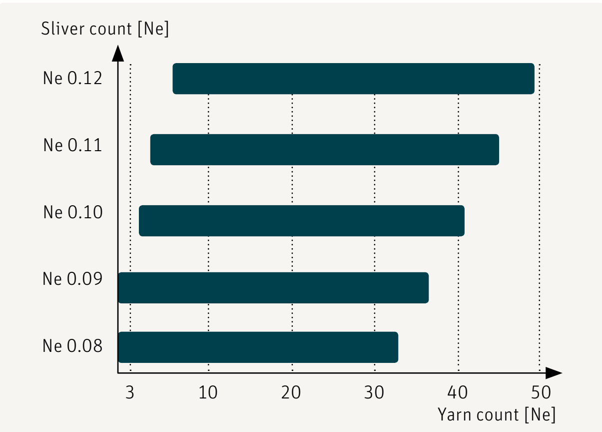


Fig. 89 – Maximum flexibility with drafts of up to 400-fold

The results of mill trials have shown – by no means surprisingly – that high drafts, especially when processing cotton, have a positive impact on both yarn quality and spinning stability. The reason for this is that sliver intake speed is very low at high drafts, and the individual fibers therefore spend longer in the opening roller zone before being released from the fiber bundle that has been fed in. Fiber neps are opened more thoroughly, while dust and trash are more effectively released and removed from the fibers.

4.6.2. Yarn twist and twist multiplyer

In contrast to ring spinning, twisting during rotor spinning takes place from the inside outwards. The rotating, brush-like open yarn end first catches fibers in the core and then with further rotation gradually takes up fibers toward the periphery. In the interior, where the fibers cannot avoid the twist, the fibers become more compact. On the other hand, toward the exterior, the compactness falls off to an increasing degree, since here the fibers are able partially to avoid being twisted in. In addition to the fiber-specific properties (fiber strength, elongation, length, friction, etc.), yarn tenacity depends primarily on how often the yarn has been rotated around its axis. In this process the angle of inclination of the fibers being twisted in plays a crucial role for the degree of tenacity (see Fig. 90). This means that twice as many twists have to be imparted to a fine count yarn in order to achieve the same angle of inclination and thus the same level of tenacity as in a yarn twice as thick. The absolute number of yarn twists therefore gives an indication of the degree of tenacity only if this is related to yarn count. However, twist multiplyer α/m or α/e can be used to describe the degree of twist in a yarn, regardless of yarn count. The higher the twist multiplyer, the higher the degree of twist and the higher the yarn tenacity, and vice versa. For detailed explanations of yarn twist, refer to the volume entitled: The Rieter Manual of Spinning, Volume 1 – The Technology of Short-staple Spinning", section „7.3.2.4. Twist formulas".

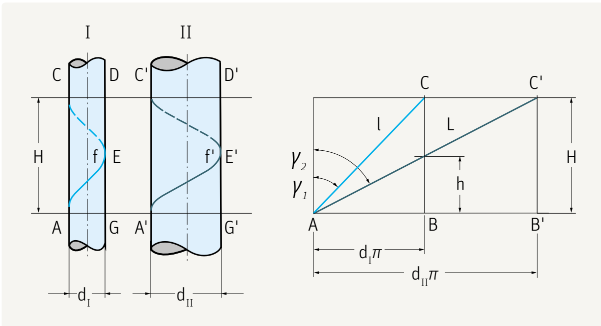


Fig. 90 – Angle of inclination of fibers in two yarns of differing thickness

However, the required twist multiplyer α/m or α/e for maximum tenacity of a given yarn varies widely with the raw material being processed. Depending on the type of fiber and its key physical characteristics

an average twist multiplyer is enough to reach a certain tenacity in one case, in other cases a higher twist mutiplyer must be selected. This means that higher twist multiplyers must be selected for cotton yarns (fiber strength 20 - 30 cN/tex) than for blended yarns (fiber strength mix of 30 - 40 cN/tex) and for these in turn higher twist multiplyers than for viscose, polyester or polyacrylic yarns with fiber strengths of 40 - 60 cN/tex. NB: overtwisting yarns reduces yarn tenacity!
Furthermore, the twist multiplyers for warp and weft yarns (in all raw materials) are generally higher than those for knitting yarns, since yarn bulk, yarn hairiness and a soft hand take priority for knitting yarns rather than the highest possible yarn tenacity, such as is required for yarns processed in weaving preparation and weaving.

Higher twist multiplyers are used,
- to increase yarn tenacity and yarn elongation;
- to produce lean yarns with low hairiness;
- to improve spinning stability;
- to obtain a clean-cut fabric appearance; and
- to improve the shifting resistance of the yarns.

Lower twist multiplyers are selected, presupposing adequate yarn tenacity,
- to achieve a soft hand in the final fabric;
- to produce bulky and more hairy yarns;
- to reduce a yarn‘s tendency to snarl; and
- increase output with the same rotor speed.

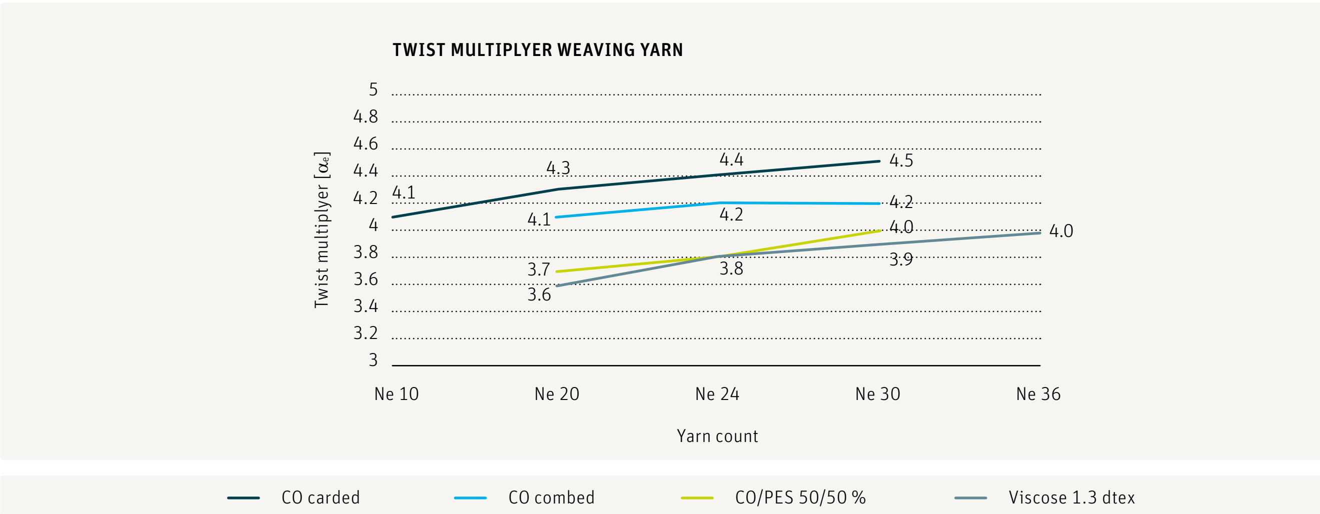


Fig. 91 – Twist multiplyers customary in mill practice for rotor-spun weaving yarns

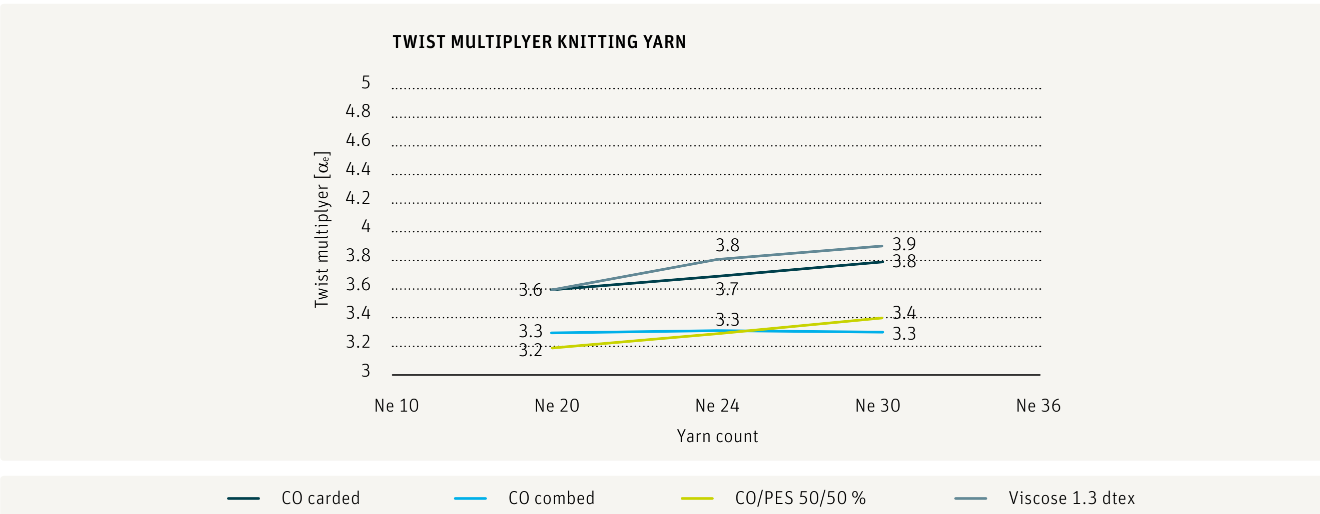


Fig. 92 – Twist multiplyers customary in mill practice for rotor-spun knitting yarns

The twist multiplyers for weaving and knitting yarns naturally differ, as do the twist multiplyers for yarns made from different raw materials (see twist multiplyers customary in mill practice for weaving yarns in Fig. 91 and for knitting yarns in Fig. 92).

Calculation of yarn twist:
yarn twist T/m $= \sqrt{Nm} \times \alpha/m = \sqrt{Ne} \times \alpha/e \times 39.37^*$
yarn twist T/″ $= \sqrt{Ne} \times \alpha/e = \sqrt{Nm} \times \alpha/m / 39.37^*$
* conversion factor dtex/Macronaire

The number of turns inserted in a yarn depends on how long a given length of yarn spends in the rotor. If a yarn is withdrawn from the rotor more rapidly at a given rotor speed, fewer turns can be inserted (by the rotating rotor) in the yarn per unit of time than at a lower take-off speed when the yarn therefore spends more time in the rotor groove:

$$\text{number of yarn turns per m (T/m)} = \frac{\text{rotor speed rpm}}{\text{delivery m/min}}$$

The specified number of turns for a given yarn is thus inserted, at a given rotor speed, by adjusting the delivery speed. The feed rollers are driven by infinitely adjustable inverters.

4.7. Yarn and machine data for the main rotor-spun yarns

The main yarn and machine data for different rotor yarns, subdivided by yarn count and raw material used, are summarized in Table 13 - Table 16. A distinction is made here between spinning operations aimed at maximum output and those where yarn quality or a specific yarn characteristic, e.g. especially soft hand of the yarn, is the main priority. The list represents typical yarns produced in substantial quantities. Nevertheless, the yarn and machine data shown can only serve as standard values, since the quality of raw material used plays a decisive role in specifying the spinning data, as do the requirements of the end products, the spinning climate and ultimately even the technical condition of the entire machinery portfolio of a spinning mill, depending on maintenance and service.

Weaving yarns in 100 % cotton										
Yarn count	Ne 5.6	Ne 7	Ne 12	Ne 16	Ne 20[1]	Ne 24[1]	Ne 30[1]	Ne 20[2]	Ne 24[2]	Ne 30[2]
α_e	4.1	4.3	4.1	4.2	4.3	4.4	4.5	4.3	4.4	4.5
T/m	382	448	559	662	757	849	971	757	849	971
Rotor ∅ mm	40	40	36	36	28	28	28	31	31	31
Rotor rpm	80 000	90 000	105	105 000	140 000	145 000	150 000	125 000	130 000	130 000
Delivery m/min	210	201	188	159	185	171	155	165	153	134
Efficiency %	95	95	96	96.5	97	97	97.5	97.5	97.5	98
Production g/h	1 295	967	532	339	318	245	178	285	221	155

Table 13 – Spinning data for weaving yarns in 100 % cotton: [1]Priority: output, [2]Priority: yarn quality

Knitting yarns in 100 % cotton						
Yarn count	Ne 20[1]	Ne 24[1]	Ne 30[1]	Ne 20[2]	Ne 24[2]	Ne 30[2]
α_e	3.6	3.7	3.8	3.6	3.7	3.8
T/m	634	714	820	634	714	820
Rotor ∅ mm	31	31	31	33	33	33
Rotor rpm	125 000	125 000	125 000	120 000	120 000	120 000
Delivery m/min	197	175	153	189	168	146
Efficiency %	96.5	96.5	96.5	97	97	97
Production g/h	337	250	174	325	241	168

Table 14 – Spinning data for knitting yarns in 100 % cotton: [1]Priority: output, [2]Priority: yarn quality

Weaving and knitting yarns in cotton / PES 50 % / 50 %						
Yarn count	Ne 20[1]	Ne 24[1]	Ne 30[1]	Ne 20[2]	Ne 24[2]	Ne 30[2]
α_e	3.7	3.8	4.0	3.2	3.3	3.4
T/m	652	733	863	564	637	734
Rotor ∅ mm	31	31	31	31	31	31
Rotor rpm	115 000	115 000	115 000	115 000	115 000	115 000
Delivery m/min	176	157	133	204	181	157
Efficiency %	97	97.5	98	96.5	97	97
Production g/h	303	226	154	349	259	180

Table 15 – Spinning data for 50 % / 50 % cotton/PES blended yarns: [1]Weaving yarns, [2]Knitting yarns

Weaving and knitting yarns in 100 % viscose 1.3 dtex								
Yarn count	Ne 20[1]	Ne 24[1]	Ne 30[1]	Ne 36[1]	Ne 20[2]	Ne 24[2]	Ne 30[2]	Ne 36[2]
α/e	3.6	3.8	3.9	4.0	3.6	3.8	3.9	4.0
T/m	634	733	841	945	634	733	841	945
Rotor ∅ mm	30	28	28	28	31	30	28	28
Rotor rpm	125 000	135 000	135 000	135 000	120 000	125 000	130 000	130 000
Delivery m/min	197	184	160	143	189	171	155	138
Efficiency %	97	97.5	97.5	98	97	97.5	97.5	98
Production g/h	339	265	185	138	325	246	178	133

Table 16 – Spinning data for knitting yarns in 100 % viscose 1.3 dtex: [1]Weaving yarns, [2]Knitting yarns

4.8. Ambient conditions in the spinning mill

The rotor spinning system imposes no special conditions and requirements on its environment; i.e. the customary ambient conditions in a spinning mill as regards temperature, humidity and air conditioning are always adequate for rotor spinning, and in many cases are even less critical than for ring spinning. Only relative humidity levels are slightly higher than for ring spinning.

Raw materials behave differently not only as regards their readiness to absorb moisture, their running properties are also affected by humidity levels in the spinning mill. Since the raw material spends several days in the spinning mill on its way through the spinning process, the moisture content of the fibers depends on the moisture content of the ambient air. Absolute moisture content in g/kg air therefore plays a crucial role in a favorable spinning climate. This moisture content is created by a combination of air temperature (°C or °F) and relative humidity (RH%). Table 17 shows the required absolute moisture content in g/kg air for a favorable spinning climate.

Raw material	g water/1 kg air
cotton, viscose and cotton/viscose	approx. 11
cotton containing honeydew	approx. 9
polyester, polyester/cotton, polyester/viscose	approx. 10 - 11
polyacrylic	approx. 11 - 12

Table 17 – Absolute moisture content in g/kg air for processing different raw materials

The more precisely the standard climate, i.e. relative humidity, is maintained within limits, the more trouble-free spinning operations are. While cotton and viscose react somewhat less problematically to changes in the ambient climate, changes soon become obviously apparent when man-made fibers are being processed.

If relative humidity is too low, this usually becomes apparent with man-made fibers in electrostatic charging and a consequent increase in ends down. When cotton is being processed, fiber damage, fiber fly and deposits in the spinning box and winding zones occur.

If relative humidity is too high, this results in lapping on cylinders and opening rollers with all fibers. The spin finish on man-made fibers tends to leave deposits on thread guide elements and in the fiber guide channel, thus obstructing fiber transport to the rotor. This then results in an increase in the number of neps and thick places.

4.9. Downstream processing and end products

4.9.1. Processing properties

First of all and quite crucially – and a significant point in favor of the economics of rotor spinning – a rewinding process can be dispensed with entirely for rotor-spun yarn. In contrast to the initial generations of machines, the rotor spinning machine delivers cylindrical or conical packages ready for sale, which can immediately be processed further. Modern quality monitoring systems enable yarn defects, extraneous matter or deviations from quality parameters to be detected and eliminated directly at the spinning position. Yarns for knitting are waxed directly at the spinning position and supplied in different package formats (cylindrical, 2°, 3°51′ and 4°20′). Dyeing packages with appropriately reduced package density also at the outer edges permit direct processing in high-pressure dyeing equipment (refer to section „2.4.3. Winding helix and delivery speed“).

Every rewinding process with guides, yarn tensioners, etc. on the winder results in neppy fiber shifting, however small, in ring-spun yarn. Since this can contribute to a more unsettled fabric appearance, dispensing with subsequent rewinding is certainly also a qualitative advantage for rotor-spun yarn.
The running properties of rotor-spun yarns in downstream processing are usually better than comparable conventional ring-spun yarns. The number of yarn-induced ends down in weaving preparation (beamer, sizing machine) are as much as 75 % lower than with ring-spun yarns. The reasons for this are the greater regularity of rotor-spun yarns, the smaller number of imperfections and their lower hairiness, as well as the significantly longer lengths of knot-free yarn. Not only the much smaller number of yarn joins, but also the quality of the piecings precisely produced by the operating robots on the rotor spinning machine make a major contribution to the good processability of rotor-spun yarns. Piecings in rotor-spun yarns are virtually identical to the original yarn in appearance but display about 90 % of its tenacity. Piecings produced by operating robots are the cause of stoppages in downstream processing only in exceptional cases. Added to this are the advantages of package weights of up to 6 kg, which enable up to 4 warp beams to be produced from one full warping creel, for example.

Fiber fly on and between the operating units of weaving and knitting machines is frequently the cause of ends down in downstream processing and of defects in the fabric structure (if accumulated fiber fly has not already caused an end down). A typical defect on circular knitting machines are holes in the fabric caused by fiber fly. The fiber fly carried along by the yarn prevents the formation of the loop on the

needle. Rotor-spun yarns produce much less fiber fly and thus have a very favorable influence on running properties in downstream processing. Yarn-induced ends down are up to 50 % lower in weaving and up to 40 % lower in circular knitting than for comparable ring-spun yarns.
The conical package formats required for circular knitting machines with overhead creels are supplied by rotor spinning machines with package tapers of 2° to 4°20'. Wider tapers are now only required for older knitting machines with overhead creels and no yarn storage devices (although they are not always absolutely necessary!), and are not produced on rotor spinning machines. However, these circular knitting machines are steadily disappearing from the market.

On the other hand, increasing numbers of circular knitting machines with lateral creels are coming into use, with the economic advantage that cylindrical packages up to 340 mm in diameter weighing some 5 kg can be accommodated on these creels instead of conical packages. The running time of these packages is almost twice that of conical packages with a maximum diameter of approx. 270 - 280 mm and a maximum package weight of approx. 2.5 to 3 kg. Not only is operator effort in creeling and joining the packages reduced by up to 40 %, the number of knots joining two packages is reduced proportionally on the same scale, and thus also the number of knots in the knitted fabric.

Table 18 rates the properties of rotor-spun yarn compared to ring-spun yarn in downstream processing, with the rating (lower, higher, etc.) relating to rotor-spun yarn.

Rotor-spun yarn compared to ring-spun yarn		
shifting resistance	lower	-
coefficient of friction (important for knitting yarns)	higher	-
abrasion resistance	better	+
hairiness	lower	+/-[1]
tendency to snarl	lower	+
work capacity under cyclical loading	higher	+
dye take-up	higher (less dye required)	+
fiber abrasion (fly generation)	lower	+

[1] Positive or negative depending on process stage
Table 18 – Properties of rotor-spun yarn compared to ring-spun yarn in downstream processing

4.9.2. Fabrics made from rotor-spun yarn

Since the introduction of this spinning system, rotor spun-yarns have become firmly established in certain ranges of application, for both woven and knitted fabrics. In many cases processing rotor-spun yarns into end products has even offered advantages over ring-spun yarns, resulting in higher-quality end products. For example, ring-spun ply yarns have been successfully replaced by single rotor-spun yarns. Early reservations regarding the use of rotor-spun yarns due to their yarn structure and the fact that the hand of the finished article was initially considered too stiff and harsh for knitted fabrics have been dispelled. However, it became apparent in mill operations that ring-spun yarns could not simply be replaced by rotor-spun yarns on weaving or knitting machines. It was very soon discovered that machine settings, such as air injection on the Air-jet weaving machine or sinking depth on the circular knitting machine, had to be adjusted to the properties specific to rotor-spun yarns (hairiness, yarn structure, tendency to snarl, etc.). Some of the prejudices against the processability and suitability of rotor-spun yarns in end products date back to the time before all yarn processors had adjusted their machine settings to the new type of yarn.

However, rotor-spun yarns were, of course, used successfully first of all where the specific properties of rotor-spun yarns corresponded particularly well to the requirements of the end products. This was the case in a surprisingly wide range of end products:

- workwear, such as smocks, overalls and hospital attire;
- denim fabrics in both light (shirts, blouses) and heavy weights (jeans, coats);
- rough-surface fabrics for outerwear (flannels) and sheets (so-called beaver sheets);
- in the coarse count yarn sector (blankets, curtains, textile wall coverings, home textiles);
- in the fine count yarn sector (sheets made from blended yarns);
- technical fabrics, e.g. coating substrates, laminates for facial protection;
- hand towels. bath towels, etc, rotor-spun yarns in both warp and weft, as well as pile, preferably loop fabric;
- knits for outerwear, sportswear and leisurewear;
- T-shirts made from single jersey (dominated by rotor-spun yarns).

Despite the approx. 15 - 20 % lower yarn tenacity of rotor-spun yarns, the difference is reduced in fabric strength. The strip tensile strength and tear propagation strength of fabrics made from rotor-spun yarn is only 10 - 15 % less than that of comparable ring-spun yarns. This is attributable to rotor-spun yarns' gain in work capacity due to their better elongation at break and smaller variations in breaking strength (CV% cN / tex). The air permeability of comparable fabrics is some 20 % greater with rotor-spun yarns, bursting pressure about the same as for fabrics made from ring-spun yarn. All these statements refer to the yarn count range covered by the rotor spinning system of tex 200 - 10 / Ne 3 - 60 / Nm 5 - 100 and a minimum number of 90 - 100 fibers in the case of man-made fibers and 100 - 120 for cotton. The use of rotor-spun yarns is still limited where especially high fabric strength is required, for example for men‘s shirting fabrics.

4.9.2.1. Bed sheetings

However, in the weaving mill rotor-spun yarns are used preferably as weft yarns, but also have a wide range of applications as warp yarns. A typical example are the bed sheetings produced in large quantities in the USA. Cotton/polyester rotor-spun yarns are usually used in the warp and, for example, an Air-jet yarn in the weft. These are very fine rotor-spun yarns in the Ne 37 - 41/Nm 62 - 70/tex 16 - 14 range, with low hairiness and high demands on serviceability, especially in terms of fabric strength, pilling and wear behavior.

4.9.2.2. Emery cloth backing

In technical textiles rotor-spun yarns are used preferably for emery cloth backing and generally for coating substrates. Especially high standards of yarn regularity, yarn purity and yarn tenacity are imposed on these fabrics. Rotor-spun yarns are predestined for use in these fabrics by virtue of their small mass variations. The fact that rotor-spun yarns are knot-free is especially advantageous. Knots are disturbing defects in these fabrics. The required high tenacity of 18 - 20 cN/tex is achieved by using polyester fibers instead of cotton.

4.9.2.3. Denim fabrics

Another range of application dominated by rotor-spun yarns are denim fabrics, usually in 3/1 or 2/1 twill weave. Rotor-spun yarns are used both in the warp and in the weft. Depending on fashion trends, the rotor-spun yarn content can be up to 70 % of the total yarn volume, although the proportion of ring-spun yarns can increase to meet fashion requirements. The incredible variety of denim fabrics, differing in terms of raw material, color, final treatment, fabric weight and a host of other parameters, can be divided into two main groups. On the one hand there is the so-called „authentic look“, where „irregular“ and rustic yarn characteristics are called for primarily in the warp yarn. Ring-spun yarns are outstandingly suitable for this type of fabric and also contribute to the soft hand of the finished product. Rotor-spun yarns are too regular for this type of fabric. Special spinning elements or fancy yarn devices have to be used in order to reproduce the more irregular character of ring-spun yarns and simulate this type of yarn (refer to section „4.5. Components for manufacturing fancy yarns”). The second main group consists of yarns that have to be very regular in order to produce a clearly defined fabric structure in warp and weft. Denim yarns are clearly dominant in this type of fabric due to their outstanding regularity and the significantly lower level of imperfections. Ring-spun yarns have virtually disappeared from this application.

Rotor-spun yarns are used in both warp and weft as well as in combination with ring-spun yarns – in this case mostly as weft yarns. The demands imposed on warp and weft yarns are very different. Weft yarns are usually coarser than the warp yarns (Ne 5 - 7), have medium hairiness and are spun with medium to high twist multiplyers in order to withstand the high loads of the weft insertion systems on modern high-performance automatic weaving machines. For the finer warp yarns (Ne 8 - 12), which are always dyed, there are two dyeing methods, with which the yarn characteristics must be coordinated. Beam-dyed yarns (the ends are guided through the dye bath parallel with each other) display low to medium hairiness and are spun with medium twist multiplyers in order to prevent an excessively high tendency to snarl in the yarns. By contrast, rope-dyed yarns may only display a very low tendency to snarl in order not to obstruct the opening of the dyed rope and rebeaming. Yarns for this application must therefore display high hairiness (hairs act as spacers between the ends) and be spun with the lowest possible twist multiplyers (yarn tenacity must not fall below a certain minimum in the process).

4.9.2.4. Flannel fabrics / beaver sheets

Among other things, rotor-spun yarns are also used for fabrics that are subsequently napped slightly. These are both fabrics for men‘s and ladies‘ outerwear, so-called flannel fabrics, and also roughened sheets (beaver sheets). Both of these used to be typical products of carded wool spinning, a spinning system that has almost entirely disappeared and been replaced almost completely by rotor spinning. Many of the products mentioned are produced from regenerated fibers, a very low-cost raw material that can be spun superbly on rotor spinning machines, but not on ring spinning machines. Very high-quality and high-priced end products, especially in the flannel sector, can be manufactured from these very inexpensively produced fabrics.

4.9.2.5. Terry fabrics

Terry fabrics, such as hand and bath towels, bathrobes, bathmats, etc., can also be mentioned in this context. In this case a pile thread in loop form is woven into a normal backing fabric. The pile thread accounts for most of the moisture absorption during drying. This pile thread must be soft-twisted and display rather higher yarn hairiness and high yarn bulk in order to ensure good moisture absorption. Pile yarns are therefore spun with spinning elements similar to those used for knitting yarns. However, rotor-spun yarns are not ideally suitable for fabrics in which the loops are subsequently clipped (pile goods), since the wrapping fibers restrict the yarn where it is clipped and prevent the formation of a uniform, dense pile.

4.9.2.6. Knitted fabrics / T-Shirts

In the knitting sector – for which rotor-spun yarns initially seemed out of the question due to their harsh hand – they have been able to establish themselves on a broad basis, despite all doubts. Some minor differences in hand still certainly exist, but these can virtually be offset by appropriate finishing. Furthermore, there are sufficient knitted fabrics for which the hand is an important, but not the crucial criterion. This range of application is successfully served by soft-twisted, hairy and bulky rotor-spun yarns.
These include, for example, T-shirts made from single jersey, where rotor-spun yarns have secured significant market share. Differences in yarn regularity and imperfections are immediately and very clearly apparent in single jersey. With their superior regularity and significantly fewer imperfections, rotor-spun yarns are therefore positively predestined for this application. Very uniform fabric appearance with high and good pile density due to the bulky nature of the yarn upgrades the knitted fabric through the use of rotor-spun yarns. Soft hand and high hairiness (if required or necessary) can reliably be achieved by appropriate spinning equipment (draw-off nozzles with a large number of notches and eddy inserts in the nozzle throat). Modern finishing methods also enable yarn properties to be significantly improved further, especially as regards the softness and suppleness of the knitted fabric. A further advantage of circular knitted fabrics made from rotor-spun yarns which should not be underestimated is that the knitted tubes do not twist as they do with ring-spun yarns. Making-up knitted tubes made from rotor-spun yarns is therefore much more problem-free than is the case with ring-spun yarns.

4.9.2.7. Sportswear / leisurewear

Rotor-spun yarns are also to be found in a wide range of sportswear and leisurewear, for example in sweat-shirts, sports socks, casual jackets, etc.; rotor-spun yarns are especially highly regarded as inside lining yarns for these items due to their bulk. By contrast, the use of rotor-spun yarns in plain knitting and warp knitting is restricted to a very small range of end products.

Rotor-spun yarn compared to ring-spun yarn		
fabric strength	rather lower	-
pile density	higher	+
abrasion resistance	higher	+
flexing resistance	higher	+
air permeability	higher	+/-[1]
fabric hand (untreated fabric)	harder	-
fabric hand (finished)	virtually identical	≈
moisture absorption	higher	+
fabric shrinkage	tends to be lower	+
surface	more regular	+
pilling tendency	lower	+
luster	duller	-
hairiness	lower	+/-[1]

[1] Positive or negative, depending on end product

Table 19 – Properties of rotor-spun yarn compared to ring-spun yarns in the final fabric

The properties of rotor-spun yarn compared to ring-spun yarn in the final fabric are rated in Table 19, with the rating (lower, higher, etc.) referring to the rotor-spun yarn.

4.9.3. Finishing

Just as in yarn processing, certain properties specific to the yarn have to be taken into account when processing fabrics made from rotor-spun yarn. However, the methods do not differ in principle from those used for items made from ring-spun yarn.

Appropriate finishing processes developed specifically for end products made from rotor-spun yarns, in addition to improvements in spinning technology, have enabled the fabric hand to be decisively influenced. Differences in hand relative to products made from ring-spun yarn, which can still unmistakably be identified in the untreated knitted fabric by specialists, only remain in traces in the finished material.

One aspect must be kept in mind in high-grade finishing of fabrics made from rotor-spun yarn. Some of these processes (e.g. non-iron finish, stone-washed denim) result in reduced fabric strength. Together with the 10 - 15 % reduction in raw fabric strength, this can result in values that no longer fulfill make-up or finished product requirements. This reduction must therefore already be taken into account when selecting the raw material and producing the yarn in such a way that yarns are spun with appropriately high strength.

As a result of the restricting influence of the wrapping fibers, napping fabrics made from rotor-spun yarns may call for 1 - 2 napping passages more than comparable fabrics made from ring-spun yarn in order to obtain a comparable napping effect.

Final dyeing results with rotor-spun yarns tend to be darker; in certain cases dyestuff savings can therefore be achieved. However, dyeing brilliancy is generally lower; the fabrics have a duller appearance – due to the yarn structure.

The size take-up of fabrics made from rotor-spun yarns is better than for ring-spun yarns; size concentration can therefore be set up to 15 - 25 % lower. This also means that size consumption is lower with the same sizing effect.

5. TECHNOLOGY

5.1. Yarn formation

5.1.1. Fiber flow to the rotor

At the start of the development of rotor spinning, the fibers were mistakenly guided directly into the fiber collecting groove. The disadvantage of this was that the fibers inevitably collided with the radial yarn end during the acceleration that had to occur. This led to deterioration in fiber orientation. Yarn produced in this way had the typical „sauerkraut" structure, with very low strength.
In current rotor spinning machines, the fibers flowing into the rotor are headed for the top of the rotor wall, above the groove. It is important that the rotor wall has a higher peripheral speed than the fibers colliding with it. Thus a drafting effect is taking place, which ensures that the fibers are straightened and aligned. The necessity to operate with a draft at this point places a lower limit on the rotation speed of the rotor, which is therefore limited not only upward but also downward.

The air flows are also very important in this zone. There should be no air turbulence between the fiber channel and the rotor wall. The aim is to generate a uniform, rotating air current that helps to forward the fibers onto the rotor wall in a straight condition. This depends, among other things, on the distance between the exit of the fiber channel and the wall and the shape of the rotor channel insert that contains the fiber channel. Accordingly, all manufacturers use replaceable channel inserts matched to the diameter of the rotor, which is also replaceable. The amount of air – which is necessary for the fiber flow – is extracted by the main fan through the gap between channel insert and rotor cup.

An incoming fiber strikes an inclined wall and is pressed outward by an enormous centrifugal force – over 100 000 times the weight of the fiber. This causes the fiber to slide downward on the rotor wall while being accelerated in the peripheral direction and to be deposited on the other fibers in the collecting groove.
Due to the fact that the fibers are continuously accelerated from the moment they are released from the sliver by the opening roller until they are deposited in the rotor groove, they are well extended longitudinally, also compared to other OE processes. This extension is also maintained in the finished yarn due to the high centrifugal force with which the fibers are then pressed into the rotor groove. Only in the outer layers of yarn are the fibers of rotor-spun yarn (core twist) less accurately aligned than in ring-spun yarn (surface twist, refer to section „5.4. Yarn structure and physical textile characteristics").

5.1.2. Fiber collection in the rotor groove (back-doubling)

The process of yarn formation in rotor spinning involves the separation by an opening roller of a fiber bundle fed in into individual fibers or small groups of fibers (no more than 5 fibers), which are then transported by the air current into the rotor, where they slide down the rotor wall. They are only combined again into fine layers of fibers in the rotor groove. A layer of these individual fibers is deposited in the rotor groove with each revolution of the rotor until the yarn reaches the required thickness. This buildup of fiber layers to the final yarn thickness is described as back-doubling, with the number of fiber layers resulting from the (genuine) yarn twist set and the diameter/circumference of the rotor used. Customary values are in the range of 60 - 90-fold back-doubling. Doubling of linear fiber formations always improves the regularity of the resulting new product, an effect that is, of course, consciously exploited in draw frames. This process is significantly finer and more intensive if it takes place at the level of the finest linear structure, namely the individual fiber. The regularity obtained in this way is of a high degree and is always better than that of ring-spun yarn. However, it must be borne in mind again that improvement in regularity is possible only over a length corresponding to the internal circumference of the rotor. With a currently widely used rotor diameter of 35 mm, the length that can be leveled out is 33 x 3.14 = 103 mm. All eveness in the sliver with a length greater than this pass into the yarn.

The numbers of back-doubled fiber layers is calculated as follows:

$$D = \frac{\text{Rotor} \varnothing \text{ mm x T/m (yarn) x } \pi}{1\,000}$$

Example: Yarn Nm 34/Ne 20, α_m 135/α_e 4.45;
Rotor ∅ 35 mm

$$T/m = \sqrt{Nm} \text{ x } \alpha_m = \sqrt{34} \text{ x } 135 = 787$$
$$T/'' = \sqrt{Ne} \text{ x } /\alpha_e = \sqrt{20} \text{ x } 4.45 = 20$$

$$D = \frac{35 \text{ mm x } 787 \text{ T/m x } 3.14}{1\,000} = 86 \text{ doubled fiber layers}$$

$$D = \frac{35 \text{ mm x } 20 \text{ T/'' x } 30.3 \text{ x } 3.14}{1\,000} = 86 \text{ doubled fiber layers}$$

When the required yarn thickness – formed from the individual fiber layers – has been reached, the yarn is withdrawn from the rotor groove. The end of the yarn extending into the rotor groove assumes the form of a fiber wedge due to the continuous take-off process. This fiber wedge is exactly the same length as the rotor groove. The diameter of the fiber wedge is at its largest – the full number of back-doubled fiber layers necessary for the required yarn thickness – at the moment it is withdrawn from the rotor groove, and at its smallest at the end of the fiber layer deposited last (Fig. 93, A). One fiber layer after the other – always the lowest (since it was the first deposited) – is thus removed by the yarn being taken off, followed successively by the subsequent fiber layers in the order they were deposited. When a layer of fibers is completely integrated it is immediately replaced by the fiber layer deposited next in the rotor groove. The wedge-shaped end of the yarn shifts continuously with the unrolling motion of the yarn lift-off point and thus ahead of the peripheral speed of the rotor.

Fig. 93, A - D shows the position of the yarn lift-off point and the corresponding fiber deposit situation in the rotor groove on 4 occasions. The lift-off point moves forward by the distance between the starting points of 2 fiber layers with each revolution of the rotor. For example: with a rotor diameter of 35 mm and 88 layers of fiber, the yarn lift-off point travels 35 mm x 3.14 / 86 = 1.28 mm with one revolution of the rotor. After 86 revolutions of the rotor (86 x 1.28 mm = 110 mm rotor circumference or 35 mm rotor ∅) the yarn lift-off point has therefore returned to its starting position (Fig. 93, A).

5.1.3. Twist insertion and yarn formation

As described in the previous section, in the rotor spinning process fibers are continuously fed into the rotor groove and the yarn is also continuously withdrawn from the rotor groove. The fibers laid parallel and untwisted in the fiber collecting groove of the rotor are given the necessary twist via the finished yarn being withdrawn from the rotor. A finished end of yarn must therefore be fed into the rotor – in the opposite direction to yarn take-off – at the start of the spinning process. The yarn end is also twisted by the rotating rotor. The yarn end is pressed into the rotor groove by the rotor's centrifugal force and is thus connected to the fiber ring fed into the rotor groove. The yarn twist penetrates into the fiber ring in the collecting groove, where the fibers are to be bound together to form a yarn. Each revolution of the yarn inserts one turn of twist.

The zone in which the yarn end inserts twist into the fiber ring is described as the twist or binding-in zone (Fig. 94). The length of this binding-in zone is of some significance for the spinning conditions and the yarn characteristics. If this length is too short, the ends down rate will be high; if it is too long, twisting-in will be very tight, and there will be many wrapping fibers.

Accordingly, in rotor spinning, it is not possible under given conditions to reduce the coefficient of yarn twist below a certain value (α_{min}) because otherwise the length of the binding-in zone will be reduced to zero (refer to „2.3.7. Rotor speed and rotor diameter"). The yam-twist momentum will then be negligible, and transmission of twist to the fibers in the ring will not be assured. The parameter αmin is therefore independent of yarn strength.

Dragging of the yarn from the rotor arises at the yarn lift-off point. The yarn is continually withdrawn at this point, which therefore shifts continuously forward within the rotor in the direction in which the rotor itself rotates, i.e. the yarn lift-off point has a higher peripheral speed than the rotor. The exact twist formula for the yarn would thus have to be represented as follows:

$$turns/m = \frac{rotation\ speed\ of\ the\ yarn\ lift\text{-}off\ point\ (rpm)}{delivery\ speed\ L\ (m/min)}$$

The lead relative to the rotor speed is, however, so small that it can be ignored on a percentage basis and it is possible to use the usual form of twist formula in relation to the rotor spinning machine as well:

$$turns/m = \frac{rotor\ speed\ (rpm)}{delivery\ speed\ (m/min)} = \frac{n_{rotor}\ (rpm)}{L\ (m/min)}$$

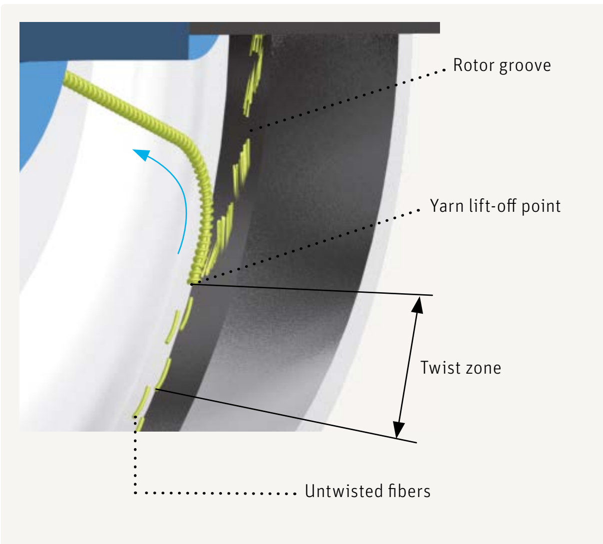


Fig. 94 – Inserting twist in the rotor groove

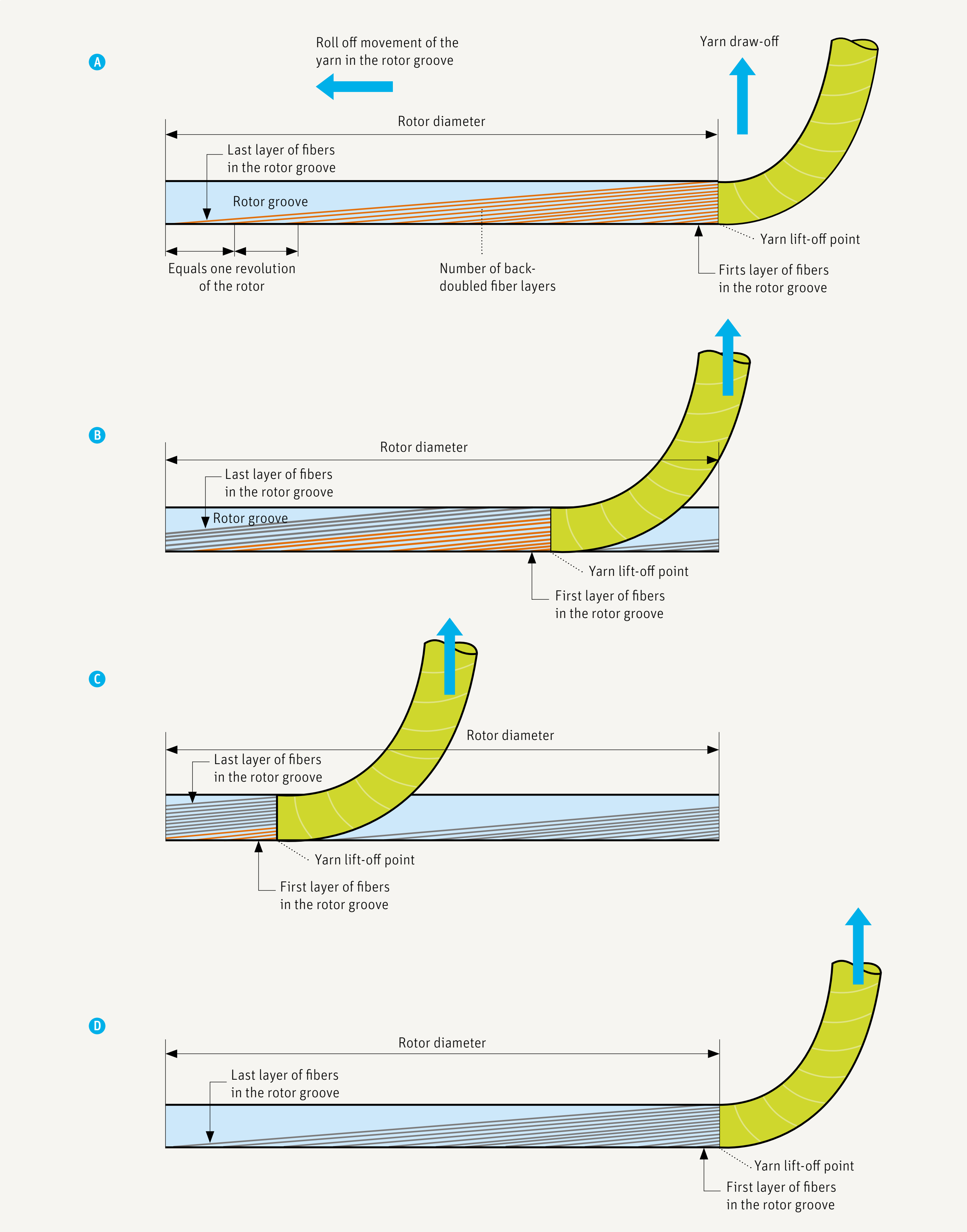


Fig. 93 – Illustration of the buildup of the fiber ring in the rotor groove by back-doubling and the corresponding position of the yarn lift-off point

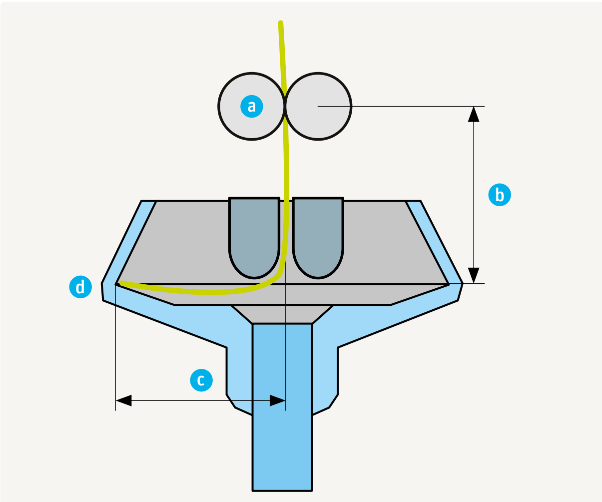


Fig. 95 –Inserting twist in the yarn

The process involved in imparting twist is far from simple. To assist in understanding the procedure, the reader can imagine a manually operated winch mechanism (see Fig. 95), in which:

- (a) represents the take-off rollers;
- the yarn on the stretch (b) represents the axis of the winch; and
- the yarn on the stretch (c) represents the hand-operated crank with the handle (d).

If yarn section (c) is now rotated like a crank at handle (d), the axis (here section (b)) rotates as in the case of the winch. However, since – in contrast to the winch – the rollers cannot rotate around the yarn axis in this model, the result is twisting only of yarn section (b). The turns imparted by this process are all in section (b); section (c) remains temporarily untwisted.

Section (c) nevertheless contains turns of twist running from section (b) by twist transmission; some of the turns generated in section (b) travel into section (c) (evening out of torsion forces).
As in the case of ring spinning, twist is transmitted against the direction of movement of the yarn. In rotor spinning, bending of the yarn at the nozzle acts as a brake for twist transmission. This means that the system itself transmits fewer turns into section (c) than were generated in section (b). Under such conditions, spinning at high speeds and normal twist coefficients would not be possible, because the twist momentum available from the yarn would be inadequate to twist the fibers together in the rotor groove (the twist momentum transmissible from the yarn is a function of the twist coefficient).

In practice, however, yarn section (c) must exhibit more twist turns than section (b). This is, in fact, the case and arises from the false-twist effect and from tension variations in the yam.

5.2. Genuine and false twist

Rotor spinning is a spinning process that produces genuine yarn twist. This „genuine" twist, which is retained in the yarn, is decisive for yarn strength. However, in order to maintain the spinning process, i.e. a stable and reliable binding-in process, a spinning twist is required, as explained in the previous section, which must be higher than the yarn twist required for yarn strength. This means that additional twist must be created in the radial length of thread extending from the draw-off nozzle into the rotor groove. This additional twist, the so-called false twist, is created by the rolling motion of the yarn on the draw-off nozzle. Depending on spinning conditions, the false twist can amount to as much as 60 % of the yarn twist set.

So how does this false twist effect arise and how does it differ from genuine yarn twist?

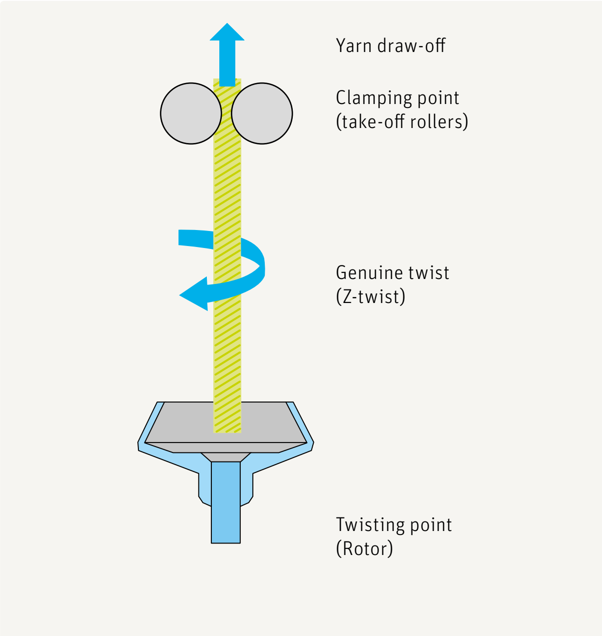


Fig. 96 – Imparting twist to the yarn: genuine twist in the Z direction

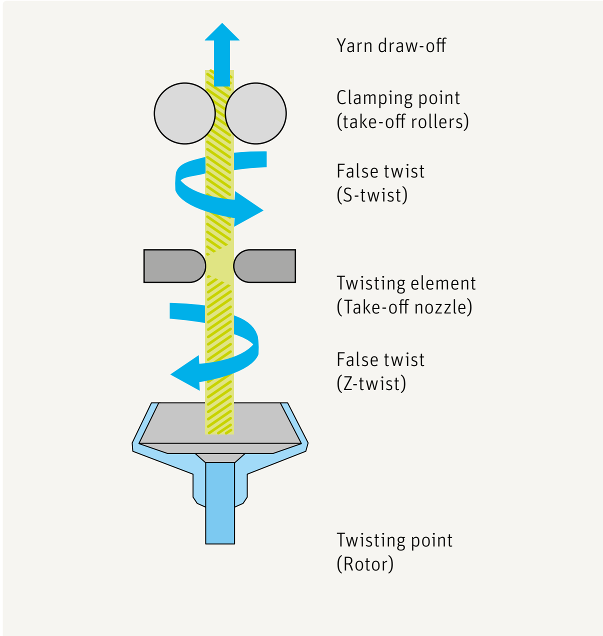


Fig. 97 – Imparting twist to the yarn: additional twist due to the false twist effect in the S and Z direction

Genuine twist that is retained in the yarn (Fig. 96) is generated when a length of yarn is clamped at one end and rotated around its axis by a twisting element at the other end. Transferred to the spinning box of a rotor spinning machine, this means that the yarn is clamped by the take-off rollers and twist is imparted by the rotating rotor. One revolution of the rotor corresponds to one turn of the yarn. The genuine twist therefore corresponds to the required twist set. The number of required turns imparted to a yarn depends on how long the length of thread remains in the rotor; the longer this time, the higher the number of turns. This means that the ratio of delivery speed (in m/min) to rotor speed (rpm) defines the number of required turns set:

$$\textit{Number of yarn turns per m (T/m)} = \frac{\textit{rotor speed in rpm}}{\textit{delivery in m/min}}$$

A nip and a twisting element are also required to generate false twist (Fig. 97), but an additional passive or active twist element is also required. If additional turns, i.e. false twist, are imparted to the yarn by this twist element, these are distributed to the left and right of the twist element in mutually opposing directions of twist (see Fig. 96). When the yarn leaves the nip the length of yarn twists back into its original form – by exactly the number of additionally inserted turns. This is precisely what happens in our rotor. The take-off rollers form the nip and the centrifugal force in the rotor groove acts as the twist-generating element; these two forces act in opposition to one another. The passive twist element in this case is the draw-off nozzle. The yarn is pressed onto the nozzle surface during take-off by the contrary tensile forces and unwinds on this surface. A certain number of additional turns – the false twist – are imparted to the yarn while it unwinds on the nozzle surface. The false twist effect created between the draw-off nozzle and the yarn unwinding on it has Z twist between the draw-off nozzle and the rotor groove, and S twist between the draw-off nozzle and the nip of the take-off rollers. The higher the friction on the nozzle surface, the higher the number of additional, reversible yarn turns inserted.

False twist, i.e. spinning tension, can be increased by:
- a larger nozzle surface diameter;
- additional notches, grooves, ridges, etc., arranged radially, axially or helically on the surface of the draw-off nozzle;
- a tighter bend in the thread draw-off tube; and
- additional twist accumulating elements in the bend of the thread draw-off tube.

During take-off, the yarn moves clockwise along the surface of the nozzle. In so doing, the yarn is twisted in the counter-clockwise direction. The partial rolling of the yarn gives rise to false twist between the twisting-in point for the fibers and the nozzle. The yarn in the spinning section (b in Fig. 95) therefore exhibits more turns of twist than the spun yarn. Moreover, the twist level increases continuously from the nozzle toward the rotor groove. The twist level at the lift-off point is about 20 - 60 % higher than at the nozzle. This difference arises from variations in tension along the yarn.

Yarn tension is generated by the take-off rollers during take-off in opposition to the centrifugal force in the rotor. Tension is highest at the take-off rollers themselves and declines toward the rotor wall. However, yarn tension and twist level are inversely proportional, i.e. if there are sections of low tension in the yarn (c), these will exhibit more twist. On the other hand, sections of high tension (b) take up less twist.

It is only these additional turns at the lift-off point, caused by false twist and yarn-tension variations, that enable spinning to be performed under stable conditions. The false-twist effect is dependent upon carrying along the yarn at the nozzle, i.e. ultimately upon the roughness and the structure of the contact surface. However, it also increases with increasing rotation speed of the rotor.

The angle of inclination of the fibers being twisted-in is the decisive factor for yarn tenacity. In order to achieve the same angle of inclination and thus the same level of tenacity, twice as many turns have to be imparted to a fine count yarn as to a yarn twice as thick. The absolute number of yarn turns only gives an indication of yarn tenacity if this is related to yarn count. However, twist multiplyer α/m or α/e enables the twist level of a yarn to be described regardless of yarn count. The higher the twist multiplyer, the higher the twist level and the higher the yarn tenacity, and vice versa. Yarn turns can thus be calculated as follows:

$$\textit{yarn turns T/m} = \frac{\alpha_{tex}}{\sqrt{tex}} = Nm \times \alpha_m = T/'' \times 39.4^*$$

$$\textit{yarn turns T/''} = Ne \times \alpha_e = \frac{T/m \times 25.4}{1\,000}$$

* Conversion factor dtex/Micronaire

Based on the fact that turns in rotor yarns are more inclined to move to the yarn core, while the yarn surface features a rather indifferent fiber layer and wrapper fibers, yarn twist can only be defined approximately in terms of measuring technology. In contrast to ring-spun yarn, rotor-spun yarn cannot be twisted until the fibers are completely parallel. That is to say, the number of turns measured is always lower than the required number of turns produced on the machine. The variances can be as much as -20 % and depend mainly on the characteristics of the fiber staple – rectangular or triangular staple – and the number of wrapper fibers.

5.3. Wrapper fibers

The rotor, and hence the fiber ring, revolve continuously under the stationary fiber channel – as also does the spun yarn in the binding-in zone. A stream of individual fibers flows from the fiber channel and is deposited in the groove. Normally, incoming fibers land on fibers that have not yet been twisted in, but in the binding-in zone they strike an already-twisted yarn section rotating around its own axis. It cannot always be avoided that fibers arriving here wrap themselves around the yarn core (so-called wrapper fibers). This is a typical characteristic, and simultaneously an identifying feature of rotor-spun yarns. The number of wrapper fibers increases, among other things, the longer the binding-in zone, the shorter the fibers relative to the rotor circumference and the higher the rotor speed.

The wrapper fibers can be wound around the yarn in both the S and Z direction. Together with the lower twist in the outer fiber layers of rotor-spun yarn, this is the reason why the number of twists measured when determining yarn twist in the laboratory is usually lower than the required figure set on the machine.

Since rotor spinning technology was not fully developed when the process was introduced – due mainly to the high twist multiplyers that were still necessary at that time, with the result that the binding-in zones extended far into the rotor groove – rotor yarns were characterized by a large number of wrapper fibers. It is also from those days that the rating of rotor-spun yarns‘ hand as too „hard“ and thus unsuitable for a whole range of end products, especially in the knitwear sector, originates.

The continuous development of rotor profiles in particular and the design of the draw-off nozzles, as well as optimized fiber and air guidance in the spinning box zone, have enabled the number of wrapper fibers to be reduced to the extent that modern rotor-spun yarns differ significantly from those of the first generation. Twist multiplyers are now only insignificantly higher than those of ring-spun yarns, so that their hand in the final fabric is much closer to that of ring-spun yarns than it was earlier. Knitting yarns now produced on rotor spinning machines have replaced ring-spun yarns to a considerable extent in certain end products, e.g. T-shirts.

5.4. Yarn structure and physical textile characteristics

Two quality criteria are decisive in describing a yarn. The structure, i.e. the arrangement of the fibers in the yarn cross-section and along the yarn, and the physical textile characteristics in terms of the uniformity and strength of the fiber bundle, the number of yarn defects (Table 20), etc. While the external structure is the decisive criterion for final appearance, form, wear behavior, etc., of the final fabric, the physical textile characteristics are decisive for the load-bearing capacity of the yarn during weaving preparation and on the weaving or knitting machine, as well as for the serviceability of woven or knitted fabrics.

Rotor-spun yarns have an unmistakable structure, characterized by the rather indifferent twist insertion in the surface of the yarn compared to ring-spun yarn – twist is imparted preferentially in the yarn core – and the system-related wrapper fibers. In contrast to rotor-spun yarn, twist is imparted in the surface of ring-spun yarn, and virtually all fibers are integrated uniformly along the spiral line of the yarn twist. Twist insertion and the creation of wrapper fibers is explained in the two previous sections (5.2. and 5.3.).

5.4.1. Count-related yarn tenacity (cN/tex)

The less pronounced – less frictional – parallelization of fibers in the yarn surface compared to ring-spun yarn is also the reason for its lower count-related yarn tenacity (cN/tex). In particular the optimization of rotor grooves (e.g. tighter groove radii) and draw-off nozzles (e.g. smaller contact surfaces, smaller surface radii), as well as optimized fiber guidance in the spinning box, have enabled the strength of rotor-spun yarns to be improved continuously and the gap relative to ring-spun yarns to be narrowed. However, differences still exist. On the other hand, the coefficient of variation in yarn tenacity (CV% cN/tex), i.e. the variation in tenacity along the yarn, is better in rotor-spun yarn, i.e. lower than in ring-spun yarn. This is due to the smaller range of short-wave mass variations in rotor-spun yarn, and results from back-doubling in the rotor.

The potential tenacity of a yarn can best be described by the substance utilization of the fiber tenacity, i.e. what percentage of the fiber tenacity can be transferred to the yarn tenacity. The substance utilization of the fibers in ring-spun yarn is between approx. 50 and 65 %*, that for rotor-spun yarns between 45 and 55 %*. The count-related tenacity (cN/tex) of rotor-spun yarn is therefore usually 10 % - 20 % lower than that of ring-spun yarn (see Uster Statistics).

$$\text{cN/tex yarn} = \frac{\text{cN/tex fiber x substance utilization \%}}{100}$$

For example, if a medium-grade cotton with a count-related fiber tenacity of 24 cN/tex is processed, the following values result for the count-related yarn tenacity (cN/tex) of rotor-spun and ring-spun yarns:

rotor-spun yarn = 24 cN/tex fiber x 45 (%) / 100 or
24 cN/tex fiber x 55 (%) / 100
= 10.8 - 13.2 (cN/tex)

ring-spun yarn = 24 cN/tex fiber x 50 (%) / 100 or
24 cN/tex fiber x 65 (%) / 100
= 12.0 - 15.6 (cN/tex)

* The absolute value for substance utilization depends essentially on the twist multiplyer selected (α_m/α_e), for both rotor-spun and ring-spun yarn. If substance utilization is below the stated range, setting-related causes usually have an adverse impact on yarn tenacity, e.g. fiber damage due to excessive take-off roller speed or inadequate fiber integration due soiled rotor grooves.

5.4.2. Elongation at break (%)

In contrast to yarn tenacity, rotor-spun yarn is more or less significantly superior to ring-spun yarn in terms of elongation at break (%). On the basis of Uster Statistics it is apparent that the elongation at break of rotor-spun yarns is higher than that of comparable ring-spun yarns, albeit only marginally in some cases. This is especially positively noticeable in the working capacity of rotor-spun yarn, in that the differences relative to ring-spun yarn are smaller than for count-related yarn tenacity. Studies by prominent weaving machinery manufacturers demonstrate that 1 % elongation at break produces the same improvement in working capacity as 2 cN/tex higher tenacity. At the high accelerations and loads to which yarns are exposed on modern high-performance machines, the elongation behavior of a yarn plays at least an equal, if not even a greater role than yarn tenacity. The advantages in processing are dealt with in greater detail in section „4.9.1. Processing properties“.

The stress-strain behavior of the rotor-spun yarn is largely identical to that of a ring-spun yarn.

Rotor-spun yarn compared to ring-spun yarn		
tenacity cN/tex	lower	-
CV% cN/tex	lower	+
elongation at break %	higher	+
irregularity CV%	lower	+
imperfections / 1 000 m	much lower	++
yarn bulk	higher	+
abrasion resistance	higher	+
stiffness	higher	[1]
hand	harder [2]	-
surface	rougher	[1]
hairiness	lower	[1]
luster	duller	-

[1] Positive or negative, depending on the end product
[2] Virtually the same as ring-spun yarn in the end product after finishing (see Table 19)

Table 20 – Properties of rotor-spun yarn compared to ring-spun yarn

5.4.3. Yarn hairiness

Yarn hairiness assumes a significance which should not be underestimated. This refers to the length and frequency of fiber ends that are not integrated in the yarn and therefore protrude from the yarn bundle.

High yarn hairiness (primarily of hairs longer than 3 mm) can have a negative impact, both due to a diffuse fabric appearance lacking in clear structure and also in downstream processing due to a tendency to cling and fiber deposits on the machines. If these deposits reach the final fabric they are usually rated as disturbing defects. However, high yarn hairiness (hairs shorter than 3 mm) is positive where it contributes to soft fabric hand. Soft, flexible fabric hand is preferred in knitted fabrics for underwear, T-shirts and leisurewear. High – albeit precisely defined – yarn hairiness is required for processing denim yarns using the rope dyeing method. However, in this case the high hairiness does not contribute to the hand, but acts as a spacer between the yarns when the dyed rope is opened.

Rotor-spun yarns display significantly lower hairiness than comparable ring-spun yarns. The reason given for this by Bunk/Trommer (see references) is that the fiber ends facing away from the yarn take-off direction point toward the interior of the yarn and the number of free fiber ends is therefore about half that in ring-spun yarns. Furthermore, the wrapper fibers wound crosswise around the yarn help to „bind-in" loose fiber ends. Abrasion resistance and pilling tendency are positively influenced by these wrapping fibers. The clinging tendency, fiber abrasion and fiber fly of rotor yarns in downstream processing are less critical than for comparable ring-spun yarns. Put simply, the higher hairiness of ring-spun yarns is caused by the uncontrolled passage of edge fibers in cylinder draw frames and in the spinning triangle at the draw frame delivery end.

However, low hairiness is a drawback where a large number of protruding fiber ends contributes to a soft hand, for example in knitted fabrics for underwear and leisurewear. Here ring-spun yarn has an advantage, since its high hairiness is especially beneficial for a soft hand in the final fabric. However, the disadvantage of rotor-spun yarn's lower hairiness can – and this is in turn an advantage over other spinning systems – be varied in a wide range by means of spinning elements (rotor groove and draw-off nozzle). First of all, rotor-spun yarns can now be produced with significantly lower twist multiplyers than previously, without any adverse effect on spinning stability. Yarn hairiness and yarn bulk can also be adapted to the end product by the skillful choice of technology components, for example:

- By the rotor groove: the larger the groove angle, the groove radius and the rotor diameter, the bulkier and hairier the yarn. If rotor speed and thus spinning tension are also reduced, further gains in hairiness and bulk are achieved. If rotor speed is reduced, the twist multiplyer can also often be reduced – since spinning tension declines – which offsets the loss of production due to the reduction in speed. Conversely, tighter groove angles and smaller groove radii and rotor diameters mean that leaner and more compact yarns with lower hairiness can be produced. And the higher the rotor speed and thus the spinning tension, the greater the effect.
- By the shape and design of the nozzle surface: the more structured the nozzle surface and the longer the contact surface (nozzle radius) on which the yarn unwinds, the higher the yarn hairiness and the yarn bulk. Additional inserts in the throat of the nozzle and additional TWISTstop elements in the draw-off nozzle further increase the hairiness of the yarn. The smoother the draw-off nozzle, the smaller the nozzle radius and thus the contact surface, and the fewer twist accumulation elements affect the passage of the thread, the lower the hairiness and bulk of the yarn.

5.4.4. Yarn irregularity (CV_m%)

The positive influence of back-doubling in the rotor has already been described several times in this paper. The result of this, compared with other yarns, is the more uniform distribution of the fiber mass along the yarn, as expressed in the regularity of the weight per unit of length. The best possible regularity of a fiber bundle in the spinning process would be achieved if the fibers were distributed at random along the yarn. However, this ideal distribution cannot be achieved in practice, neither in ring-spun, rotor-spun nor in any other staple fiber yarn. Deficiencies in machine operation or the drafting system are the cause of more or less pronounced cross-section variations. The size of the cross-section variations is expressed in mean linear irregularity

(U%) or – more correctly and customarily in terms of physical textile properties – in mean square irregularity (CV_m%).

Only the rotor spinning system is able to offset this process-related deterioration in cross-section variations to some degree by back-doubling the fiber layers in the rotor. The mass uniformity of the rotor-spun yarn is therefore better than for ring-spun yarn (given equal machine conditions).

According to Brunk/Trommer (see references), the irregularity limit (CV_{lim}) of a rotor-spun yarn is some 75 % of the irregularity limit of a comparable ring-spun yarn. The CV_m% values that can actually be achieved with rotor-spun yarns are therefore usually better than with yarns from other spinning processes.

5.4.5. Imperfections (thin places, thick places, neps)

Rotor-spun yarns are also characterized, among other things, by the fact that the number of so-called yarn defects – stated as the number of thick places, thin places and neps per 1 000 m of yarn – also referred to in the literature as imperfections, is much lower than for comparable ring-spun yarns. Imperfections can both be the cause of ends down in downstream processing and also make a disturbing appearance in the fabric. According to the latest Uster Statistics, the number of thick places and neps per 1 000 m of yarn are up to 60 % and 80 % lower in rotor-spun yarn than in ring-spun yarn.

However, if the number of imperfections rises above the usual level, this can be attributable to both raw material and machine-related causes. For example, immature cottons are very inclined to produce neps during processing. However, thick places and neps also occur when spinning elements or other fiber-guiding machine components are worn or damaged. Bent, broken or notched clothing teeth on the opening roller in particular can cause steep increases in the numbers of neps and thick places. Wear or deposits in the fiber guide channel also result in fibers accumulating at these points and being fed uncontrolled to the rotor as larger or smaller clumps of fiber. Depending on their mass, these clumps result either in ends down or – if spun in – in defects in the yarn and the final fabric.

6. ECONOMICS OF ROTOR SPINNING

Any new spinning process launched on the market can only be successful if it fulfills certain criteria for economic benefits and can claim advantages over an established spinning system in at least one of these criteria, such as:
- higher quality of the product manufactured;
- higher productivity of the system as a whole;
- lower costs of the production process in relation to the quantity produced (labor, energy, capital);
- greater flexibility of the process, i.e. a wide range of yarn products can be manufactured or a wider range of raw materials can be used.

If these criteria are applied to the many spinning processes brought out in recent decades, it is clear why most of these processes were unable to establish themselves, i.e. soon disappeared again. Only rotor spinning and – with some qualifications – Air-jet spinning, albeit with a limited range of yarns, can be said to fulfill the aforementioned criteria.

When considering the economics, higher productivity certainly ranks first with rotor spinning. Rotor-spun yarns have always established themselves in the past where they could be produced more cheaply than ring-spun yarns, while at the same time meeting the requirements of the end product. This will continue to be the case in future. In the course of development the economically relevant factors have intensified to the extent that the break-even point compared with the established ring-spinning process has been moved in the direction of increasingly fine rotor-spun yarns.

If productivity takes first place in terms of the success of rotor spinning, the conclusion should not be drawn that even a single yarn manufacturer today would be prepared to sacrifice yarn quality for lower manufacturing costs. Yarn quality and economy are not only not mutually exclusive, they are necessary prerequisites for each other! In contrast to ring-spun yarn, significant quality improvements have been achieved in recent years while continuously increasing rotor speeds and delivery speeds.

The following aspects have contributed significantly to the economic success of rotor spinning versus ring spinning:
- elimination of the roving frame passage and the lower number of draw frame passages for many applications (refer to section „4.3.3.3. Draw frames“);
- elimination of the cost-intensive rewinding process due to direct processing of rotor-spun yarns;
- elimination of the doubling process (for some applications) by using single rotor-spun yarns instead of doubled ring-spun yarns;
- cards and draw frames for the rotor spinning process can be operated 30 % - 50 % faster;
- lower energy consumption due to the shorter spinning process; savings can be up to 30 %;
- material flow in a shorter spinning line is simpler and therefore easier to organize; the throughput time is shorter;
- increased productivity in the spinning mill due to delivery speeds up to 10 times higher, lower ends down rates and higher machine efficiency compared with ring spinning;
- use of shorter and therefore less expensive cottons, especially for manufacturing coarser yarns; no compromises may be made as regards raw material quality for spinning finer count yarns;
- increased productivity in downstream processing due to large package formats and longer, defect-free yarn lengths, and the resulting improved running properties of the yarns.

6.1. Cost structures of comparable rotor-spun and ring-spun yarns

The economics of a spinning process are essentially defined by three major cost blocks: capital costs and the interest burden on them, direct labor costs and energy costs. In order to compare economics, manufacturing costs are usually related to the production of 1 kg of yarn.

In rotor spinning, capital costs account for the majority of manufacturing costs (Fig. 99), followed by energy costs. Direct labor costs figure only in third place. This applies especially to countries with low labor costs. In countries with significantly higher wage levels, labor costs are higher than energy costs in the coarse count sector (but not in the fine count sector), due to the frequency of manual can and package transport movements (Fig. 98).

With the ring spinning system, direct labor costs in countries with higher wage levels account for a much greater proportion of the total and are almost identical to capital costs, followed by energy costs. This order changes accordingly in countries with low labor costs. Ongoing spare parts costs are a larger factor with rotor-spun yarn than with ring-spun yarn, and space requirements account for a smaller proportion of total costs. Regional differences result in different weightings of the cost blocks.

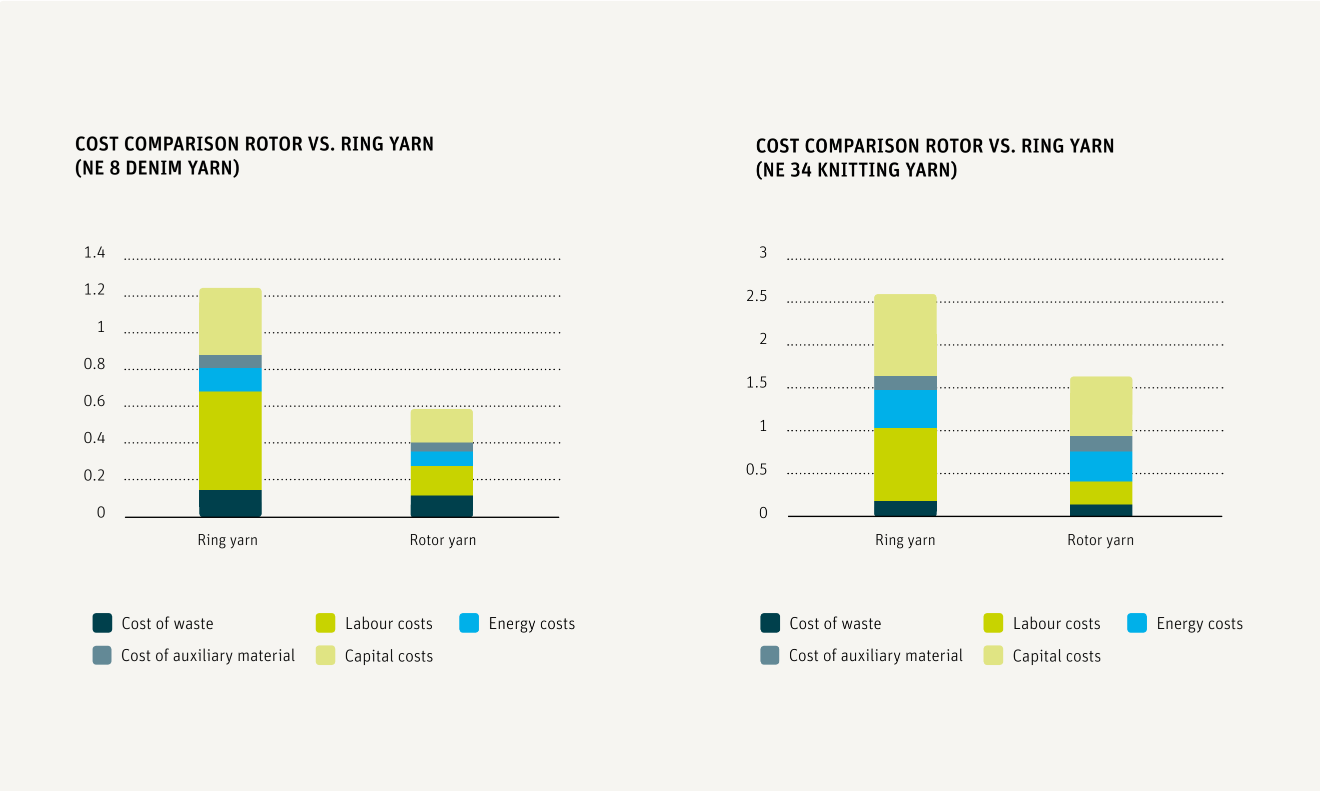


Fig. 98 – Cost structure: rotor-spun vs. ring-spun yarn (Ne 8 left and Ne 34 right) in countries with higher wage levels

Fig. 99 – Cost structure: rotor-spun vs. ring-spun yarn (Ne 8 and Ne 34) in countries with lower wage costs

The break-even point, up to which rotor-spun yarns can be produced more economically than ring-spun yarns, has moved continuously in the direction of fine count yarns in recent years – due to the increase in output. The output advantage of rotor-spun yarns is now so large that even the finest rotor-spun yarns (in the Ne 60 / Ne 70 range) can be produced more economically than ring-spun yarns, and even in countries with low labor costs the cost of manufacturing rotor-spun yarns finer than Ne 40 is less than that for ring-spun yarns. Fig. 100 shows the manufacturing costs of ring-spun and rotor-spun yarns as a function of yarn count with differing regional labor cost levels.

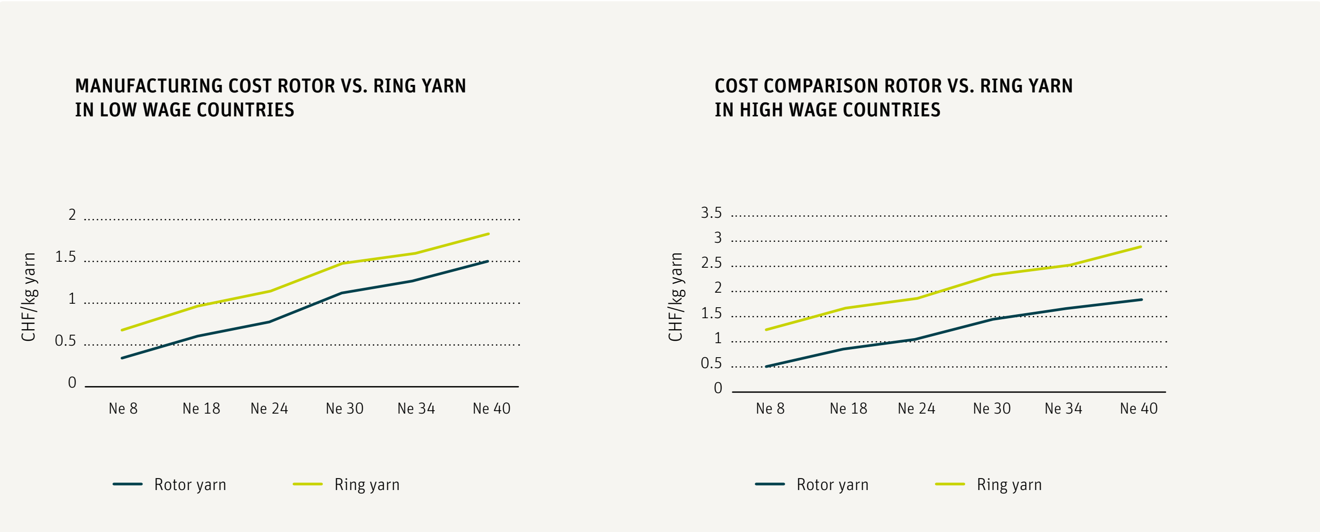


Fig. 100 – Comparison of manufacturing costs/kg of yarn for different yarn counts in low- and high-wage countries

The lower the share of the relatively high capital costs in manufacturing costs per kg of yarn, the more economically rotor-spun yarn can be produced. The importance of capital costs declines if material throughput, i.e. the quantity of yarn produced per machine or spinning position, rises. Coarser yarns (with higher material throughput) can therefore be produced more economically than fine count yarns, both in absolute terms and also in comparison with ring-spun yarns.
The capital costs included the cost of purchasing the machine and all accessory equipment. Due to the high degree of automation and the ancillary equipment for quality control and waxing, a spinning position on a rotor spinning machine costs about 5 times as much as a spindle on a ring spinning machine. This is offset by the cost benefits of the rotor spinning system due to the elimination of sliver production, the possible saving of one draw frame passage and the elimination of the rewinding process.
If the capital costs and the production potential of the different spinning systems are compared, the situation given the current status of mechanical engineering is as follows:

- delivery speeds of the rotor spinning machine are a factor of 7 (fine yarns) to 10 (coarse yarns) higher than those of ring spinning machines;
- spinning-related ends down in rotor spinning are higher in proportion to spindle running times (per 1 000 spindle hours), but some 75 % lower than those of ring-spun yarns in relation to a yarn length of 1 000 km;
- machine efficiencies of up to 99 % are not unusual in well-managed rotor spinning installations; these figures are thus significantly higher than can be achieved with ring spinning machines.

To a limited extent, longer machines can help to reduce the specific capital employed per spinning position. Rotor spinning machines are currently being offered with up to 500 spinning positions. However, the useful limits are defined by reliably operating and economical drive technology.

Energy costs are becoming increasingly important worldwide. Limited resources mean that they are rising almost continuously. Their share of the cost of manufacturing a yarn is in many cases already on the same order of magnitude as labor costs. Close attention is therefore given to how much energy has to be expended to produce a given quantity of yarn. Machinery manufacturers make their contribution by working continuously and intensively to reduce the power input of the major consumers – i.e. the drives for the rotors and the fan for generating the partial spinning vacuum – as far as possible.

High rotor speeds can always be achieved when fine count yarns are being spun. In principle, the energy required on the rotor spinning machine increases with rising rotor speeds (Fig. 101). However, smaller rotors require less energy. For reasons of the mechanical stability of the rotors, higher rotor speeds can only be achieved with small rotors. Energy consumption with small rotors can therefore be entirely comparable with energy consumption using large rotors at much lower speeds. Yarn twist only has to be increased slightly with rising rotor speeds, since optimized spinning elements and improved spinning geometry contribute to improved spinning stability.
By contrast, the increase in energy consumption on the ring spinning machine is directly dependent on spindle speed. The diameter of the ring defines the weight of the cop and therefore cannot be exchanged like a rotor.

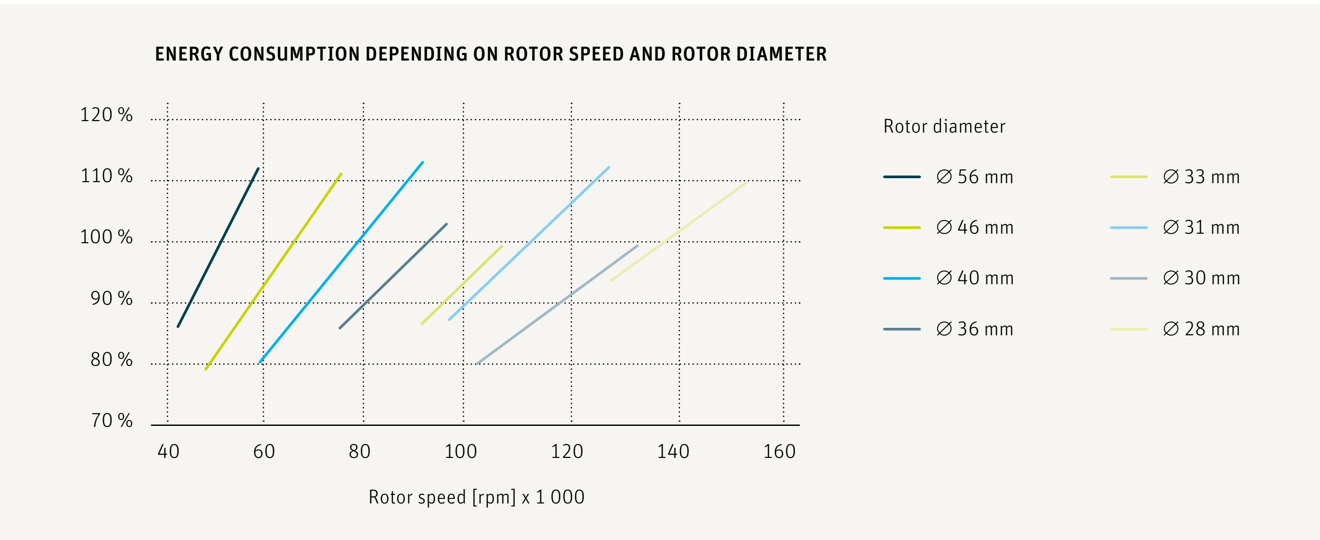


Fig. 101 – Energy consumption as a function of rotor speed and rotor diameter

Rotor spinning offers especially high benefits compared to ring spinning as regards direct labor costs. High productivity, combined with the automation of the piecing and package changing process, means that the personnel effort required per kg of rotor-spun yarn is much lower than in ring spinning.

Automated rotor spinning machines now require only minimal operator effort. Many more machines can now be allocated per employee, less and less personnel are required to operate a spinning mill. Automated solutions are available even for the remaining manual activities, such as replacing spinning cans, introducing the sliver into the spinning box and removing the full packages at the end of the machine (refer to section „3. Machine and transport automation").

6.2. Lower labor costs due to advantages in transport and service

Despite the technical possibilities available, the manual transport of cans and packages to and from highly automated rotor spinning machines still defines personnel deployment in the majority of textile mills. However, the effort involved can be reduced substantially by using large units for spinning cans and cross-wound packages, such as those supplied by several machinery manufacturers (Fig. 102*).
For example, using 18½″ cans* instead of 16″ cans saves more than 12 % of the transport movements over the long distances between the draw frame and the rotor spinning machine. Longer running times mean that large cans have to replaced less frequently. Appropriate machine design nevertheless permits space-saving layout with comparatively short transport distances. This also applies to the rectangular cans used in the context of transport automation. The filling weight of these cans is up to twice that of 16″ cans and still some 70 % higher than that of 18½″ round cans (Fig. 103).

Similarly, the effort involved in transporting the finished yarn packages can be minimized by using larger units (Fig. 103). If packages weighing 5 kg can be produced, this implies 20 % less handling effort in transport, palletizing or packaging, compared with 4 kg packages. In addition to the gains in the spinning mill, the same savings in handling effort can be made in downstream processing. Added to this are savings on the corresponding number of empty tubes, for which disposable tubes are usually used. The savings here can certainly amount to some 0.05 €/kg of yarn in large installations. In combination with appropriate automation solutions this amount can be even higher.

* Can formats that fit under the rotor spinning machine in 2 rows, depending on machine type.

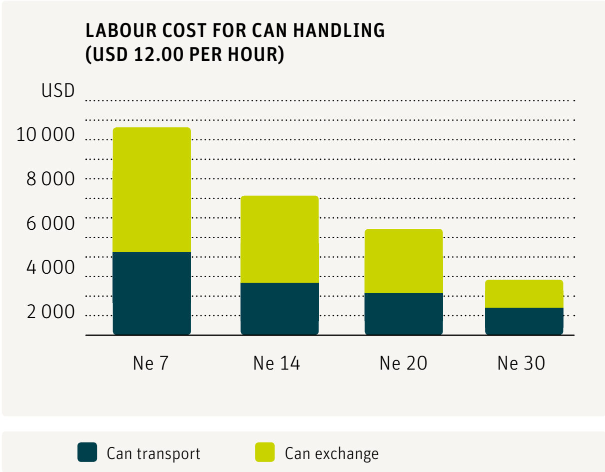


Fig. 102 – Cost advantages per rotor spinning machine and year of large cans (18½″ versus 16″)

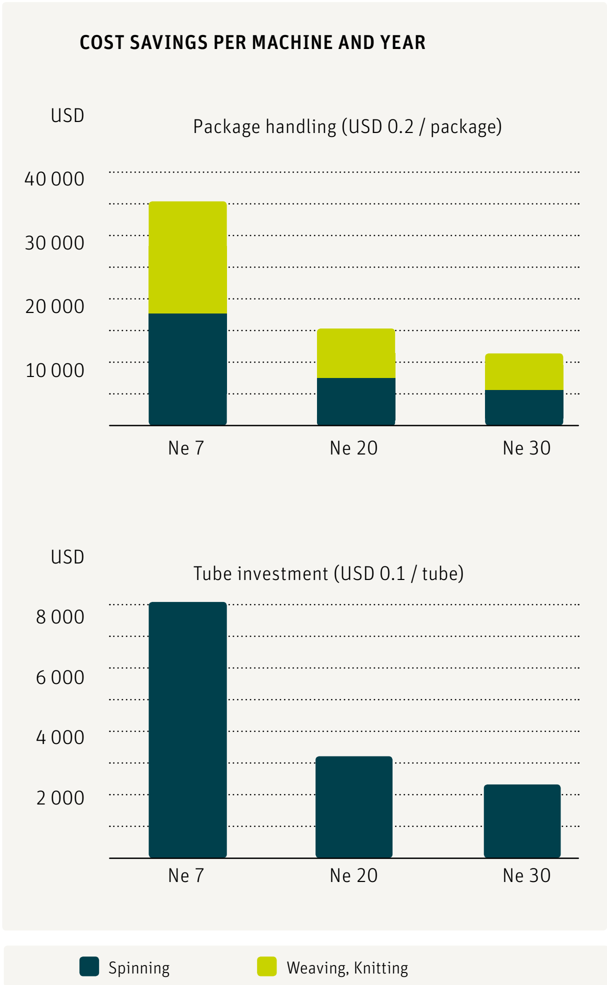


Fig. 103 – Cost savings per rotor spinning machine and year with large packages (5 kg versus 4 kg) and lower tube investment

Personnel for setting and maintaining the machines represent a further cost block in labor costs. Optimized setting capabilities enable the necessary machine downtime and the personnel time and effort expended on this to be reduced. On machines equipped entirely or partly with infinitely adjustable inverter drives, time-consuming and usually repeated changes of gear wheels or drive pulleys with the associated machine downtime at batch changes are eliminated. Setting values for draft, yarn twist, tensioning draft, rotor and opening roller speed can be entered very easily directly at the machine control panel.

Further savings in labor costs can be made if an intelligent machine and control concept helps to simplify maintenance work and shorten cleaning operations, for example by means of:

- operating robots of modular design;
- easy, rapid replacement of technology components, as far as possible without tools;
- oil-free and thus low-maintenance rotor bearings requiring little cleaning;
- working elements that can also be replaced while the machine is running (technology components, rotor bearings, etc.).

Not all of these aspects can be quantified in terms of euros and cents, since concepts for maintenance and technical supervision of the machines vary widely between different mills. However, irrespective of the effort expended in a spinning mill, a maintenance-friendly machine concept will always have a beneficial impact on manufacturing costs.

6.3. Reduced labor costs in downstream processing

Besides cost benefits in the manufacture of rotor-spun yarns versus ring-spun yarns in the coarse and medium count range, rotor-spun yarns also offer significant cost savings in some cases in downstream processing by virtue of technical application advantages (refer to section „4.9.1. Processing properties"). Results from mill practice demonstrate that the following economies can be achieved, for example when processing Nm 50/Ne 30/tex 20 rotor-spun yarns versus ring-spun yarns:

- **Warping:** Machine downtimes reduced from 4.8 stoppages/10^7 meters for ring-spun yarn to 1.1 stoppages/10^7 meters. Assuming the cost of a machine stoppage of 0.5 €, this results in a cost reduction of € 0.02/kg of yarn.
- **Weaving:** Machine downtimes reduced from 1 - 3 stoppages/10^5 picks for ring-spun yarn to 0.5 - 1.5 stoppages/10^5 picks for rotor-spun yarn. Assuming the cost of a machine stoppage of 1.0 €, this results in a cost reduction of € 0.25/kg of yarn.
- **Knitting:** Significantly lower levels of contamination by fly when processing rotor-spun yarns enable machine downtime to be reduced in some cases; specific data on its influence on processing costs are not yet available, nor on the advantages of the straight flow of stitches in knitted fabrics made from rotor-spun yarns, which have a positive impact in make-up.

The cost benefits of using rotor-spun yarn are immediately and clearly demonstrable with regard to manufacturing costs in downstream processing in particular in vertically integrated mills.

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The Rieter Manual of Spinning

Volume 5 – Rotor spinning

The rotor spinning process was developed as a result of research into alternative spinning systems. Through continual development, such great improvements have been achieved in spinning elements and conditions that it is now almost impossible to distinguish rotor-spun from ring-spun yarn. This volume contains in-depth information on the rotor spinning process and its properties.

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