The Rieter Manual of Spinning
Volume 1

RIETER

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Volume 1 – Technology of Short-staple Spinning

Werner Klein

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The Rieter Manual of Spinning

Volume 1 – Technology of Short-staple Spinning

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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

Spinning technology has made tremendous progress in recent decades, not only with regard to the quality of the yarns produced, but also in terms of economic efficiency. For example, the productivity levels now being achieved in new mills were inconceivable in the 1980s.

The introduction of new spinning processes, in particular compact spinning, has opened up new applications for ring yarn. For quality criteria such as yarn strength, yarn hairiness, and elongation, new standards had to be introduced in order to take these innovations into account.

Major technological advances have also consolidated the position of rotor spinning among the spinning systems. Piecers, for example, which in the past were often troublesome, have been vastly improved with regard to visibility and consistency of strength, with the result that now, at last, rotor spinning is no longer confined to the production of inferior-quality yarns. New methods such as air-jet spinning are already assuming an importance that augurs well; further improvements may be expected in this area. The Rieter Manual of Spinning endeavors to describe the contemporary state of the art in spinning technology, with the objective of providing a reliable overview of currently available processes and technologies.

The main author of these books, Werner Klein, is a former senior lecturer of the Swiss Textile College and author of the original edition of the „Manual of Textile Technology“ published by The Textile Institute Manchester. All further authors are textile industry experts, who among others in various positions within the Rieter Company, have many years of experience to their credit. The Manual also addresses aspects that extend beyond Rieter’s current product range, taking processes and solutions developed by other manufacturers into account.

The structure of this manual and the organization of its subject matter were taken over 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. The updating which became necessary in the course of time by new developments, was carried out with the assistance of the Rieter staff.

I wish all users of this compendium pleasant reading.

Heiner Eberli, Head of Marketing, Rieter Spun Yarn Systems

CONTENTS

INTRODUCTION TO SPINNING

The annual world fiber consumption in 2004 amounted to approx. 70 mio tons (synthetics: 38 mio tons, cotton: 22 mio tons, cellulose fiber: 2.5 mio tons and others: 7.5 mio tons).
While about one third of the man-made fibers is processed as endless filament, still two thirds come in staple fiber form. The larger part of staple fiber, approx. 33 mio tons are processed in short staple spinning. This part of the spinning industry therefore is of great significance in the world of textile production.
It is correspondingly important that adequate trained management personnel is available, with the necessary technical and technological knowledge. While technical knowledge relates more to machines, technological aspects are concerned with processing. Technological knowledge is the summarized expression of the basic principles involved in conversion of raw material to semi-finished or fully finished products – separated from the actual or currently realizable possibilities for putting these principles into effect.
In relation to spinning, technology is concerned with the study of the production of a yarn. In this context the word "spinning" refers to the conversion of a large quantity of individual unordered fibers of relatively short length into a linear, ordered product of very great length by using suitable machines and devices. In processing natural fibers, the same basic operations are always involved.
It is the aim of this volume to provide an introduction to the technology of spinning, to the relationships and laws involved in the performance of these basic operations and to awaken or to deepen understanding of what happens during material processing.

Werner Klein, former senior lecturer of the Swiss Textile College

Operation	**Machines used in short-staple spinning**
Opening	• blowroom machines • card • OE rotor spinning machine
Cleaning	• cleaning machines • card • comber • draw frame (dust removal) • rotor spinning machine
Blending	• blowroom machines • card (fiber blending) • draw frame
Aligning	• card • comber • draw frame • roving frame • final spinning machines
Uniting	• card • comber • OE rotor spinning machine
Equalizing	• card with leveller • draw frame • OE rotor spinning machine
Attenuating	• card • draw frame • roving frame • final spinning machines
Imparting strength	• final spinning machines
Winding	• roving frame • final spinning machines

Table 1 – Machines used in short–staple spinning

1. RAW MATERIAL AS A FACTOR INFLUENCING SPINNING

1.1. Characteristics of the raw material

Raw material represents about 50 - 75 % of the manufacturing cost of a short-staple yarn. This fact alone is sufficient to indicate the significance of the raw material for the yarn producer. The influence becomes still more apparent when the ease in processing one type of fiber material is compared with the difficulties, annoyance, additional effort, and the decline in productivity and quality associated with another similar material. But hardly any spinner can afford to use a problem-free raw material because it would normally be too expensive.

Adapting to the expected difficulties requires an intimate knowledge of the starting material and its behavior in processing and subsequent stages.

Optimal conditions can be obtained only through mastery of the raw material. Admittedly, however, the best theoretical knowledge will not help much if the material is already at the limits of spinnability or beyond. Excessive economy in relation to raw material usually does not reduce costs and often increases them owing to deterioration of processability in the spinning mill.

As an introduction to the subject of raw material, the following pages will sketch out several relationships which are important for the yarn producer. Only cotton will be dealt with here. Man-made fibers will be dealt with separately in another volume.

1.2. Fiber fineness

1.2.1. The influence of fineness

Fineness is normally one of the three most important fiber characteristics. A multitude of fibers in the cross-section provide not only high strength but also better distribution in the yarn. The fineness determines how many fibers are present in the cross-section of a yarn of given thickness. Additional fibers in the cross-section provide not only additional strength but also better evenness in the yarn.

About thirty fibers are needed at the minimum in the yarn cross-section, but there are usually over 100. One hundred is approximately the lower limit for almost all new spinning processes. This indicates that fineness will become still more important in the future.

Fiber fineness influences primarily:
- spinning limit;
- yarn strength;
- yarn evenness;
- yarn fullness;
- drape of the fabric;
- luster;
- handle;
- productivity of the process.

Productivity is influenced via the end-breakage rate, the number of turns per inch required in the yarn (giving improvement of the handle), and generally better spinning conditions. In the production of blends, it must be borne in mind that, at least in conventional ring spinning processes, fine fibers accumulate to a greater extent in the yarn core and coarser fibers at the periphery. Blending of fine cotton fibers with coarse synthetic fibers would produce a yarn with an externally synthetic fiber character.

1.2.2. Specification of fineness

With the exception of wool and hair fibers, fiber fineness cannot be specified by reference to diameter as in the case of steel wire, because the section is seldom circular and is thus not easily measurable. As in the case of yarns and fibers, fineness is usually specified by the relation of mass (weight) to length:

$$tex = \frac{mass\ (g)}{length\ (km)} \quad or\ dtex = \frac{mass\ (dg)}{km}$$

Whereas for man-made fibers dtex is used almost exclusively, the Micronaire value is used worldwide for cotton. The fineness scale is as follows:

Mic VALUE	FINENESS
up to 3.1	very fine
3.1 - 3.9	fine
4.0 - 4.9	medium (premium range)
5.0 - 5.9	slightly coarse
above 6	coarse

Conversion factor: dtex = Mic × 0.394
(heavily dependent on degree of maturity).

It should be remembered, however, that the Micronaire value does not always represent the actual fineness of the fibers. Owing to the use of the air-throughflow method for measuring the Mi value, for example, a low average value is obtained where there is a high proportion of immature fibers, and this does not correspond to the true value for the spinnable fibers.

Specification by linear density (tex) is more accurate in such a case, but far harder to obtain. There is a further difficulty. Cotton is a natural fiber. It grows in various soils, in various climates, and with annually changing cultivation conditions. The fibers therefore cannot be homogeneous in their characteristics, including their fineness. Schenek [1] indicates that the Mic value varied, in an extreme example, between 2.4 and 3.9 from bale to bale in a lot of 500 bales. Long-staple cotton varieties are commonly finer than medium-staple.

1.2.3. Fiber maturity

The cotton fiber consists of cell wall and lumen. The maturity index is dependent upon the thickness of this cell wall. Schenek [1] suggests that a fiber is to be considered as mature when the cell wall of the moisture-swollen fiber represents 50 - 80 % of the round cross-section, as immature when it represents 30 - 45 %, and as dead when it represents less than 25 %. Since some 5 % immature fibers are present even in a fully matured boll, cotton stock without immature fibers is unimaginable: the quantity is the issue. ITMF recommended the Fiber Maturity Tester FMT for cotton maturity determination. Measurement by FMT gives the Maturity Index (MI) refred to by Lord and Heap [3].

Immature fibers have neither adequate strength nor adequate longitudinal stiffness, they therefore lead to:
- loss of yarn strength;
- neppiness;
- a high proportion of short fibers;
- varying dyeability;
- processing difficulties, mainly at the card.

1.3. Fiber length
1.3.1. The influence of length

Fiber length is also one of the three most important fiber characteristics. It influences:
- spinning limit;
- yarn strength;
- yarn evenness;
- handle of the product;
- luster of the product;
- yarn hairiness;
- productivity.

Productivity is influenced via:
- the end-breakage rate;
- the quantity of waste;
- the required turns of twist (which affects the handle);
- general spinning conditions.

It can be assumed that fibers of under 4 - 5 mm will be lost in processing (as waste and fly), fibers up to about 12 - 15 mm do not contribute much to strength but only to fullness of the yarn, and only those fibers above these lengths produce the other positive characteristics in the yarn. It is not only the condition at purchase that is important in assessment of fiber length; still more decisive is the length after carding. Processing conditions at the card, and also the fiber characteristics, must be such that the fibers survive carding without noticeable shortening. Where there is a high proportion of immature fibers, this will not be the case.

1.3.2. The staple diagram

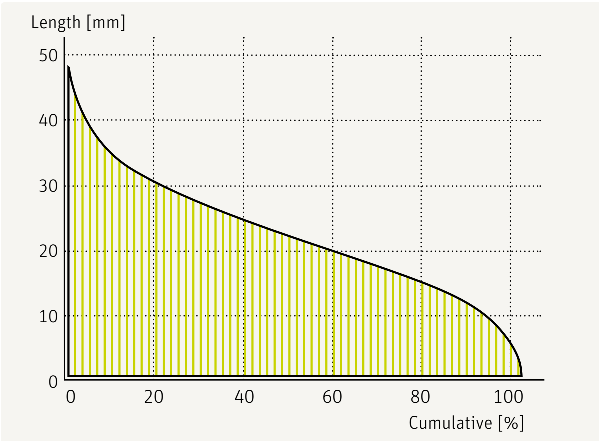


Fig. 1 – The staple diagram, by number

The fibers in the boll do not exhibit extremely great length differences. Noticeable shortening of many fibers arises before the spinning process owing to mechanical working, for example, ginning and cleaning. The effect is such that fiber length exhibits the greatest irregularity of all the fiber characteristics.

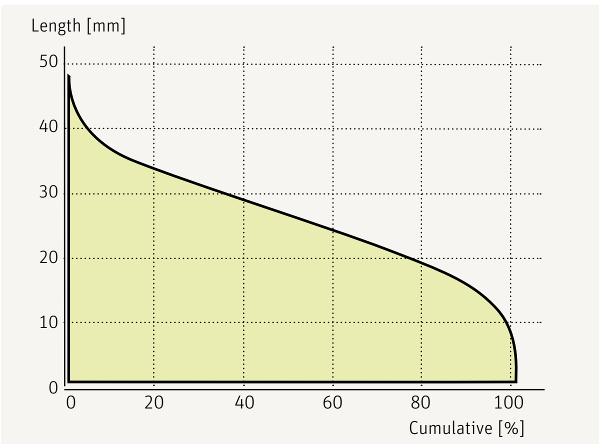


Fig. 2 – The staple diagram, by weight

In even the smallest tuft of cotton taken up in the hand, there will be all lengths from the absolute minimum (2 mm) to the absolute maximum (between 30 and 60 mm depending on origin). If the fibers of such a tuft are arranged next to each other with their ends aligned and sorted according to length in a coordinate system, then the staple diagram (Fig. 1) typical of cotton is obtained, the so-called numerical diagram . If the diagram is derived abstractly from the masses of the length groups, then the weight-based diagram is obtained (Fig. 2). This has a notably higher curve compared with the numerical diagram, because long fibers have more mass than short fibers and therefore a greater effect. The weight-based diagram corresponds to the distribution of fibers in the yarn cross-section. This diagram should therefore be referred to in considerations and calculations relating to the yarn. On the other hand, the numerical diagram emphasizes the proportion of short fibers. It provides in visual form a good assessment of the running behavior in the process. The two average staple lengths are related as follows:

$$\bar{l}_W = \bar{l}_N + \frac{s^2}{\bar{l}_N}$$

Where $\bar{l}_W$ is the average fiber length based on the weight-based diagram; $\bar{l}_N$ is the average fiber length based on the numerical diagram; *s* is the standard deviation of the fiber length distribution. In addition, in relation to fiber materials, five types of diagrams can be distinguished according to their form (Fig. 3 - Fig. 7). Measurment of the staple diagram is possible by AFIS-Systems.

1.3.3. Various diagram forms

1.3.3.1. Rectangular staple

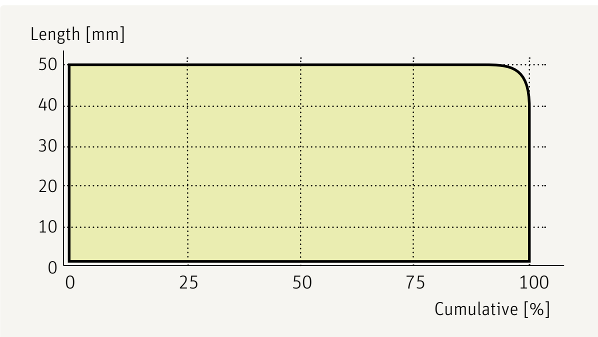


Fig. 3 – Staple diagram, rectangular staple

The rectangular staple (Fig. 3) is achievable, and imaginable, only with man-made fibers. Since the fibers are all equally long, no length variations are present, and material of this type would seem ideal. Such an impression would be false, however. For one thing, the length evenness cannot be maintained into the yarn because fibers are shortened in the spinning mill, mainly at the cards. For another, spinning machines are not suited to the processing of fibers having all the same length. In the drafting arrangement, for example, such fibers are moved not individually but in bunches, thereby finally producing a high degree of unevenness in the yarn.

1.3.3.2. Triangular staple

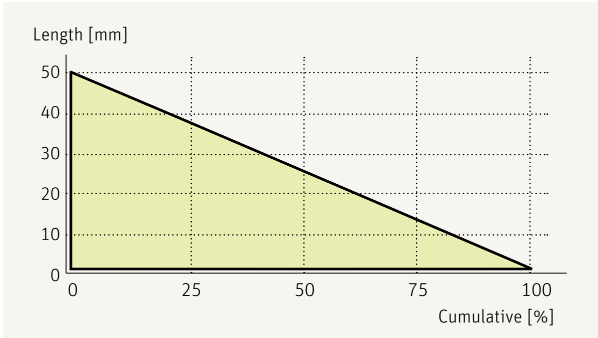


Fig. 4 – Staple diagram, triangular staple

The triangular staple (Fig. 4) permits better processing than the rectangular staple, but contains too many short fibers. During movement of fibers, for example, in the drafting arrangement, the short fibers cannot be kept under control; they move freely and produce substantial unevenness. Moreover, they cannot always be bound into the body of fibers, so that some of them are lost, thereby producing waste and fly at the machines and devices. If a short fiber is bound-in, however, one end often projects. The yarn is hairy. A certain hairiness is necessary for some product properties (e.g. knitted fabrics).

1.3.3.3. Trapezoidal staple

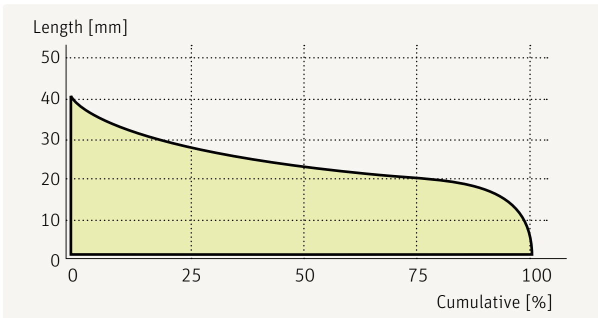


Fig. 5 – Staple diagram, trapezoidal staple

The trapezoidal staple (Fig. 5) is the ideal staple for processing and is more suitable the flatter the curve is. However, a flat curve often means a high price. This diagram is typically for Cotton.

1.3.3.4. Stepped staple

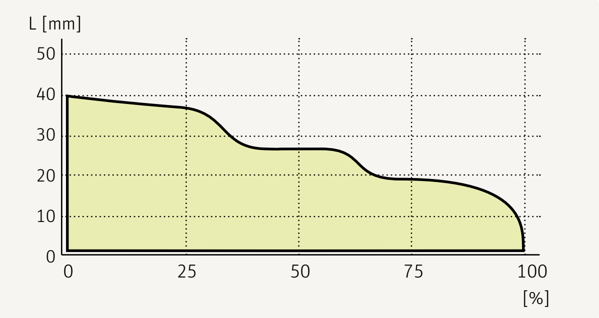


Fig. 6 – Staple diagram, stepped staple

If fiber materials of very different lengths are blended in the wrong proportions, then a stepped staple curve (Fig. 6) can arise. As with a rectangular staple, the fibers can be moved only in groups, with the same effects as mentioned before.

1.3.3.5. Fibrogram

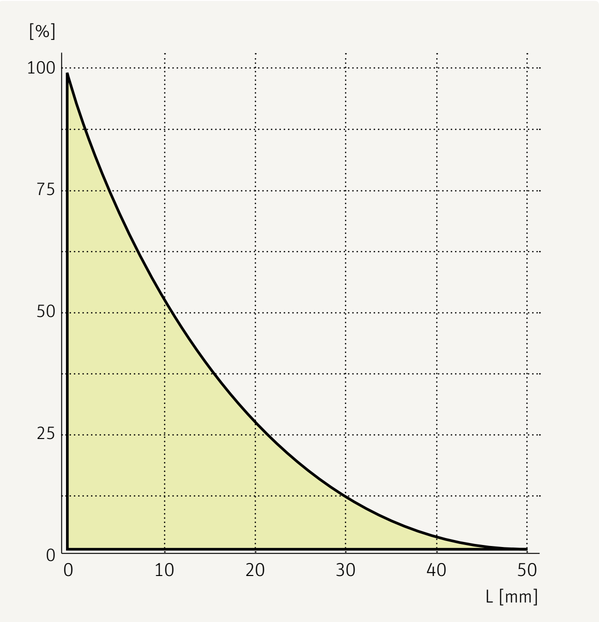


Fig. 7 – Staple diagram, Fibrogram

In addition to the staple diagram, the Fibrogram (Fig. 7) is available. Whereas in the staple diagram the fibers are aligned at one end, in the Fibrogram they are arranged by clamping randomly distributed fibers of a cotton sample. The fibers protuding from the clamps are straightened by a brushing process and measured optically.
The normal staple diagram represents an artificial picture, which does not occur anywhere in practice, but the Fibrogram corresponds to the arrangement of fibers at the nip line of rollers. It gives a good representation of the drafting operation and of the arrangement of the fibers in the yarn. It is produced by high volume instrumentation such as HVI. The lengths are stated as span-lengths, that is, lengths of clamed fibers that exceed a certain distance.

1.3.4. The specification of length

Both a parallelized, ordered bundle of fibers in the classers hand and the real staple length derived from it are referred to as the staple. The accurate fiber length derived from this is referred to as the staple diagram. Looking at the staple diagram in Fig. 8, it is clear that various measures of length can be derived, for example:

- maximum fiber length;
- minimum fiber length;
- average fiber length.

With some expections these values may be of interest to the statistician, but they tell the spinner nothing because they enable a statement to be made neither regarding the product nor regarding the process. The trade and the processor commonly use the following data, such as:

- classifying staple (trade staple, classer's staple length);
- upper quartile length (with end oriented methods);
- upper half mean length or mean length (according to weight) ($\bar{x}$);
- 1 %, 2.5 %, 5 % or 50 % span length measurements (as setting staples) (e.g. 2.5 % span length).

The trade staple (classer's staple, s) is the most important specification of length. It is established to 1/32 inch during classifying of the cotton and corresponds to the fiber length in the weight-based diagram at about 25 % (s) and in the numerical diagram at about 15 % (s). It corresponds also to the 2.5 % span length of Fibrogram and to the upper half mean length of HVI (calculated from Fibrogram).

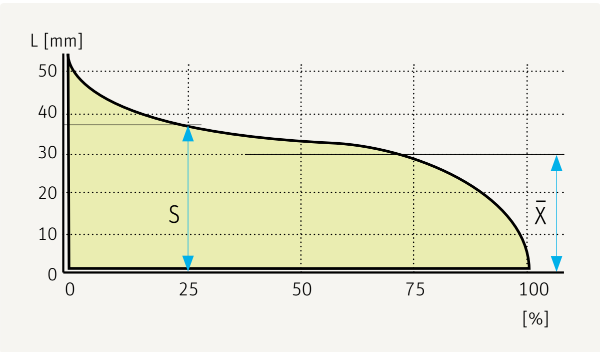


Fig. 8 – Staple diagram by weight, specification of lengths

The 1 % and 2.5 % span length are lengths that are needed in setting machines, especially roller spacings. The following length groupings are currently used in stating the trade staple (classer's staple) for cotton:

- short staple: 1″ or less;
- medium staple: 1 1/32″ - 1 1/8″;
- long staple: 1 5/32″ - 1 3/8″;
- extra-long staple: 1 13/32″ and above.

Specification of the trade staple alone is not enough, because the slope of the curve is not taken into account. With the same trade-staple length, the staple diagram could approach either the rectangular or the triangular form. The proportion of short fibers will then be correspondingly high or low. In order to estimate how good the distribution of length is, the following data can be used:

- a second point on the Fibrogram curve (e.g. 50 % span length derived from staple);
- the coefficient of variation; or
- the proportion of short fibers (e.g. percentage diagram shorter tahn 1/2 inch); or
- Uniformity Ratio (UR) from HVI measurements.

1.3.5. The proportion of short fibers

The proportion of short fibers has a very substantial influence on the parameters listed under Section 1.3.1. (except in the case of rotor spinning, where this influence is less). Besides this influence, a large proportion of short fibers also leads to considerable fly contamination (among other problems), and thus to strain on personnel, on the machines, on the workroom, and on the air-conditioning, and also to extreme drafting difficulties. Unfortunately, the proportion of short fibers has increased substantially in recent years in cotton available from many sources. This is due to mechanical picking and hard ginning. Schenek [2] and Lord [3] distinguish according to absolute short-fiber content and relative short-fiber content. In the great majority of cases, the absolute short-fiber proportion is specified today as the percentage of fibers shorter than 10, 11, 12 or 12.5 mm (½ in.).
The short-fiber limit has not been standardized but may settle at around 12 or 12.5 mm. Rieter is using 12.5 mm as a standard. Since the short fibers cannot be measured easily, this value is seldom really accurate. If more exact values are required, the relative short-fiber content must be established as proposed by Lord. The procedure is, however, very demanding.

1.4. Fiber strength

Strength is very often the predominant characteristic. This can be seen from the fact that nature produces countless types of fibers, most of which are not usable for textiles because of inadequate strength. The minimum strength for a textile fiber is approximately 6 cN/tex (about 6 km breaking length). Since binding of the fibers into the yarn is achieved mainly by twisting, and thus can exploit only 30 - 70 % of the strength of the material, a lower borderline of about 3 cN/tex is finally obtained for the yarn strength, the minimum strength of a yarn. Fiber strength will increase in importance in future, since most new spinning processes exploit the strength of the material less well than older processes.
Some significant breaking strengths of fibers are:

- polyester fiber 35 - 60 cN/tex
- cotton 15 - 40 cN/tex
- wool 12 - 18 cN/tex

In relation to cotton, the strength of fiber bundles was measured and stated as the Pressley value. The following scale of values was used (93 000 p.s.i = 93):

- 93 and above = excellent
- 87 - 92 = very strong
- 81 - 86 = strong
- 75 - 80 = medium
- 70 - 74 = fair
- 70 and below = weak

Conversion to physical units should be avoided because the measuring procedure is not very exact.
Today the fiber bundles are commonly tested with HVI instrumentation. Depending on the used calibration standard (USDA- or HVI-calibration cottons) the strength is expressed in g/tex (cN/tex).
For the commonly used HVI-CC calibration the following scale of values is used (1/8 in. gauge strength g/tex) [27]:

- 32 and above = very strong
- 30 - 32 = strong
- 26 - 29 = base
- 21 - 25 = weak
- 20 and below = very weak

Except for polyester and polypropylene fiber, fiber strength is moisture-dependent. It is important to know this in processing and also in testing. Since fiber moisture is dependent upon the ambient-air conditions, it depends heavily on the climatic conditions and the time of exposure before operation. Whereas the strength of cotton, linen, etc., increases with increasing moisture content, the reverse is true for polyamide fiber, viscose and wool.

1.5. Fiber elongation

Three concepts must be clearly distinguished:

permanent elongation: that part of the extension through which the fiber does not return on relaxation;

elastic elongation: that part of the extension through which the fiber does return on relaxation;

breaking elongation: the maximum possible extension of the fiber until it breaks, i.e. the permanent elongation and the elastic elongation together.

Elongation is specified as a percentage of the starting length. The elastic elongation is of decisive importance since textile products without elasticity would hardly be usable. They must be able to deform (e.g. at knee or elbow) in order to withstand high loading (and also during processing), but they must also return to shape. The fiber elongation should therefore be at least 1 - 2 % (glass fibers), and preferably slightly more. The greater crease-resistance of wool compared with cotton arises, for example, from the difference in their elongation:

- cotton 6 - 10 %;
- wool 25 - 45 %.

The following scale represents the cotton fiber elongation [27]:

- below 5.0 % = very low;
- 5.0 - 5.8 % = low;
- 5.9 - 6.7 % = average;
- 6.8 - 7.6 % = high;
- above 7.6 % = very high.

Man-made fibers show higher elongation values from about 15 to 30 %. For functional textile goods, still higher elongations are necessary sometimes, but they make processing in the spinning mill more difficult, especially in drafting operations. Higher elongations are needed for sportswear, hosiery, corsetry, and stretch products. If a fiber is subjected to tensile loading, demands are made on both its strength and elongation. Strength and elongation are therefore inseparably connected. This relationship is expressed in the so-called stress/strain diagram. For each type of fiber, there is a typical curve. In blending, it should be ensured that the stress-strain curves of the fibers to be blended are similar in shape. Measurment of elongation is difficult and time consuming.

1.6. The slenderness ratio (stiffness)

Fiber stiffness (Fig. 9) plays a significant role, mainly when rolling, revolving, and twisting movements are involved. A fiber that is too stiff has difficulty in adapting to these movements. For example, it is not properly bound into the yarn, produces hairiness, or is even lost in processing. Fibers that are not stiff enough have too little springiness. They do not return to shape after deformation. They have no longitudinal resistance. In most cases, this leads to the formation of neps. Fiber stiffness is dependent upon fiber substance and also upon the relationship between fiber length and fiber fineness. Fibers having the same structure and diameter will be stiffer, the shorter they are.

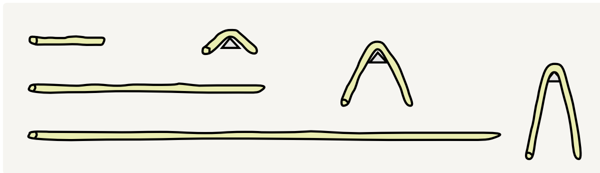


Fig. 9 – Stiffness of fibers of different lengths

The slenderness ratio can serve as a measure of stiffness:

Slenderness ratio = Fiber length/Fiber diameter

Since the fibers must wind, as they are bound-in during yarn formation in the spinning machine, the slenderness ratio also determines to some extent where the fibers will finish up:

- fine and / or long fibers in the core;
- coarse and / or short fibers at the yarn periphery.

1.7. Fiber cleanness

1.7.1. Impurities

In addition to usable fibers (lint), cotton stock contains foreign matter of various kinds [1, 25]:

Vegetable matter

- husk portions
- seed fragments
- stem fragments
- leaf fragments
- wood fragments

Mineral material

- earth
- sand
- ore dust picked up in transport
- dust picked up in transport

Sticky contaminations

- honeydew (insect sugar)
- grease, oil, tar
- additives

Other foreign matter
- metal fragments
- cloth fragments
- packing material (mostly polymer materials)

Fiber fragments
- fiber particles (which finally make up the greater portion of the dust)

This foreign material can lead to extreme disturbances during processing.
Metal parts can cause fires or damage card clothing. Cloth fragments and packing material can lead to foreign fibers in the yarn and thus to its unsuitability for the intended application.
Vegetable matter can lead to drafting disturbances, yarn breaks, filling-up of card clothing, contaminated yarn, etc.
Mineral matter can cause deposits, high wear rates in machines (grinding effects, especially apparent in rotor spinning), etc.

The new spinning processes are very sensitive to foreign matter. Foreign matter was always a problem but is becoming steadily more serious from year to year. This is due primarily to modern high-performance picking methods; hard ginning and cleaning; pre-drying; careless handling during harvesting, packing, and transport; modern packing materials.
Today, foreign fibers, for example, have become almost a nightmare for the spinner. The amount of foreign material (primarily of vegetable origin) is already taken into account in grading. Fig. 10 shows the ranges for impurities in American cotton as given in the literature of the Trützschler company. The scale below represents the degree of trash:
- up to 1.2 % = very clean;
- 1.2 - 2.0 % = clean;
- 2.1 - 4.0 % = medium;
- 4.1 - 7.0 % = dirty;
- 7.1 % and more = very dirty.

ITMF publishes biannually a survey on cotton contamination and states most affected origins.

1.7.2. Neps

Neps are small entanglements or knots of fibers. In general, two types of neps can be distinguished: fiber neps and seed-coat neps, that is, small knots that consist only of fibers and others containing foreign particles such as husk, seed or leaf fragments. Investigations made by Artzt and Schreiber [11] indicate that fiber neps predominate, particularly fiber neps having a core mainly of immature and dead fibers. Thus it is clear that there is a relationship between maturity index [3] and neppiness. Neppiness is also dependent, exponentially, on fiber fineness, because fine fibers have less longitudinal stiffness than coarser fibers. The processing method also has a considerable influence. A large proportion of the neps in raw cotton is produced by picking and hard ginning, and the amount of neps is substantially increased in the blowroom. The card is the first machine to reduce the amount of neps to a usable level, and nep reduction at the card is achieved primarily by disentanglement rather than by elimination. Neps not only create disturbance in themselves as thick places, but also in dyed fabrics because they dye differently from the rest

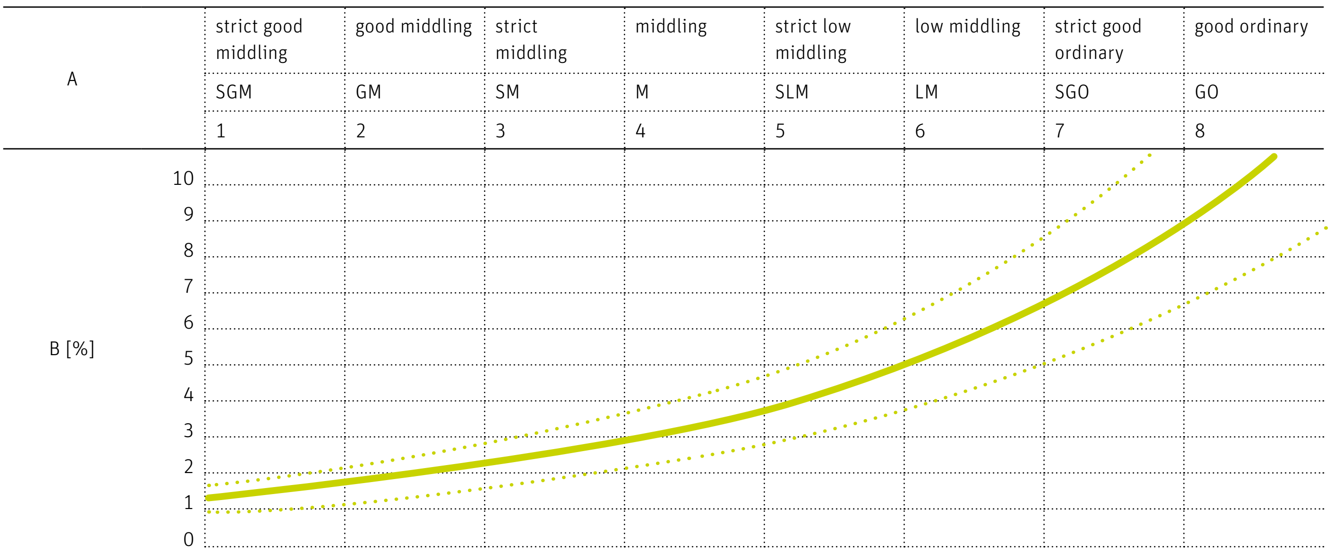


Fig. 10 – Proportion of waste in cotton of different classes
A, classification; B, proportion of trash as percentage

of the fibers, and thus become clearly visible in the finished cloth.
Based on the consolidated findings of Uster Technologies Inc. (Zellweger Luwa AG) [28], the following scale represents the amount of neps per gram in 100 % cotton bales:
- up to 150 = very low;
- 150 - 250 = low;
- 250 - 350 = average;
- 350 - 450 = high;
- above 550 = very high.

1.7.3. Dust
1.7.3.1. Definition

Dust consists of small and microscopic particles of various substances, which are present as suspended particles in gases and sink only slowly, so that they can be transported in air over substantial distances. In accordance with a classification system established by the International Committee for Cotton Testing Methods (ITMF), the following types are to be distinguished:

PARTICLE SIZE (µm)	
Trash	above 500
Dust	50 - 500
Microdust	15 - 50
Breathable dust	below 15

A paper published by the International Textile Bulletin [4] indicates that microdust consists of 50 - 80 % fiber fragments, leaf and husk fragments, 10 - 25 % sand and earth, and 10 - 25 % water-soluble materials. The high proportion of fiber fragments indicates that a large part of the microdust arises in the course of processing. Mandl [5] states that about 40 % of the microdust is free between the fibers and flocks, 20 - 30 % is loosely bound, and the remaining 20 - 30 % is firmly bound to the fibers.

1.7.3.2. Problems created by dust

Leifeld [6] lists the following problems as created by dust.

Additional stress on personnel:
- dust is unpleasant, e.g. for eyes and nose;
- it can induce allergies;
- it can induce respiratory disease (byssinosis).

Environmental problems:
- dust deposits;
- accumulations, which can fall into the machines;
- contamination of the air-conditioning.

Effects on the product:
- quality deterioration directly;
- or indirectly through machine faults.

Stress on the machines:
- dust accumulations leading to operating disturbances;
- jamming and running out of true;
- increased yarn unevenness;
- more end breaks;
- rapid wear of machine components (e.g. rotors).

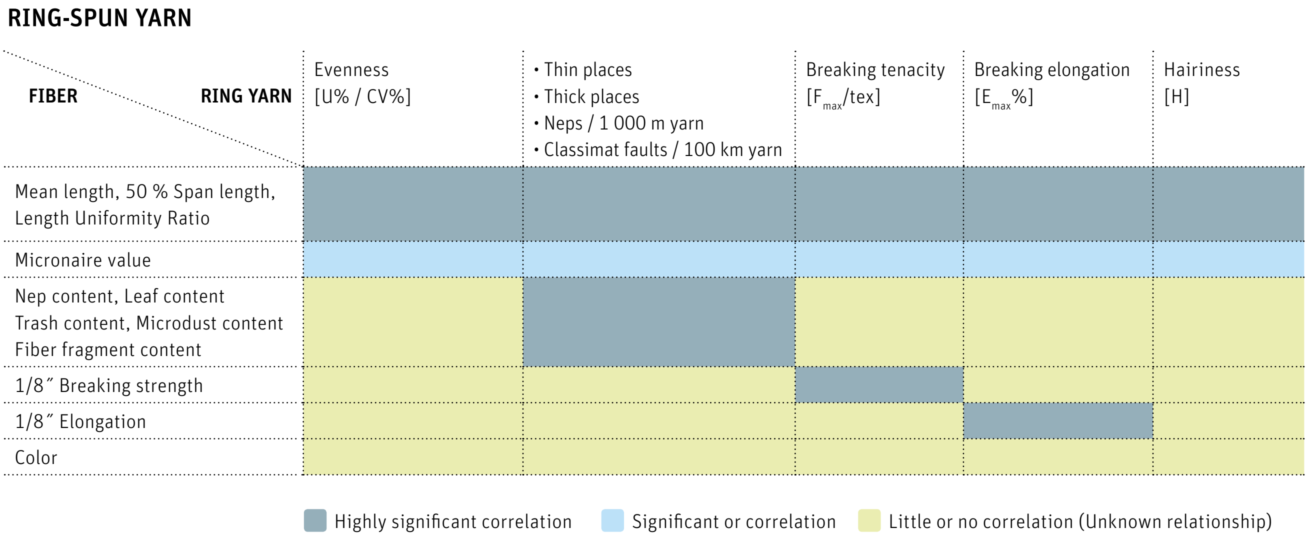


Fig. 11 – Correlation between fiber properties and yarn properties according to Uster Technologies [23]

1.8. Chemical deposits (sticky substances)

The best-known sticky substance on cotton fibers is honeydew. Strictly, this is a secretion of white fly or aphid, but today all sticky substances are incorrectly called honeydew. Schenek [1,7] identifies these sticky substances as:

Secretions	honeydew;
Fungi and bacteria	decomposition products;
Vegetable substances	sugars from plant juices, leaf nectar, overproduction of wax;
Fats, oils	seed oil from ginning;
Pathogens	
Synthetic substances	defoliant, insecticides, fertilizers, oil from harvesting machines.

In the great majority of cases, however, the substance is one of a group of sugars of the most variable composition, primarily, but not exclusively, fructose, glucose, saccharose, melezitose, trehalose and trehalulose, as found, in sticky cottons [26].
These saccharides are mostly, but not always, produced by insects or the plants themselves, depending upon the influences on the plants prior to picking.

Whether or not a fiber will stick depends, however, not only upon the quantity of the sticky coating and its composition, but also upon the degree of saturation as a solution [1] and the working temperature in the spinning mill. Accordingly, conclusions regarding stickiness in the production process cannot be drawn automatically from the determination of quantity. Elsner [8] states that the sugars are broken down by fermentation and by microorganisms during storage of the cotton. This occurs more quickly, the higher the moisture content. During spinning of sticky cotton, however, the relative humidity of the air as well as the ambient temperature in the production area should be kept as low as possible.

1.9. Relative importance of the fiber influences

The influence of fiber parameters on yarn parameters and on running performance varies with circumstances. Their significance also differs for the individual spinning systems, new or conventional. Fig. 11 shows the correlation between fiber and yarn properties as determined by Uster Technologies [23], and Fig. 12 the influence on yarn strength determined by Sasser [24].

FIBER CHARACTERISTICS WHICH AFFECT YARN BREAKING FORCE PROPERTIES

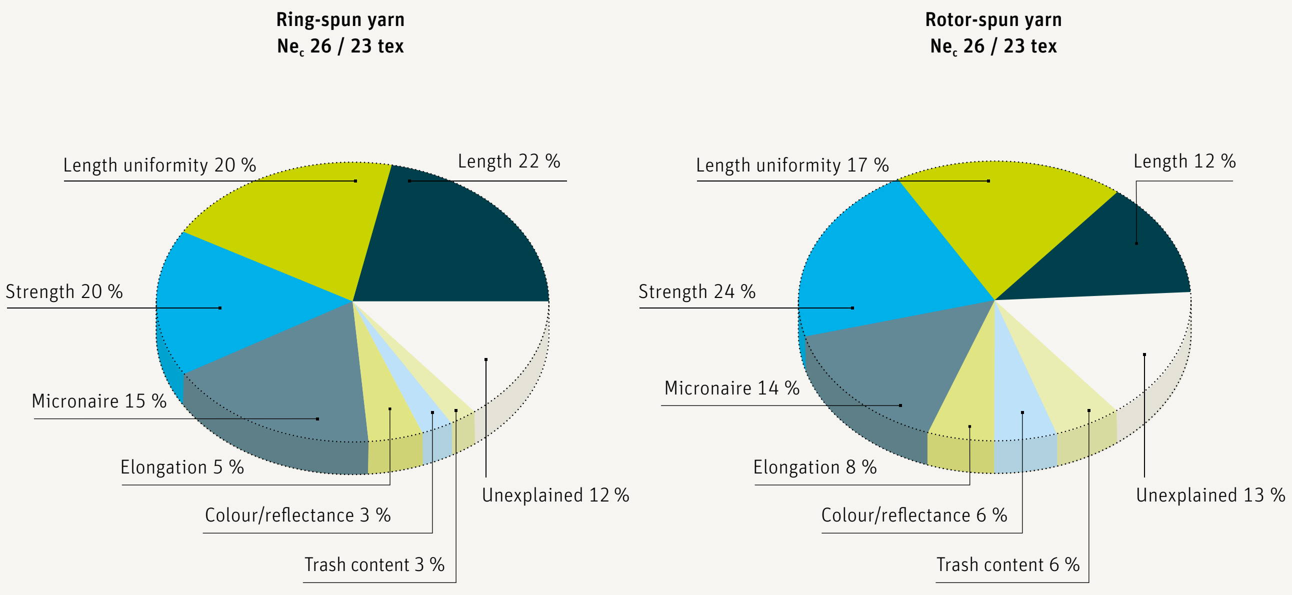


Fig. 12 – Influence of fiber properties on yarn strength according to Sasser [24]

2. OPENING

2.1. The need for opening

Carrying out the basic operations of spinning demands, almost without exception, an open, processable material. However, the raw material enters the spinning mill in highly pressed form (bale) for optimum transport and storage. Thus, opening must precede the other basic operations.

2.2. Type and degree of opening

Two stages of opening must be distinguished:
- opening to flocks: in the blowroom;
- opening to fibers: in the card and OE spinning machine.

In addition, the technological operation of opening can include:
- opening out – in which the volume of the flock is increased while the number of fibers remains constant, i.e. the specific density of the material is reduced; or
- breaking apart – in which two or more flocks are formed from one flock without changing the specific density.

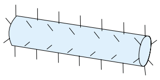
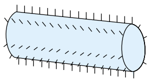
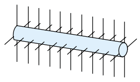
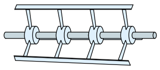
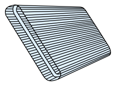
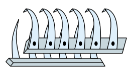
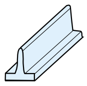
Type	Appearance	Description
Rollers		Small diameter, widely used, e.g. in step cleaners.
Drums		Larger diameter, e.g. in the mono-cylinder cleaner.
Quilted shaft		Shaft with many long beater rods, hardly used.
Multiple-blades beater		Two, three, or more arms. Now used only in old blowroom lines.
Spiked lattice		Endless belts with transverse wooden or plastic bars in which needles are set, gives very gentle opening.
Picker		In the bale picker and blending grab (both outdated).
Carding bars or plates		The devices associated with the carding drums of the card.

Table 2 – Opening devices

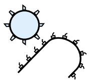
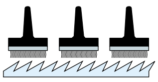
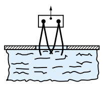
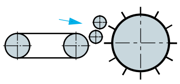
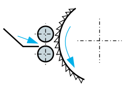
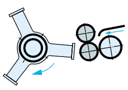
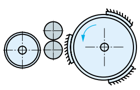
Opening operations	Opening device	Type of opening		Intensity	Gentleness	Remarks
		Opening out	Breaking apart			
Tearing up		x	xx	++	+++	At the bale opener. Neps are produced when there is considerable tumbling in the hopper.
Picking apart		xxxx		++++	+	At the card and the rotor spinning machine. The only means of separating to individual fibers.
Picking out		x	xx	++	+++	Bale picker. Very gentle.
Plucking out		x	x	++	+	Widely used, e.g. on horizontal cleaners. The intensity is dependent on the point density of the clothing.
Tearing out		xx	x	+++	–	Carding rollers. They are aggressive, but necessary to remove fine particles produced at the gin.
Beating out		(x)	xx	–	+	Two or three bladed beaters. Give very poor opening. Hardly produce new surfaces (outdated).
Combing out		xxx	(x)	+++	++	Kirschner beater. Very gentle expansion. If operated as a cleaner, it usually produces high fiber losses (outdated).
Floating in air		(x)		–		Extremely small opening effects, e.g. in transport ducting.

Table 3 – Opening variants

Breaking apart would suffice for cleaning, but opening out is needed for blending and aligning. Both opening out and breaking apart are found in each opening operation – the degree of each is decisive. If, at the infeed to the card, there is a flock which has been mainly broken apart, but relatively little opened out, then staple shortening will quite certainly result. To enable an exact evaluation to be made of the degree of opening, therefore, both a measure of breaking apart, that is the size of the flock, and a measure of density (in g/cm^3) would be needed. Since both measures can be obtained only with considerable effort, the specification of the mass in milligrams/flock usually has to suffice. Such information is provided, for example, by a diagram from Rieter (Fig. 13) showing the degree of opening of several machines as a function of the material throughput. Fig. 14 from Trützschler [10] shows the increasing opening of the material from one blowroom machine to another. The curve in this example shows, amongst other things, that machines M4 to M5 are already superfluous. They not only make the process more expensive, but also stress the raw material in an unnecessary manner. Their use can only be justified if it substantially increases the degree of opening out (specific density) and thereby improves carding. Fig. 15 represents the ideal form of the opening curve as established by Trützschler [10].
Table 2 shows opening devices;
Table 3 shows opening variants.

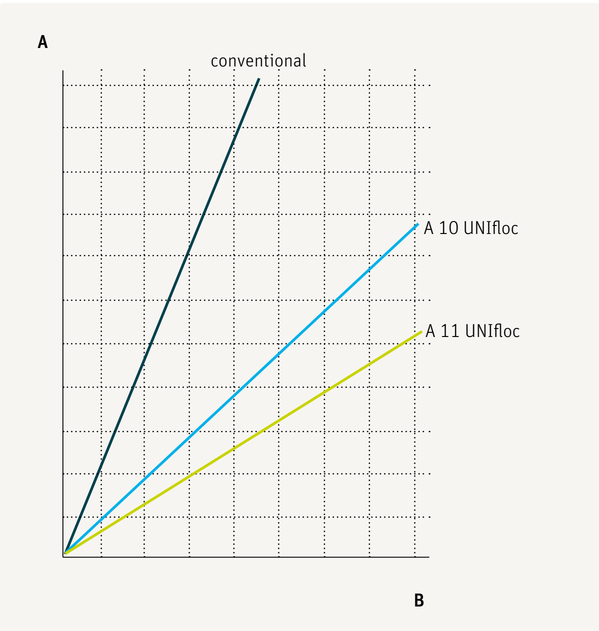


Fig. 13 – Dependence of degree of opening upon throughput
A, degree of opening (flock weight, mg); B, material throughput (kg/h)

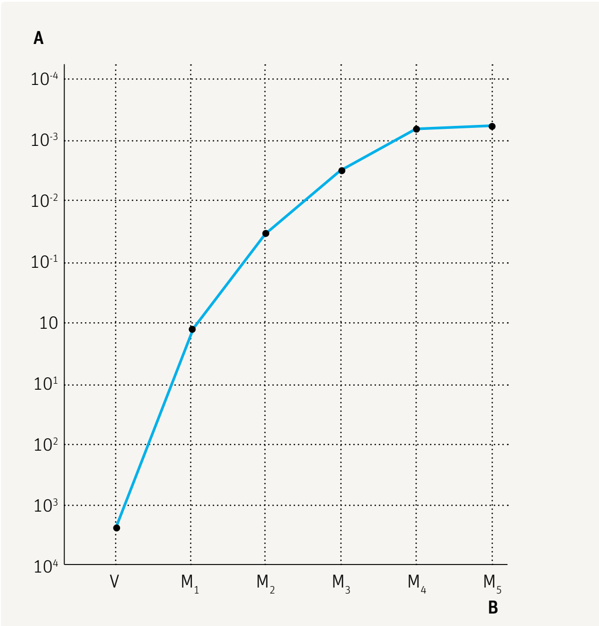


Fig. 14 – Increase in the degree of opening from machine to machine in a certain blowroom
A, degree of opening, flock weight in g/flock; B, machine passages;
V, feed material; M1 - M5, machines 1 - 5.

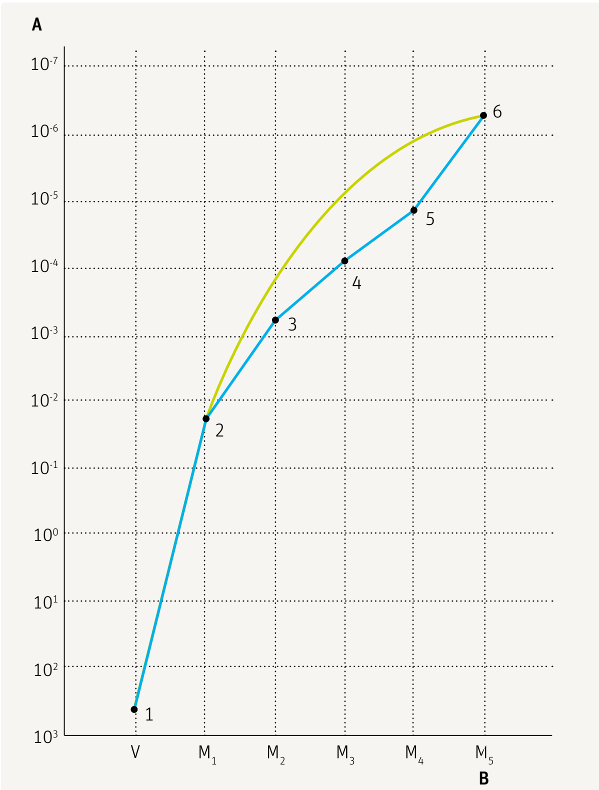


Fig. 15 – Ideal form of the opening curve (green line) in an older blowroom
A, degree of opening, flock weight in g/flock; B, machine passages;
M1 - M5, machines 1 - 5. It is clearly apparent that machines 4, 5 and 6 are superfluous; in modern lines, they should be omitted.

2.3. The intensity of opening

The intensity of opening is dependent amongst other things on the following:

- Raw material:
  - thickness of the feed;
  - density of the feed;
  - fiber coherence;
  - fiber alignment;
  - size of flocks in the feed.

- Machines / devices:
  - type of feed – loose or clamped;
  - form of feeding device;
  - type of opening device;
  - type of clothing;
  - point density of clothing;
  - arrangement of pins, needles, teeth, etc., on the surface, i.e. aligned or staggered;
  - spacing of the clamping device from the opening device.

- Speeds:
  - speed of the devices;
  - throughput speed of the material.

- Ambient conditions:
  - humidity;
  - temperature.

2.4. General considerations regarding opening and cleaning

The degree of cleaning cannot be better than the degree of opening. Accordingly, the following should be noted:

- Dirt can be removed practically only from surfaces.
- New surfaces must therefore be created continuously.
- The form of the opening machine must therefore be adapted to the degree of opening already achieved.
- The opening devices should become continually finer, i.e. within the blowroom line, a specific machine is required at each position.
- The degree of cleaning is linearly dependent upon the degree of opening.
- Newly exposed surfaces should as far as possible be cleaned immediately.
- This means that each opening step should be followed immediately by a cleaning step without intervening transport, during which the surfaces would be covered up again and would require re-exposure.
- Ideally the opening and cleaning machines should form a unit.
- A high degree of opening in the blowroom facilitates cleaning in the carding room.
- A high degree of opening out in the blowroom reduces shortening of staple at the cards.
- Opening and cleaning of cotton on only one (universal) opening machine is very difficult owing to the requirement for continual improvement of the degree of opening.
- On the other hand, each machine in the line represents often considerable stress on the fibers.
- Aside from economy, therefore, quality considerations indicate the smallest possible number of machine passages in the blowroom.
- Feeding of flocks in a clamped condition gives an intensive but usually not very gentle opening action.
- Feeding in a loose condition gives gentle, but not very intensive opening.
- Opened flocks should approach as closely as possible a spherical shape. Long narrow flocks lead to entanglements during rolling movements and pneumatic transport. Finally, they form neps.
- Narrow setting of the feed device relative to the roller increases the degree of opening, but also the stress on the material.

2.5. Carding
2.5.1. The purpose of carding

Chiefly, carding should separate the flocks into individual fibers. Additionally, carding results in cleaning, reduction of neps, aligning, blending, and elimination of some short fibers. The elimination of short fibers must, however, be viewed in proportion.
The main eliminated material is in the flat strips. Assuming flat waste at 1 to 2 %, with about half in the form of short fibers there is such a minor precentage of short fiber elimination that it could hardly be measured with the current coarse staple measuring equipment. The operation of carding is performed with the aid of oppositely disposed sets of teeth or small wire hooks.

2.5.2. Clothing arrangements

There are two possible arrangements of the clothing surfaces relative to each other: the carding disposition and the doffing (or stripping) disposition.

2.5.2.1. Carding disposition

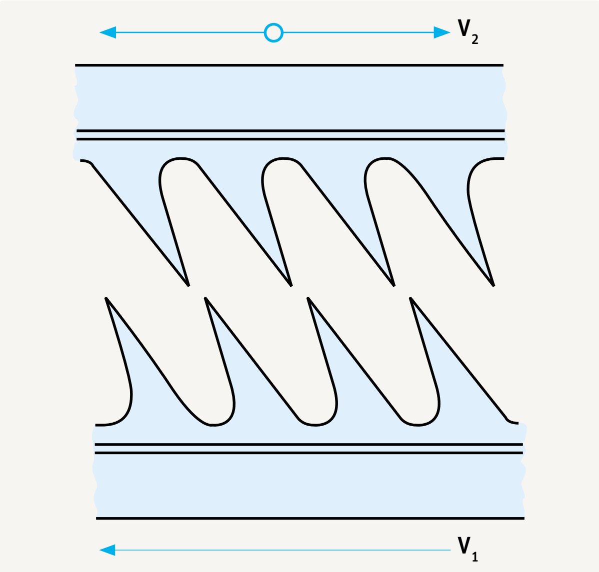


Fig. 16 – Carding disposition

The teeth face in opposite directions (Fig. 16). This is the typical arrangement between the main cylinder and the flats, and also between the main cylinder and the doffer. In order to enable carding to take place, v_1 must be greater than v_2 or v_2 must be in the opposite direction to v_1. In this action, the fibers are drawn apart, separated, and aligned.

2.5.2.2. Doffing disposition

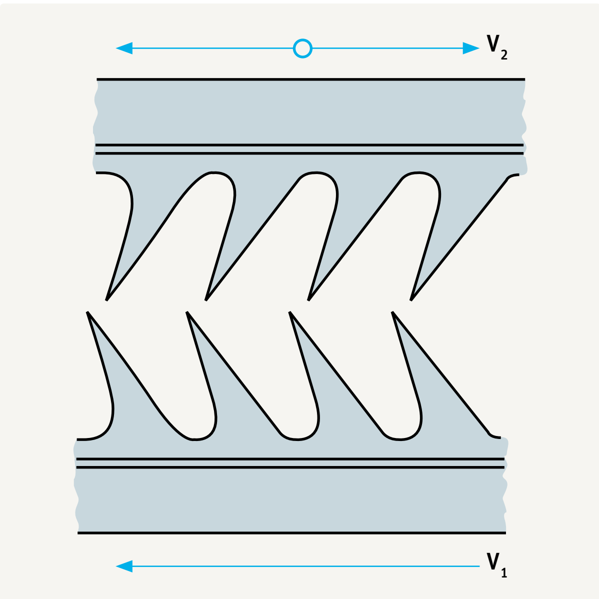


Fig. 17 – Doffing disposition

The teeth of both clothing surfaces face in the same direction (Fig. 17). This arrangement is typical of the licker-in/main cylinder region. Here there is a deliberate transfer of material from one clothing surface to another, but v_1 must be greater than v_2 (feeding clothing).

2.5.3. Forces acting on the fibers

2.5.3.1. Carding disposition

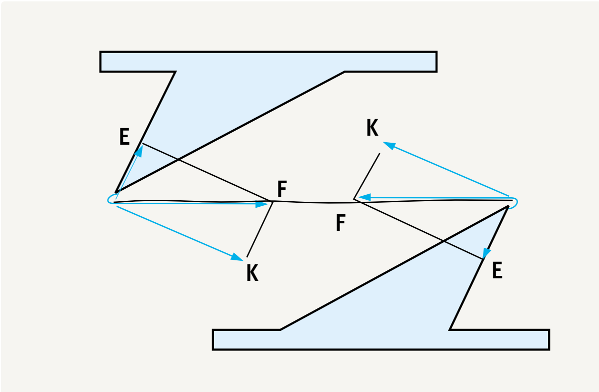


Fig. 18 – Forces in the carding disposition

If a fiber is held by friction at its ends on two teeth that are moving apart, tensile forces *F* act on the fiber in the axial direction owing to the drag from both sides (Fig. 18). Since the fibers are held on inclined surfaces, this tensile force can be resolved in accordance with the parallelogram of forces into two easily derivable components *E* and *K*, *E* being the component tending to draw the fibers into the clothing. The retention capability of the clothing is dependent on this component. The parameter *K* is the carding component, which presses the fiber towards the points of the other clothing surface. The fibers are in close contact with the other clothing surface and are processed intensively.

2.5.3.2. Doffing disposition

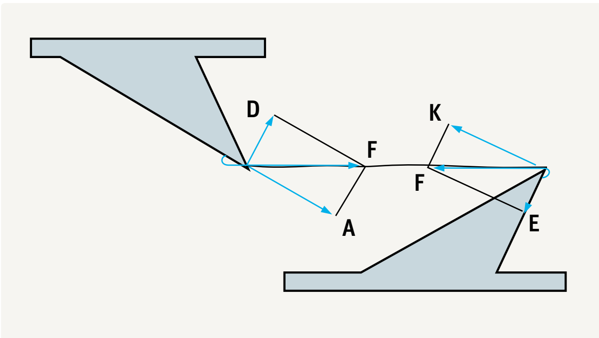


Fig. 19 – Forces in the doffing disposition

In the doffing arrangement, the directions of the forces acting at one tooth have changed (Fig. 19). Resolution of force *F* into its components gives component *D*, which presses the fiber against the tooth, and a stripping component *A*, which tends to push the fiber off the tooth. The fiber catches on the other tooth and is stripped.

2.5.3.3. Centrifugal forces

Centrifugal force is superimposed on the forces produced by the machine parts. However, in order to produce noticeable effects, substantial speeds are required, and these speeds arise practically only at the main cylinder and to some extent at the licker-in.
The centrifugal forces are effective mainly in directions away from the main cylinder, and act both on fibers and on foreign particles. In spite of this, the fibers are not thrown off (at least the longer ones), because the high air resistance due to the rotation presses the fibers back flat against the surface of the main cylinder. In comparison to all other forces, centrifugal forces are of minor significance except when considering trash and short fibers. In this case the centrifugal forces support the transfer of trash and short fibers from the main cylinder into the flats.

2.5.4. Fiber transfer factor

Reference to the forces exerted by the teeth in the carding disposition will show that, all other things being equal, it is a matter of chance on which tooth tip the fiber will remain caught.
Such a random result is not acceptable everywhere. The doffer, although it is in the carding disposition relative to the main cylinder, must be able to take up a portion of the fibers. This is only possible if the doffing conditions are improved by the following:

- An increased tooth density in the doffer clothing (no longer used with rigid wire clothing).
- A clothing supporting the carding capacity, by using a greater carding angle for the doffer clothing and thus obtaining an increased drawing-in component *E*.
- Maintaining the catching effect of the clothing by frequent sharpening.
- Keeping the doffer clothing clean and receptive by continually withdrawing the web.
- A very narrow setting between main cylinder and doffer.
- Assisting transfer of fibers by special air-circulation conditions in the convergent space between the main cylinder and the doffer.

Even with these measures, the odds in favor of transfer are not even 50:50.
According to Artzt and Schreiber [11], the transfer factor with rigid wire clothing is only 0.2 - 0.3.
This means that, on average, a fiber rotates from three to five times with the main cylinder before it passes to the doffer. The effect is caused by the strong adherence of the fibers to the main cylinder, the fibers being drawn into the main cylinder clothing during continual movement past the flats.

2.5.5. The most important working regions in carding

2.5.5.1. Pre-opening between feed roller and licker-in

This is the most serious problem zone of the card because the licker-in must tear individual flocks out of the fairly thick feed sheet with enormous force. Fiber damage is scarcely to be avoided here.
However, stress on the fibers is not the only important aspect. The degree of opening, on which the quality of carding is directly dependent, is also important – the more so, the higher the production rate of the card.
The degree of opening, degree of cleaning and, above all, damage to the raw material can be influenced by:

- thickness of the feed sheet;
- density of the feed sheet;
- evenness of the feed sheet;
- throughput speed;
- rotation speed of the cylinders;
- cylinder clothing;
- form of the feed plate;
- arrangement of the feed plate (co-rotation or counter-rotation).

On the other hand, the licker-in is the main elimination zone for coarse impurities.

2.5.5.2. Carding between main cylinder and flats

The main work of the card, separation into individual fibers, is performed between the main cylinder and the flats. Only by means of this fiber separation is it possible to eliminate the last dirt, especially the finer particles and dust. These pass into the flats, the extraction system, or the droppings.

When a flat moves into the working zone, it first fills up. This occurs relatively quickly, i.e. after only a few flats have moved into the working zone. Thereafter, hardly any further take-up of fibers occurs, and only carding takes place. Accordingly, if a fiber bundle does not find a place in the first few flats, then it can be opened only with difficulty.

It will be rolled between the working surfaces and usually leads to nep formation [13].

Equally important at this working position is the reduction of neps. Kaufmann [12] indicates that 75 % of all neps can be disentangled, and of these about 60 % are in fact disentangled.
Of the remaining 40 % disentanglable neps:
- 30 - 33 % pass on with the sliver;
- 5 - 6 % are removed with the flat strips;
- 2 - 4 % are eliminated with the waste.

The intensity of separation depends on:
- the sharpness of the clothing;
- the spacing of the main cylinder from the flats;
- the tooth density of the clothing;
- the speed of the licker-in (high, but not too high);
- the speed of the doffer (high, but not too high).

2.5.5.3. Transfer zone at the doffer

The arrangement of the clothing between the main cylinder and the doffer is not, as might have been expected, a stripping arrangement, but a carding arrangement. This is the only way to obtain a condensing action and finally to form a web. It has both advantages and disadvantages. The advantage, is that an additional carding action is obtained here. This is important, since the processing of the fibers differs somewhat from processing at the flats.
A disadvantage to be noted is the formation of hooks at this point. Before transfer, some of the fibers remain caught at one end on the teeth of the main cylinder (Fig. 20, *T*). During transfer, the other ends of the projecting fibers are caught by the clothing of the doffer and taken up. Since, however, the velocity of the main cylinder is much higher than that of the doffer, the teeth of the cylinder wire (*T*) smooth out the fibers in the direction of rotation, whereby the rear ends of the fibers remain caught on the teeth of the doffer (*A*).
By this means, they form hooks at their ends. In the web, and then in the card sliver, most of the fibers in the strand possess trailing hooks. However, aside from the serious disadvantage of hook formation, the carding effect mentioned is also produced here, since either the main cylinder clothing rakes through the fibers caught in the doffer clothing, or the doffer clothing rakes the fibers on the main cylinder. Neps can still be disentangled here, or non-separated neps disentangled during the next passage through the flats [11, 14].

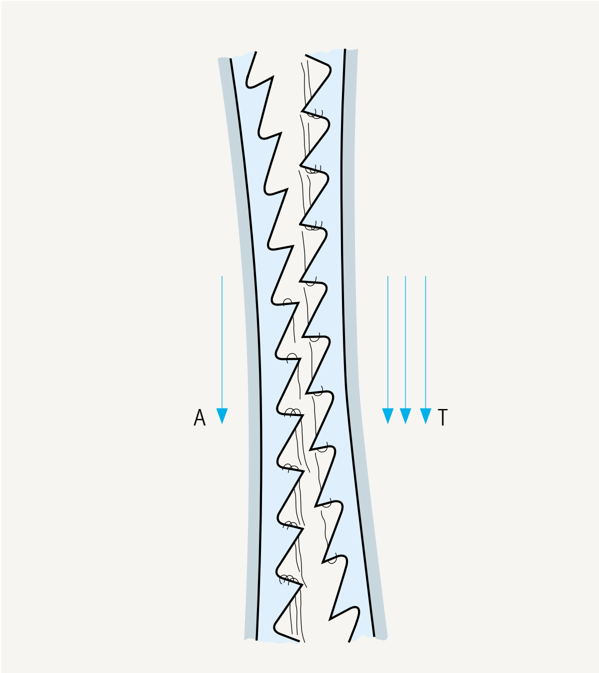


Fig. 20 – Transfer of fibers from the main cylinder (*T*) to the doffer (*A*)

The intensity of carding (as at other carding positions) is here dependent upon [14]:
- type of clothing;
- geometry of the teeth;
- number of teeth per surface;
- distance between the carding surfaces;
- speed relationships;
- sharpness of the clothing;
- degree of wear of the clothing.

The diameter of the cylinders is also relevant. Large diameters imply a large contact surface at the working positions and thus, in addition to improvement of the transfer factor, longer raking of the raw material by the clothing.

2.6. Straightening-out of fiber hooks
2.6.1. The straightening-out operation

A disadvantage of web formation at the card that has already been mentioned is the formation of hooks. According to investigations by Morton and Yen in Manchester, UK, and others, it can be assumed that the fibers in the web show the following hooks:
- more than 50 % have trailing hooks;
- about 15 % have leading hooks;
- about 15 % have doubled hooks, and
- less than 20 % have no hooks.

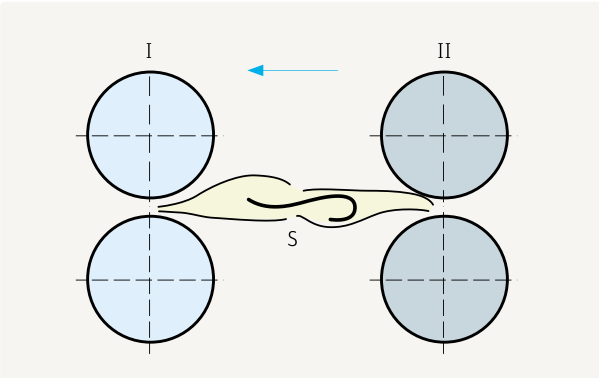


Fig. 21 – Trailing hooks in the drafting arrangement

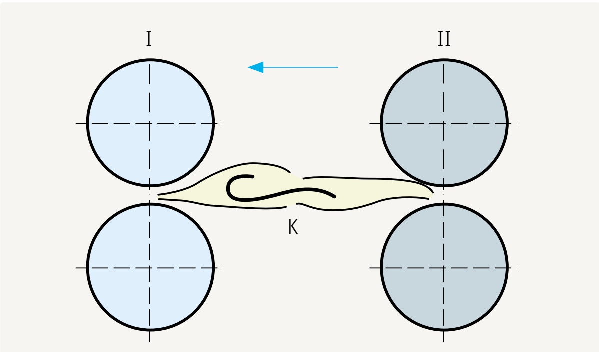


Fig. 22 – Leading hooks in the drafting arrangement

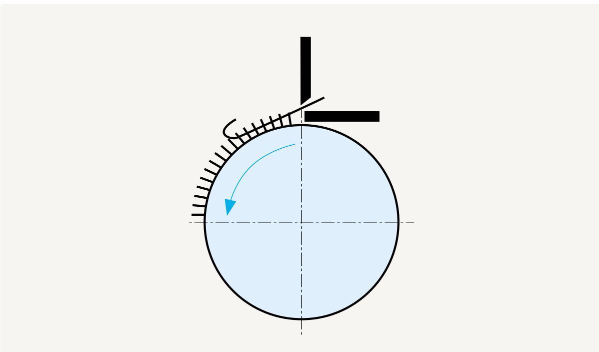


Fig. 23 – Leading hooks in the comber

Such fiber hooks, which effectively convert longer fibers to short fibers, cannot be permitted in the yarn. They must therefore be removed before yarn formation. This is done by the draft or by combing as the following description shows:
In the drafting arrangement, the fiber hooks may be bedded in the body of fibers either as leading or as trailing hooks (Fig. 21 and Fig. 22). Consider first a trailing hook (*S*): it will be seen that for a certain period it moves with the remainder of the fiber strand at the speed of the back roller towards the front roller. If the fiber tip passes into the nip region of the drawing roller, the fiber is accelerated. However, since the trailing end is moving with a relatively thick body of slowly moving fibers, the fiber is straightened before the whole fiber can reach the drawing speed – the hook is eliminated. On the other hand, leading hooks (*K*) are immediately caught bodily by the front roller and carried along unchanged (Fig. 22). The comber however mainly straightens out leading hooks, because the needles of the circular comb can grasp only these (Fig. 23).

2.6.2. Required number of machine passages

To eliminate the hooks, leading hooks must be presented to the comber and trailing hooks to the ring spinning machine. As Fig. 24 and Fig. 25 show, reversal of the hook occurs at each processing stage between the card and these machines. Accordingly, a definite number of machine passages are required in intervening stages. Between the card and the comber, there must be an even number of passages, and there must be an odd number between the card and the ring spinning machine. In rotor spinning, the disposition of the hooks is of little significance [15].

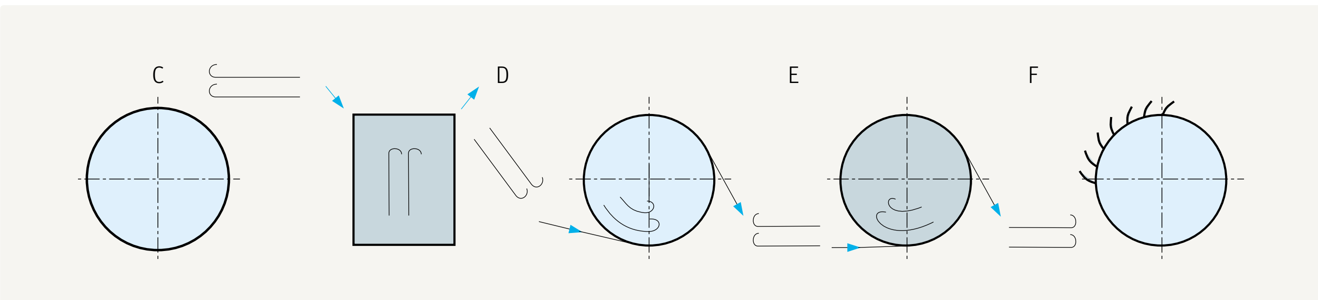


Fig. 24 – Reversal of the dispositions of hooks between the card and the comber
C, card; D, sliver-lap machine; E, ribbon-lap machine; F, comber

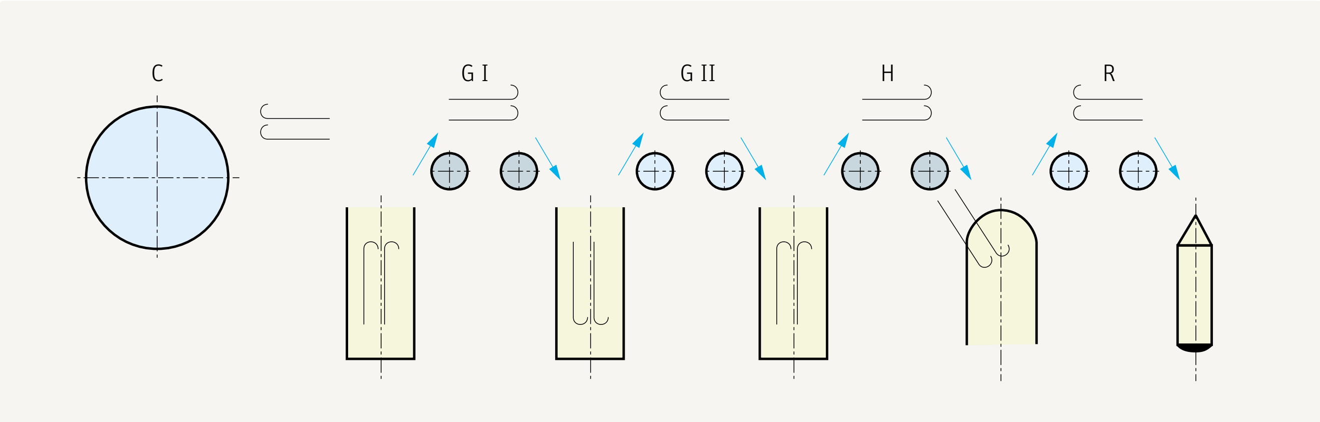


Fig. 25 – Reversal of the dispositions of hooks between the card and the ring spinning machine
C, card; GI, draw frame I; GII, draw frame II; H, roving frame; R, ring spinning machine

3. CLEANING

3.1. Impurities to be eliminated

In cleaning, it is necessary to release the adhesion of the impurities to the fibers and to give particles an opportunity to separate from the stock. This is achieved mostly by picking flocks out of the feed material and by rapid acceleration of these flocks over a grid. Dirt, dust, foreign matter, and neps should be eliminated.
Cleaning was always an important basic operation, and it will become steadily more important. For one thing, owing to machine harvesting, cotton contains more and more impurities, which furthermore are shattered by hard ginning; for another, almost all new spinning processes impose substantially higher demands on the cleanliness of the material than the conventional methods.

3.2. Possibilities for cleaning

The available possibilities for cleaning natural fibers can be divided broadly into three groups:

- chemical cleaning;
- wet cleaning (washing);
- mechanical cleaning.

This discussion will be confined to mechanical cleaning, in which usually only particles on the surface of the flocks can be removed.
The following procedures can be used:

- striking = falling out;
- beating = ejecting;
- scraping = separation;
- suction = separation;
- combing = extracting;
- use of centrifugal force = ejecting.

Striking, carried out by pins, noses, etc., on the opening devices, leads to repeated collisions of the flocks with the grid-bars, causing foreign particles to drop through.
In a beating operation, the flocks are subjected to a sudden strong blow. The inertia of the impurities, accelerated to a high speed, is substantially greater than that of the opened flocks owing to the low air-resistance of the impurities. The latter are hurled against the grid and, because of their small size, pass between the grid-bars into the waste box, while the flocks continue around the periphery of the rotating beater. Impurities can be scraped off when the fibers are guided, under relatively high friction, over machine components, grid-bars, mote knives, or even other fibers.

This operation is chiefly of importance in dust removal. Suction is less suited to the elimination of coarse particles than to extraction of dust. Transport air is fed through filters or perforated sheets; the small dust particles, which have been released during beating or transport, pass with the air through the fine openings. The flocks cannot pass.
In combing, needles pass completely through the body of fibers and draw impurities out of the inner regions. This is the only form of mechanical cleaning in which regions other than simple surfaces are cleaned.

Genuine exploitation of centrifugal force, in which there is no need for beating, is achieved, for example, in the card. Because of their high ratio of mass to surface, when compared with the fibers, the dirt particles are thrown out into the flats while the fibers are retained in the clothing by the air current. This system was used still more intensively in the "air stream cleaner" from the former Platt company (Fig. 26). In this machine the transport flow of air and stock (*A*) was subjected to rapid acceleration (V) before the transport direction was sharply altered, i.e. by more than 90° (*E*). The flocks were able to follow the diversion but the heavier impurities flowed straight on through a slot in the duct into a waste box (*C*).
However, as impurities have become smaller and smaller in recent decades, this system does not function any longer – it has been abandoned.

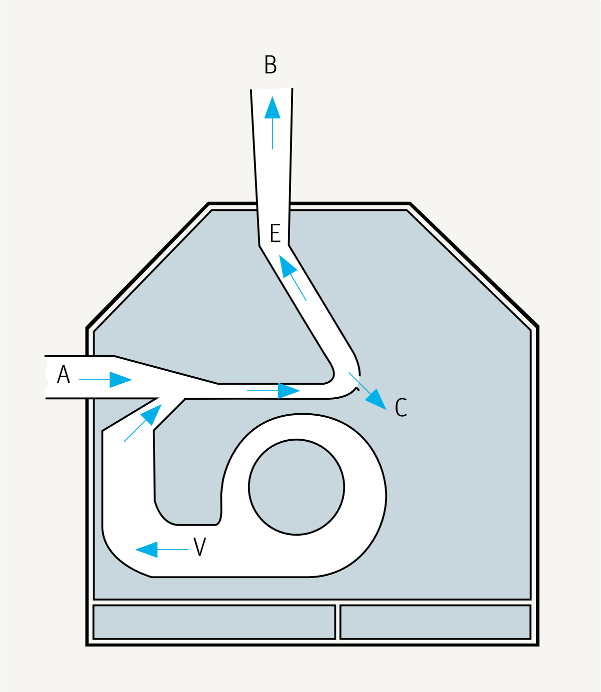


Fig. 26 – Former Platt air-stream cleaner

3.3. Grid and mote knives

Ignoring perforated surfaces and combs, separation of stock and impurities is achieved by devices which let the impurities pass but retain the stock. In most cases a grid (beneath the beater) is used, and this can be additionally fitted with one or two mote knives in front of the grid (Fig. 27). Grids can be made of perforated sheet (low elimination effect); slotted sheet (low elimination effect); bars with edges, arranged one after the other. A controlled influence on the elimination effect can be obtained by means of grid and mote knives. The intensity of cleaning depends on the spacing of the grid from the opening device; the setting angle of the bars relative to the opening device; the width of the gaps between the bars.

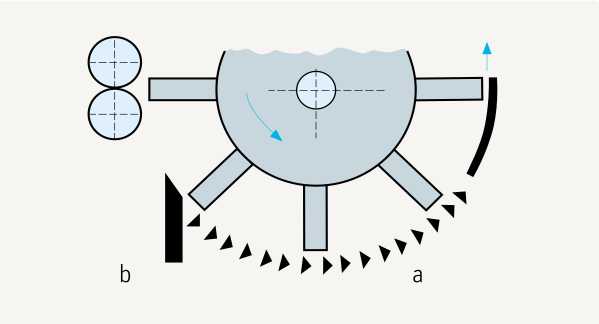


Fig. 27 – Co-operation of opening element, grid bars (a) and mote knife (b)

3.4. Influencing factors

- The larger the dirt particles, the better they can be removed.
- Since almost every blowroom machine can shatter particles, as many impurities as possible should be eliminated at the start of the process.
- Opening should be followed immediately by cleaning (if possible, in the same machine).
- The higher the degree of opening, the higher the degree of cleaning.
- A very high cleaning effect is almost always obtained at the expense of high fiber loss.
- In borderline cases, there should be slightly less cleaning in the blowroom and slightly more at the card.
- Where a waste recycling installation is in use, a somewhat higher waste percentage can be accepted in the blowroom.
- Higher roller speeds result in a better cleaning effect, but also more stress on the fibers.
- Above a certain optimum roller speed, no improvement in the elimination capability is achieved, but stress on the fibers goes on rising and so does fiber loss.
- Cleaning is made more difficult if the impurities of dirty cotton are distributed through a larger quantity of material by mixing with clean cotton.
- Damp stock cannot be cleaned as well as dry.
- High material throughput reduces the cleaning effect, and so does a thick feed sheet.

3.5. Degree of cleaning and resistance to cleaning

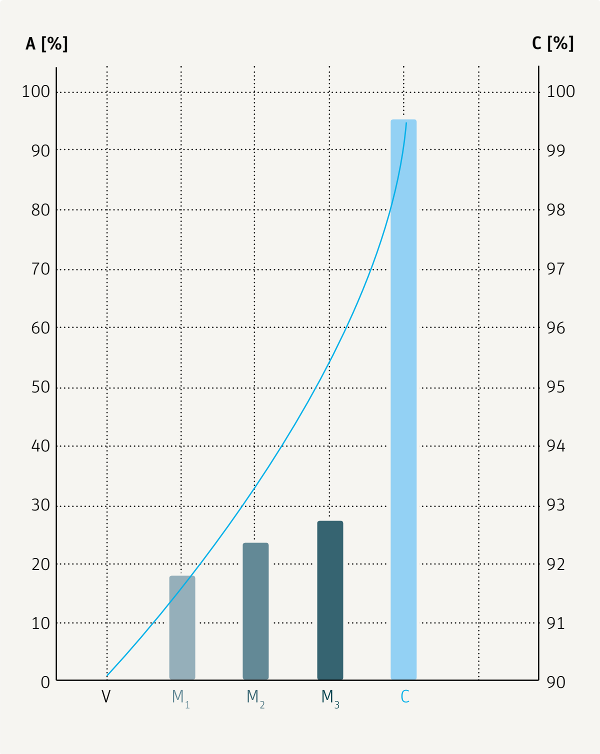


Fig. 28 – Increasing degree of cleaning from machine to machine
A, degree of cleaning of blowroom machines; C, degree of cleaning (on the vertical axis); V, feed material; M1 - M3, blowroom machines 1 - 3; C, card

Whereas formerly the cleaning effect of a machine could only be estimated, today it can be established fairly exactly, reproducibly and so as to enable comparisons to be made. For this purpose, the cleaning index *C* is defined as:

$$C_T = \frac{D_F - D_D}{D_F} \times 100\,\%$$

where D_F = the dirt content of the feed material; D_D = the dirt content of the delivered material; and T = total.

The dirt content is usually determined with the aid of gravimetrical methods such as MDTA3, AFIS or Shirley Analyser. Fig. 28 from Trützschler [16] illustrates the cleaning indices of individual machines and the complete blowroom/card installation.

The cleaning index is heavily, but not solely, dependent on the dirt content. The particle size and adhesion of the dirt to the fibers, among other things, also have an influence. Hence, the cleaning index may be different for different cotton types with the same dirt content. There are types that can be cleaned easily and others that can be cleaned only with difficulty.
A new concept has been introduced to represent this ease of cleaning, namely, "cleaning resistance". Fig. 29 [16] shows the conditions in a horizontal cleaner:

- zone I represents a cotton with low cleaning resistance;
- zone II a cotton with medium resistance; and
- zone III a cotton with high cleaning resistance;

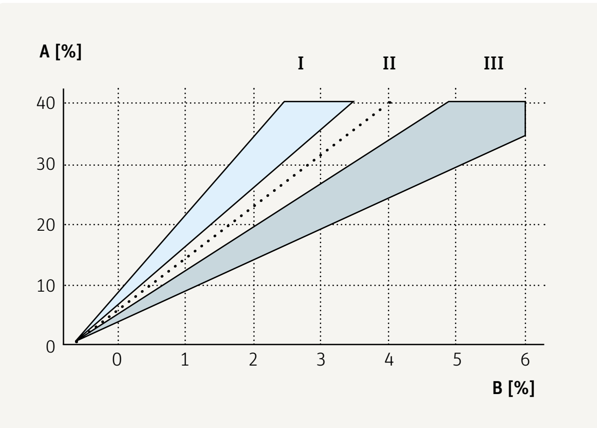


Fig. 29 – Resistance to cleaning (cleaning compliance) of various types of cotton
A, degree of cleaning of the machine;
B, initial dirt content of the cotton;
I, zone of low resistance to cleaning;
II, zone of medium resistance to cleaning;
III, zone of high resistance to cleaning.

3.6. Dust removal

Cotton contains very little dust before ginning, but working of the material on the machines causes dust. Even where dust is removed, new dust is being created through shattering of impurities and smashing and rubbing of fibers. Formerly, dust was of no great significance for the spinner, but now it poses a problem.

Firstly, increasingly strict laws have been passed regarding observation of specified dust-concentration limits in the air of blowing rooms, and secondly, many new spinning processes, especially OE rotor spinning react very sensitively to dust.
However, the removal of dust is not simple. Dust particles are very light and therefore float with the cotton in the air transport stream. Furthermore, the particles adhere quite strongly to the fibers. If they are to be eliminated, they must be rubbed off. The main elimination points for adhering dust, therefore, are those points in the process at which high fiber/metal friction or high fiber/fiber friction is produced. The former arises in the card, between the main cylinder and the flats, and the latter arises in drafting arrangements, mainly in the draw frame. Today the draw frame is a good dust removal machine owing to the suction extraction system around the drafting arrangement. Material leaving the draw frame contains only about 15 % of the dust originally present or newly created [4].
Dust that separates easily from the fibers is removed as far as possible in the blowroom. Various machinery manufacturers offer special dust-removing machines or equipment to be installed in the blowroom. These operate mostly with perforated surfaces together with suction. However, it must always be borne in mind that flocks resting on the perforated surface act as a filter, so that generally only the undersides can be cleaned.
It is also important that dust released during processing is sucked away immediately at the point of release.

4. BLENDING

4.1. The purpose of blending

Raw materials used in the spinning mill are always inhomogeneous in their characteristics. In part, this is inevitable owing to the different cultivation conditions of natural fibers and the different production conditions for man-made fibers. Partly, it is deliberate in order to influence the end product and the process.
Blending is performed mainly in order to:
- give the required characteristics to the end product (e.g. blending of man-made fibers with natural fibers produces the desired easy-care characteristics);
- compensate for variations in the characteristics of the raw materials (even cotton of a single origin exhibits variability and must be blended);
- hold down raw material costs (blending-in of raw material at low price level);
- influence favorably the behavior of the material during processing (improve the running characteristics of short staple material by admixture of carrier fibers); and
- achieve effects by varying color, fiber characteristics and so on.

4.2. Evaluation of the blend

The evenness of the blend must always be assessed in two directions: the longitudinal direction and the transverse direction. Where there is unevenness in the longitudinal direction, yarn portions exhibit different percentage distributions of the individual components (Fig. 30). These can lead to stripiness. Where there is unevenness in the transverse direction, the fibers are poorly distributed in the yarn section (Fig. 31). This irregularity leads to an uneven appearance of the finished product.

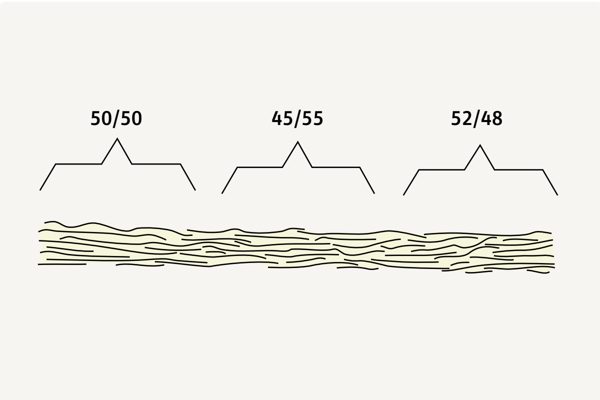


Fig. 30 – Unevenness of the blend in the longitudinal direction

The determination of the evenness of a blend, e.g. of synthetic and natural fibers, is costly and not simple. One component is usually dissolved out or colored differently.

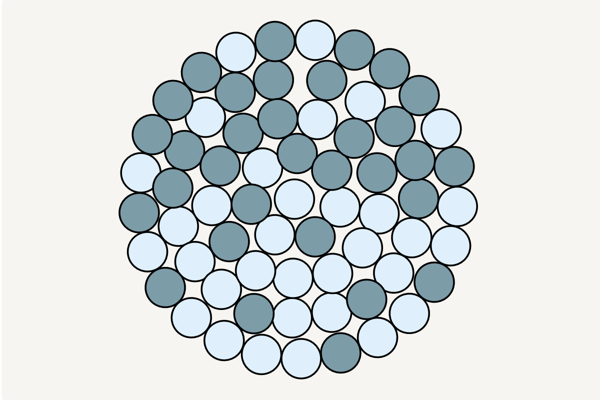


Fig. 31 – Unevenness of the blend in the transverse direction

4.3. De-blending

The spinner aims to distribute the different fibers evenly in the yarn. For this purpose, he must firstly produce a good blend at some stage of the process, and secondly be able to maintain the blend up to the stage of binding into the yarn. It is a well-known fact that meeting the first of these requirements is not always easy; sometimes the second is harder still. Fibers of different length, surface structure, crimp, etc., also behave differently during movements as individuals. A “de-blending” effect can very often arise. During rolling of fibers in hoppers (bale openers, hopper feeders), migration of the components occurs where the fibers have different structures (e.g. cotton and man-made fibers). A similar effect is found during drawing in drafting arrangements. Fibers with large differences in length or surface form (smooth/rough, dyed/undyed, etc.) do not exhibit the same cohesive contact with each other.
When a drafting force is applied, they move differently – this leads to clumping of fibers into clusters and finally to de-blending. Pneumatic transport can also cause de-blending.

4.4. Types of blending operations
4.4.1. Possibilities

Blending can be carried out at various process stages, by using various methods, equipment, machines, and intermediate products. The following can be distinguished:

BLENDING TYPE	PROCESS STAGE
Bale mixing	before the blowroom
Flock blending	within the blowroom
Lap blending	(by using scutchers)
Web blending	at the ribbon-lap machine or the blending draw frame
Sliver blending	at the draw frame, the sliver-lap machine (or the comber)
Fiber blending	at the card or the OE spinning machine
Roving blending	at the ring spinning machine

In addition, a distinction must also be made between controlled and uncontrolled blending. In uncontrolled blending, the components are brought together at random and without a mixing system (e.g. often in bale mixing). In controlled blending, the individual components are supplied to the machines in an ordered fashion and precisely metered (e.g. in weighing-hopper feeders). The various blending processes often differ widely from one another with respect to capital cost, labor-intensiveness, precision of blending, liability to error, and simplicity. Each method has advantages and disadvantages. It is therefore not possible to put forward patent recipes for the use of one or another blending principle.

4.4.2. Bale mixing

This is carried out at the start of the process – for both natural fibers and man-made fibers, since even man-made fibers exhibit variations in their characteristics.
From 6 to 60 bales are laid out for simultaneous flock extraction. With careful use, this enables the yarn characteristics to be kept almost uniform over several years. Blending conditions are very favorable if controlled mixing is carried out, i.e. if the bales are selected and laid out within tolerance limits so that, for all the bales taken together, the same average values of fiber length, fineness, and/or strength are always obtained. Since it is followed by many other processing stages, bale mixing gives a good blend in the transverse direction (cross section). With widely differing raw materials (e.g. blends of natural and man-made fibers), the blend is often unsatisfactory in the longitudinal direction owing to uncontrolled extraction of flocks from the bales and the danger of subsequent de-blending.

4.4.3. Flock blending

This is already substantially finer than mixing of bales and is becoming steadily more important because of the use of automatic bale-opening machines (not always a sufficient number of bales in the mix). Flock blending takes place in an uncontrolled manner, inevitably and to a small degree, at each blowroom machine. It occurs in a controlled manner and to a greater degree at weighing-hopper feeders and blending machines.
It normally has the same advantages and disadvantages as bale mixing, but in these systems both the longitudinal and transverse blends are mostly satisfactory because of the possibility of metering. However, the longitudinal blend can be substantially improved if blending is carried out immediately before the card, since hardly any rolling movement, and consequently de-blending, occurs thereafter.
Flock blending is becoming more important in many countries nowadays.

4.4.4. Lap blending

This is hardly used now but was previously used occasionally, e.g. for blending cotton with man-made fibers. A doubling scutcher is required in this case; this has a conveyor lattice in the infeed on which four to six laps (*L*) could be laid (Fig. 32), and jointly rolled-off. The lap-sheets from these laps passed doubled through a beater position followed by a pair of cages and a lap-winding device.

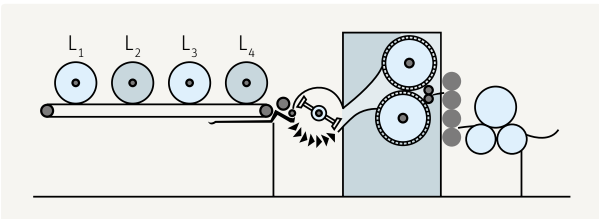


Fig. 32 – Lap blending on an old scutcher

Lap blending produces very good transverse blends and also a good longitudinal blend, because subsequent rolling movements are also excluded here. In addition, it has the advantage of all scutcher installations: a high degree of flexibility in operation with a variety of feed materials. This flexibility, however, is achieved at the expense of uneconomic operation and complication, since an additional processing stage must be included.

4.4.5. Web blending

Web blending (Fig. 33) has been used for a long time at the ribbon-lap machine, admittedly not to bring together different components but rather to provide a very even lap as feed material for the comber. Another development was a draw frame which enabled controlled blending to be achieved by bringing together components in web form (after drafting on four drafting arrangements), instead of doubling in sliver form. This gives a good longitudinal blend and also a slightly better transverse blend than is obtained with sliver blending. but with higher costs and more effort, mainly in maintenance, adjustments etc.

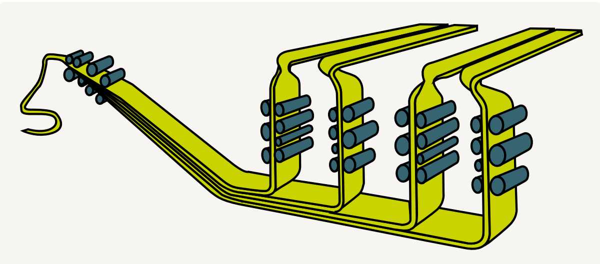


Fig. 33 – Web blending

4.4.6. Sliver blending

For the most part, blending of natural and man-made fibers is still carried out in sliver form on the draw frame. This provides the best blend in the longitudinal direction. Up to the draw frame, each raw material can be processed separately on the machines best suited to it. However, an additional blending passage must be inserted preceding the two usual draw frame passages in the cotton-spinning mill. For a 67/33 blend, four slivers of one component are fed in together with two slivers of the other component – assuming equal sliver hank (Fig. 34). The main disadvantage, aside from the necessity of a third draw frame passage, is poor transverse blending in the product. Since a machine which performs further blending does not follow the draw frame, the individual components remain as adjacent fiber strands in the yarn. This can produce stripiness in the finished product.

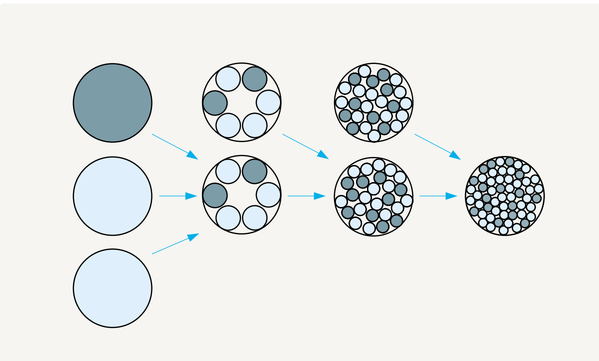


Fig. 34 – Blending of slivers of different raw materials

4.4.7. Fiber blending

Without any doubt, the most intimate blend is obtained if individual fibers are brought together. This can be achieved only on the cotton card (to a small degree), on the woolen card (sometimes fairly intensively), and in rotor spinning (over short lengths only). Controlled, metered blending cannot be carried out on these machines, but can only make a previously produced blend more intimate.

4.4.8. Roving blending

This is not common in short-staple spinning mills. Some use is still made of the process in wool spinning for producing fancy yarns. Two rovings of different colors are fed into the drafting arrangement of the ring spinning machine. Since the single fibers do not blend in the drafting arrangement, but the fiber strand is twisted directly after passing the drafting arrangement, either one or the other color predominates over short lengths of thread. The yarn is called jaspé yarn. Another application is the production of SIRO-yarns (two-ply replacement).

4.5. Blending procedures

4.5.1. Stages in the blending operation

Blending is carried out in three stages [17] (Fig. 35):
- metering, determination, and precise establishment of the quantities of the individual components;
- mixing, i.e. bringing together the metered quantities;
- intermingling, i.e. distributing the components evenly in the body of fibers.

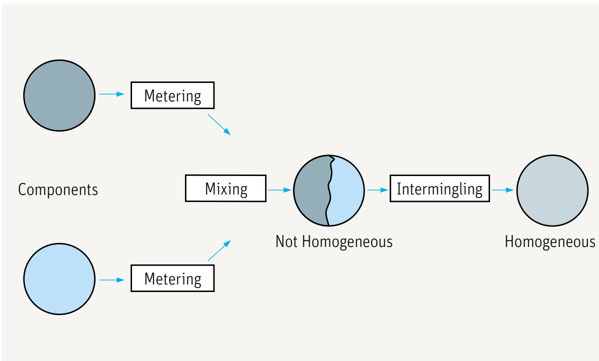


Fig. 35 – Stages of the blending operation

Each stage is as important as the other. However, difficulties arise primarily in intermingling and in maintaining the blend once it has been achieved. The latter is very difficult with fibers of different surface structure and varying energy-absorbing capacity on stretching, because de-blending tends to occur at various processing stages.

4.5.2. Metering

The following methods are distinguished [17]:

- Random mixing, for example, as occurs within blowroom machines, cards, etc.
- Metered but intermittent mixing, for example, as occurs in weighing-hopper feeders, where the components are fed intermittently in batches.
- Metered and continuous mixing, for example, in the A 81 UNIblend (Rieter), the Flockblender (Trützschler), and the draw frame. Formation of batches does not take place in the draw frame, but the individual components probably remain as strands throughout the whole product.

5. REDUCING THE UNEVENNESS OF YARN MASS

5.1. Unevenness of yarn mass

5.1.1. The unevenness limit

The spinner tries to produce yarn with the highest possible degree of homogeneity. In this connection, evenness of the yarn mass is of the greatest importance. In order to produce an absolutely regular yarn, all fiber characteristics would have to be uniformly distributed over the whole thread. However, that is ruled out by the inhomogeneity of the fiber material and by the mechanical constraints. Accordingly, there are limits to achievable yarn evenness. Martindale indicates that, in the best possible case, if all favorable conditions occurred together, the following evenness limit could be achieved (for ring-spun yarn):

$$U_{lim} \frac{80}{\sqrt{n}} \times \sqrt{1 + 0.0004 CV_D^2}$$

or

$$CV_{lim} \frac{100}{\sqrt{n}} \times \sqrt{1 + 0.0004 CV_D^2}$$

where n is the number of fibers in the yarn cross section and CV_D is the coefficient of variation of the fiber diameter. Since the variation in the diameter of cotton and man-made fibers is small enough to be ignored in industrial use, the equations reduce to:

$$U_{lim} \frac{80}{\sqrt{n}} \quad \text{or} \quad CV_{lim} \frac{100}{\sqrt{n}}$$

This can be expressed (admittedly to an approximation) as $CV = 1.25U$. The number of fibers can be estimated from the relation:

$$n_F = \frac{tex_{yarn}}{tex_{fiber}}$$

The unevenness index I is used in evaluation of the evenness achieved in operation. This is:

$$I = \frac{CV_{actual}}{CV_{lim}}$$

5.1.2. Deterioration in evenness during processing

In processing in the spinning mill, the unevenness of the product increases from stage to stage after the draw frame. There are two reasons for this:

- The number of fibers in the section steadily decreases. Uniform arrangement of the fibers becomes more difficult, the smaller their number.
- Each drafting operation increases the unevenness.

The contribution made by any one machine to the overall deterioration in evenness can be calculated. If, for example, a ring-spun yarn produced from a roving with a CV value of $4\ \%$ has an unevenness of $CV = 13.6\ \%$, then the contribution of the ring spinning machine is:

$$CV_{actual}^2 = CV_{feed}^2 + CV_{additional}^2$$

for our example:

$$CV_{additional} = \sqrt{13.6^2 - 4^2} = 13\ \%$$

5.1.3. Unevenness over different lengths

A length of yarn, for example of 10 mm, contains only few fibers. Every irregular arrangement of only some of these fibers has a strong influence on the unevenness. In a length of yarn of 10 m, incorrect arrangement of the same fibers would hardly be noticed against the background of the large number of such fibers in the total length. Accordingly, the *CV* value of the same yarn can be, for example, 14 % based on 8 mm length, and only 2 % based on 100 m length. The degree of irregularity is dependent upon the reference length. Unevenness is therefore discussed in terms of short lengths (Uster Tester); medium lengths (seldom used); long lengths (count variation). If the coefficients of variation are arranged in a co-ordinate system in accordance with their reference lengths, then the well-known length-variation curve is obtained (shown here in simplified form in Fig. 36). If continual variations of mass over short lengths are involved, then an uneven appearance of the product will result. Mass variations over medium (to long) lengths lead to stripiness in the product, and variations over long lengths lead to bars in knitted and woven fabrics.

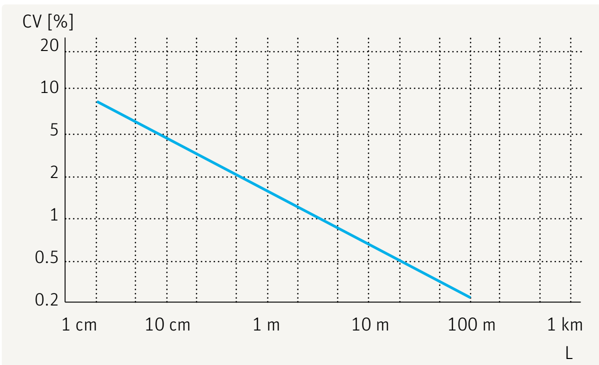


Fig. 36 – Length variation curve (CV_L%)

5.2. Basic possibilities for equalizing

Each processing stage is a source of faults. Drafting arrangements in particular increase unevenness very considerably. In order finally to achieve usable yarn characteristics, the process must include operations that have an equalizing effect. These can be: doubling; leveling; drawing while simultaneously imparting twist.
Doubling is still the most widely used, but leveling is becoming gradually more significant. Drawing while twisting simultaneously is now found on a significant scale only in woolen-spinning mills. These operations are sketched out below.

5.3. Doubling

5.3.1. The averaging effect

This is a simple, not very precise, but mostly adequate method of equalizing (Fig. 37). Several intermediate products are fed in together, for example several slivers into a drafting arrangement, and a single new product is produced. There is only a small probability that all thin places and, separately, all thick places will coincide. On the contrary, they will tend to be distributed and so to offset each other, admittedly largely at random. Only variations over short-to-medium lengths can be averaged out.

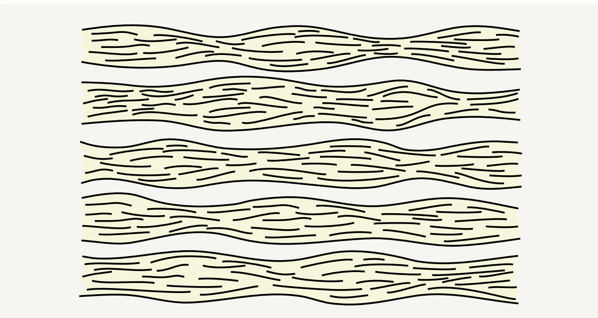


Fig. 37 – The averaging-out effect in doubling

5.3.2. Transverse doubling

In principle, every doubling process is a transverse doubling because the feeds are united side by side. In this context, however, the expression is used to refer to a quite specific type of blending, i.e. transverse doubling.

If two draw frames operate as passages *I* and *II*, respectively, and each has two deliveries, then all cans from delivery *1* of the first passage can be passed only to delivery *I* of the second passage, and the cans of delivery *2* can be handled in the same way.
This gives a straight-line throughflow. However, half the cans of the first passage could also be crossed over, i.e. in the transverse direction (Fig. 38) for feed to the second passage. Transverse doubling can improve both maintenance of long-term evenness and blending. Unfortunately, owing to the elimination of machine passages and the continual increase in production speeds, transverse doubling is becoming steadily more infrequent in practice. Previously, an important transverse doubling point was, for example, lap blending between the scutcher and the card.

In this buffer zone, the laps were laid out in one (vertical) direction and removed in the other (horizontal).

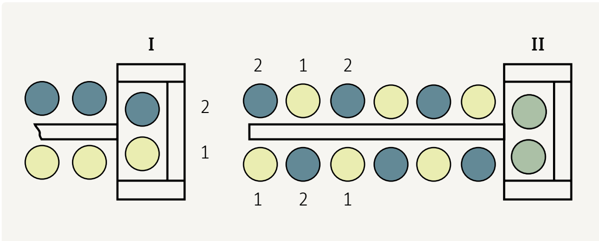


Fig. 38 – Transverse doubling at the draw frame

5.3.3. Back-doubling

In the past, doubling could be carried out only with intermediate products, such as slivers, webs, etc. With the use of rotor spinning, a still more intensive possibility has arisen, i.e. doubling of fibers.
The opening roller and feed tube separate the sliver almost into individual fibers. These are re-collected into a body of fibers in the rotor, the fibers being laid neatly one upon the other in the rotor groove.

This so-called back-doubling results in intimate blending and good equalizing, but only over the length of the rotor circumference. Long-term unevenness, which may already be present in the sliver, cannot be positively influenced.

5.4. Leveling
5.4.1. Measuring, open- and closed-loop control

For better understanding of the subsequent remarks, these three concepts will be defined briefly by using room heating as an example. If a thermometer is provided in a heated room and the temperature is read, then nothing more has happened than the determination of a condition by measuring. If that condition is not satisfactory, then appropriate action would be required. The heating system could, however, also be controlled with the aid of an external thermostat. More or less heat could be supplied depending upon the outside temperature.
As long as the conditions in the room remain constant – if, for example, only one person is present all the time – no problems arise. If the owner of the apartment gives a party for 10 - 15 people, however, then it will certainly become very warm. Open-loop systems lack a check upon the effects of a change, even as to whether a change has occurred. The system can be referred to as a control chain. The system is different if a thermostat is provided in the room itself and is set for a specific temperature. There is a continual comparison of the actual and the set conditions, and the temperature is held constant, regardless of what happens in the room. This operation, with constant self-monitoring, can be referred to as a closed-loop control system. Both open-loop and closed-loop control are used in spinning mills. In every case, the volume of fibers passing through is measured, and adjustment is made by altering the draft. This can be carried out as described below.

5.4.2. Open-loop control

A measuring sensor is provided in the region of the infeed for continuous detection of the actual value (volume) – mechanically, optically, pneumatically, or otherwise (Fig. 39). A regulator compares the result with the set reference value, amplifies the difference signal, and feeds it to an adjusting device (actuator), which then finally converts the impulse into a mechanical adjustment.
Control by this chain of steps requires an additional element, namely a storage device. Since the material has to travel a certain distance between the measuring and adjusting points, and therefore arrives at the adjusting point with a time delay, the signal must be held back in the storage device until this instant. This additional requirement represents a second disadvantage of open-loop control in addition to the lack of self-monitoring. There is a third disadvantage, since very exact values of the adjustment are required at all times.

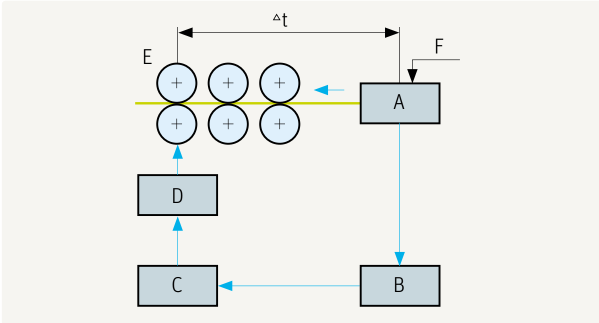


Fig. 39 – The principle of open-loop control
A, measuring sensor; B, store; C, amplifier; D, adjusting device;
E, adjustment point; F, set-value input

5.4.3. Closed-loop control

The measuring sensor is usually arranged in the delivery region, i.e. downstream from the adjusting device (Fig. 40). In contrast to open-loop control, the measuring point is after the adjusting point. The same measuring, regulating, and adjusting devices can be used, but no storage is needed. Moreover, the actual value does not have to be established as an absolute value but can be derived as negative, positive, or neutral pulses.

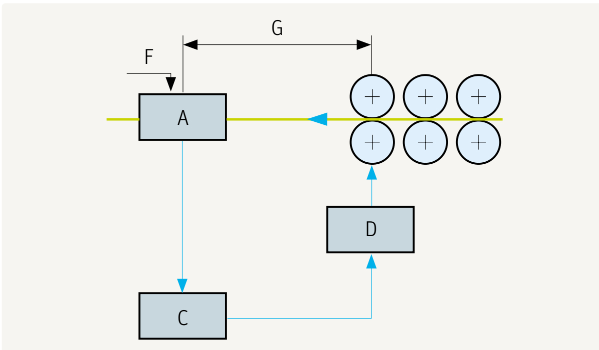


Fig. 40 – The principle of closed-loop control
A, measuring sensor; C, amplifier; D, adjusting device;
F, set-value input; G, dead-time distance

If too much material passes through the sensor, the regulating transmission receives a negative signal (i.e. reduce speed) until the actual and set values coincide again. Neither a positive nor a negative signal is produced when there is coincidence – the instantaneous speed is maintained. The principle is substantially simpler than open-loop control. However, this advantage, and the advantage of self-monitoring, must be weighed against a serious disadvantage, namely the dead time inherent in the system. The measured portion has already passed the adjusting point when the adjusting signal arrives.

Compensation cannot be achieved in this measured portion; i.e. some of the long and medium-term errors, and all of the short-term errors, remain in the product. It is therefore clear that closed-loop control is unsuited to compensation of irregularity over short lengths.

5.4.4. Adjustment of the draft

Compensation is effected by altering the degree of draft. In a drafting arrangement, both the break draft and the main draft could be adjusted, but the main draft is almost always used.
Since this draft is greater than the break draft, it permits finer modification. In addition, alteration of the break draft could result in entry into the stick-slip region.
There is also a choice between adjustment of the feed or delivery speed. In cotton-spinning mills, adjustment of the feed speed is generally used. Changing the delivery speed would, among other things, lead to continually changing production conditions. However, if cards and draw frames are combined into production units, constant infeed speed is required to maintain synchronism.

5.5. Drafting with simultaneous twisting

If twist is imparted to a fiber strand, it takes effect primarily where it encounters least resistance, i.e. in the thin places.
If a draft is now applied to the strand, the fibers begin to slide apart at the locations where the friction between them is least, i.e. where the twist is lowest. This is at the thick places. They are drawn first until they reach the volume of the thin places.
After that, the twist is distributed and the draft affects all portions uniformly. If another thin place were to arise, the whole procedure would be repeated. Compensation occurs continually. This operation is typical of selfactor spinning and woolen spinning systems.

6. ATTENUATION (DRAFT)

6.1. The draft of the drafting arrangement

6.1.1. Draft and attenuation

In most spinning mills today, the first intermediate product is a card sliver. It contains about 20 000 - 40 000 fibers in cross-section.
This number must be reduced in several operating stages to about 100 in the yarn cross-section. The reduction can be effected in two ways:

- through the draft, i.e. the distribution of an approximately constant total number of fibers over a greater length of the product [13]; or
- through elimination of fibers (loss) into waste (*p*).

Elimination is not an intentional reduction of the number of fibers but arises as an unavoidable side effect of the necessity for cleaning; it occurs in the blowroom, in carding, and in combing (Fiber loss is intentional in combing, as the aim is to remove short fibers.).
However, since drafting takes place simultaneously here, the term “*attenuation*” is used. This is defined by:

$$Attenuation = Draft \times \frac{100}{(100 - p)}$$

p is the waste percentage.

The reduction of the number of fibers in the cross-section logically leads to a reduction in diameter of the strand. In terms of fineness, the following relationship is obtained:

$$\frac{d_A}{d_Z} = \frac{\sqrt{tex_A}}{\sqrt{tex_Z}}$$

where d_A = diameter of delivered product;
d_Z = diameter of infeed product.

6.1.2. The drafting operation

During drafting, the fibers must be moved relative to each other as uniformly as possible by overcoming the cohesive friction. Uniformity implies in this context that all fibers are controllably rearranged with a shift relative to each other equal to the degree of draft.
However, such regularity is utopian as regards both the fiber material and the mechanical means available. Drafting operations always run irregularly, and each draft stage will therefore always lead to an increase in unevenness.

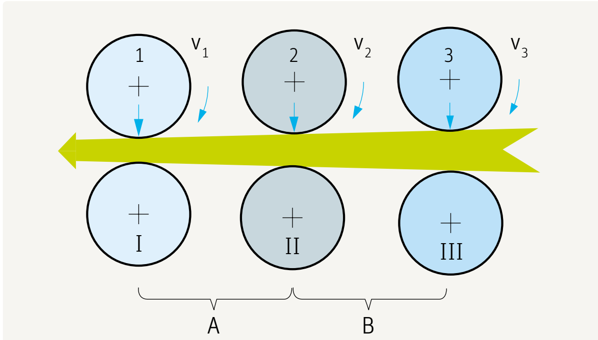


Fig. 41 – Draft through a roller drafting arrangement

Drafting is effected mostly on roller-drafting arrangements (Fig. 41). The fibers are firmly nipped between the bottom steel rollers and the weighted top pressure rollers. If the rollers are now rotated in such a way that their peripheral speed in the throughflow direction increases from roller pair to roller pair, then the drawing apart of the fibers, i.e. the draft, takes place. This is defined as the ratio of the delivered length (L_D) to feed length (L_F), or the ratio of the corresponding peripheral speeds:

$$V = \frac{L_D}{L_F} = \frac{v_D}{v_F}$$

where *v* = peripheral speed of cylinder, *D* = delivery and *F* = feed. The drafting arrangement illustrated has two sub-drafting zones, namely:

- a break draft zone (B): $V_B = v_2 / v_3$, and
- a main draft zone (A): $V_M = v_1 / v_2$

The total draft is always the product of the individual drafts and not the sum:

$$V_{total} = V_1 \times V_2 \times_{\dots} V_n$$

6.2. The drafting operation in the drafting arrangement

6.2.1. Drafting force

As fibers are carried along with the roller surfaces they are drawn apart. For this to occur, the fibers must assume the peripheral speed of the rollers. The transfer of the roller speed to the fibers represents one of the problems of drafting operations. The transfer can be effected only by friction, but the fiber strand is fairly thick and only its outer layers have contact with the rollers; furthermore, various non-constant forces act on the fibers.

For the purpose of illustration (Fig. 42), the forces acting on a fiber *f* in the drafting arrangement will be considered here. The fiber is bedded at its trailing end in a body of fibers (B_1) which is moving forward slowly at speed v_2. The leading end is already in a body of fibers (B_2) having a higher speed v_1. In this example, a tensile force F_Z acts on the fiber *f*; this arises from the adjacent fibers of the body B_2 already moving at the higher speed and the retaining force F_R exerted by the fibers of the body B_1. To allow acceleration of the fiber *f* and finally a draft, F_Z must be greater than F_R. Permanent deformation of the fiber strand could not be achieved if F_Z is only slightly greater than F_R. In this case, straightening and elongation of the fibers would produce a temporary extension, which would immediately disappear on removal of the extending force.

As already indirectly indicated, drafting takes place in three operating stages:
- straightening of the fibers (decrimping);
- elongation of the fibers;
- sliding of the fibers out of the surrounding fiber strand.

The effective drafting force can be represented by the curve form shown in Fig. 43. Up to point *m*, at which the fibers begin to slide apart, the curve climbs steeply. This is the straightening and extending stage. From point *n* onwards, by which stage many fibers are already sliding, the curve falls slowly with increasing draft. The reduction of the drafting force with the increasing extent of draft is easy to explain – there is a continuously declining number of fibers to be accelerated, i.e. to be drawn out of the slowly moving strand, since a higher degree of draft implies fewer fibers in the cross-section.

Besides the number of fibers in the cross-section, the drafting force is also heavily dependent upon:
- the arrangement of the fibers in the strand (parallel or crossed, hooks);
- cohesion between the fibers (surface structure, crimp, finish, etc.);
- fiber length;
- nip spacing.

6.2.2. Stick-slip motion

With a small amount of draft, namely with *V* between *1* and *2*, the drafting forces are often inadequate to induce permanent relative fiber shifts. In this region, the so-called critical drafting region, extremely disruptive stick-slip effects are often observed.
Here, the drafting force has to take the fibers from a static condition (motionless coherence of the fibers in a compact strand) to a dynamic condition, that is, to set the fibers in motion relative to their neighbors. As often also found in other fields, this mechanical operation not only requires considerable force, but also does not always occur without disturbance. In the critical region, the drafting force may suffice to overcome the frictional coherence instantaneously, but not to maintain acceleration.
The fibers are therefore braked and again take on the speed of their slowly moving neighbors.
The drafting force will again take effect and accelerate the fibers but will not be able to maintain the acceleration. Thus, there is a continual changing of conditions between acceleration and standstill, i.e. a kind of stop-and-go movement, with often disastrous consequences for the evenness. In the force-draft diagram (Fig. 44), this is clearly recognizable as greater or smaller deviations.

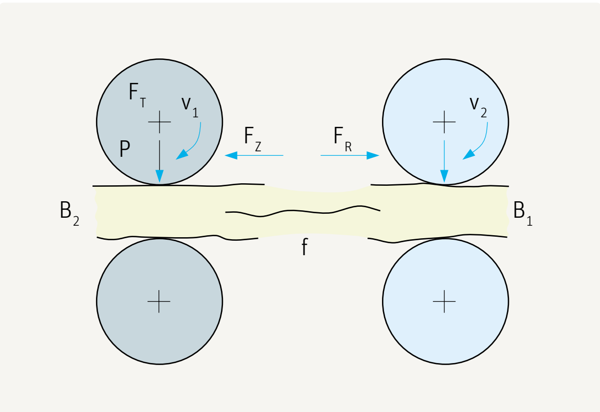


Fig. 42 – The forces acting on fiber (f) during drafting

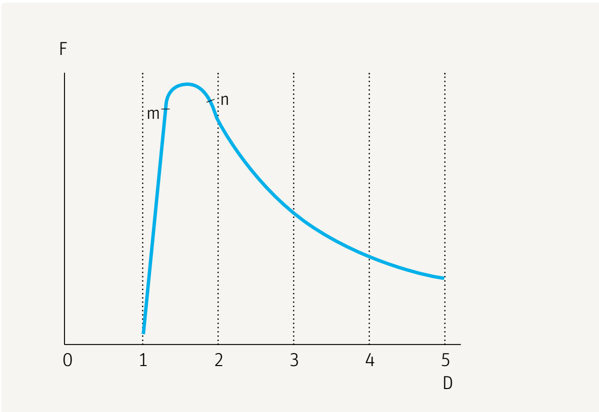


Fig. 43 – Drafting force diagram
F, magnitude of the drafting force; D, magnitude of the draft

For cotton sliver, the critical drafting region lies somewhere between V = 1.15 and 1.4, and, for cotton roving (on the ring spinning machine), it is between V = 1.3 and 1.7. For man-made fibers, for which the stick-slip effect is usually more strongly marked, the range lies somewhat higher, depending upon friction between fibers e.g., delustering, spin finish, etc. Operating in the critical drafting region can be risky.

6.3. Behavior of fibers in the drafting zone
6.3.1. Fiber guidance

Fibers arriving for processing exhibit very considerable length variations. In a drafting field, they are therefore found in two conditions (see Fig. 45):
- guided (*a, b, c*);
- floating (*d*).

Fiber *a*, which has a greater length than the nip spacing and thus temporarily extends across both nip lines, is gripped by at least one roller pair at all times and is thus moved in a controlled fashion. As far as only fiber guidance is concerned, this fiber is optimal, but nevertheless causes disturbance. Firstly, when it is gripped at two places with different speeds, it may break; secondly, if it can resist the tension, it will be pulled out of one nip line, dragging neighboring fibers with it. This leads to fiber clumps and hence to unevenness. Fibers *b, c,* and *d* are shorter than the roller spacing. Upon entry into the drafting field, they will first move with speed v_2 (as fiber *b*). When they finally pass into the nip region of the delivery roller, they will take on the speed v_1, (as fiber *c*). In both cases, they are subject to controlled guidance and movement. Over a certain interval of their movement, however, i.e. after leaving the nip line of the entry roller pair and before reaching the nip of the delivery roller pair, they are without controlled guidance – they are floating (like fiber *d*).

6.3.2. Floating fibers

With a roller setting of, for example, 50 mm, a 40 mm fiber would be theoretically under control for 40/50 or 4/5 of its path and would be without control for only 1/5; a 10 mm fiber, on the other hand, would be controlled over only 1/5 and uncontrolled over 4/5. These floating fibers are the problem in drafting.
The ideal movement of the fibers would be achieved if the whole fiber strand moved with speed v_2 into the nip region of the delivery roller pair without internal shifts, and if drawing-out of fibers first occurs here, and if only the nipped fibers were drawn out. In this case, each fiber would have either speed v_2 or speed v_1 at any given instant.
The fibers would be continuously guided under control. This is achievable to the maximum extent, however, only when the infed fiber mass is glued together (as in the former Pavil spinning system from Rieter), since fiber acceleration can then occur only when the fibers are gripped by the front rollers. Under normal circumstances, however, conditions are not nearly so favorable. The majority of floating fibers can take on any speed between v_2 and v_1 at any instant in their movement through the drafting zone, or can even change speed several times, which always leads to greater or lesser unevenness. Fortunately, however, there are a few helpful circumstances which reduce these adverse influences to some extent.
A certain additional guidance of floating fibers is achieved by:
- a sufficient number of longer fibers as carrier fibers for the shorter ones;
- guiding devices, such as rollers, needles, aprons, etc; and
- the friction field.

This last factor, which is extremely important for drafting behavior, will now be dealt with specifically.

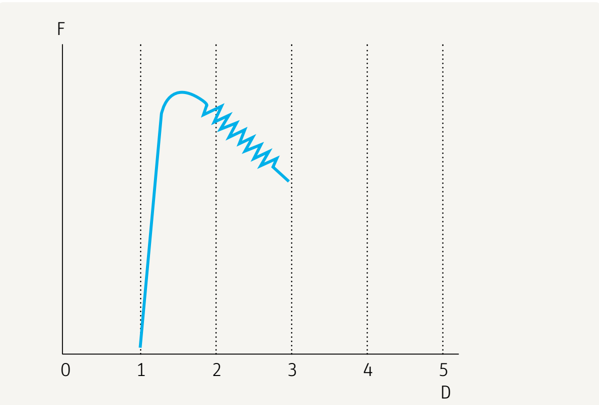


Fig. 44 – Drafting force diagram for the stick-slip zone
F, magnitude of the drafting force; D, magnitude of the draft
(The zigzag line shows the continuous change from sticking to slipping and back of the fibers.)

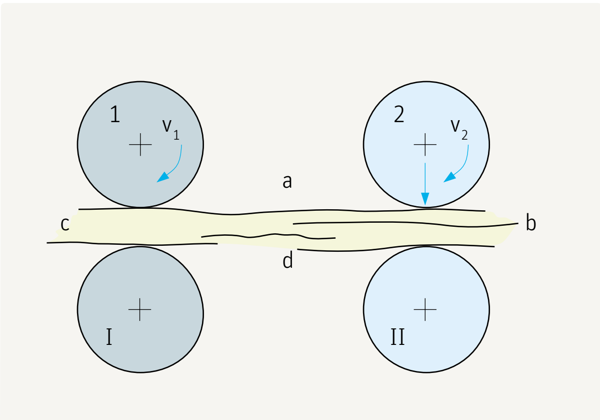


Fig. 45 – Guided and floating fibers in the drafting field

6.4. Friction fields

6.4.1. The fiber friction field

The top rollers must be pressed against the bottom rollers with considerable pressure to ensure that the fibers are transported. This pressure is not only effective in the vertical direction but also spreads through the fiber stock in the horizontal direction. The compression of the fibers, and thus the inter-fiber friction, is transmitted into the drafting zone. The intensity declines, however, with increasing distance from the nip line and finally reduces to zero. The friction field is an extremely important medium of fiber guidance [18]. It keeps the disturbing effect of drafting within tolerable bounds.

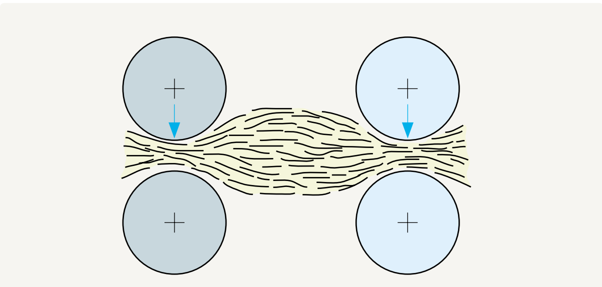


Fig. 46 – The friction field created in the fiber strand by applied pressure

Each drafting zone has two friction fields – a rear field spreading outwards from the infeed roller pair, and a front field spreading backwards from the delivery roller pair. If the rollers are set too close to each other, so that the fields overlap, then drafting disturbance will arise.
If, on the other hand, the spacing is too great, and the intermediate zone between the two friction fields too long, then poor guidance of the floating fibers results in high unevenness. The ideal condition is achieved when the rear field extends far into the drafting zone in order to guide the fibers over a long distance and the front field is short but strongly defined, so that as far as possible only the nipped fibers are drawn out of the fiber strand.

6.4.2. Influencing factors

Both the spinner and the machine designer can exert strong influence on the friction field, via:

- pressure of the top rollers;
- hardness of the top roller coverings;
- roller diameter;
- mass of the fiber strand;
- density of the strand;
- cross-section of the strand;
- width of the strand;
- twist in the strand.

The individual parameters produce the following effects: High roller pressure causes strong compression and a correspondingly long friction field, but only up to an optimum pressure. Since, in modern drafting arrangements, pressures have already reached the optimum, no further improvement in fiber guidance can be expected from pressure increases. Very hard top rollers, e.g. steel rollers (Fig. 47, a), give very high pressure in the center of the nip line. However, since the outer layers can evade the pressure, there is a steep decline in the pressure curve from the center towards each edge. It is therefore clear that the friction field cannot be very long in directions away from the nip line. An improvement is obtained with a covering (Fig. 47, b) of medium hardness, and the optimum for loose but compact fiber material is a soft covering (Fig. 47, c), since it completely surrounds the fiber body. Similar results are obtained with rollers of different diameter (Fig. 48). Rollers of larger diameter, which spread the total pressing force over a greater area, give a lower pressure peak but a larger pressure width. The increased friction penetrates more deeply into the drafting zone.

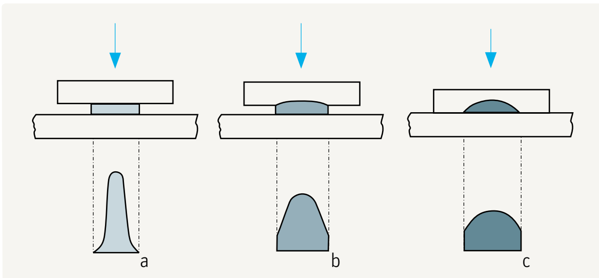


Fig. 47 – Effect of roller hardness on the friction field

The mass of the fiber body exerts its effect mainly through the number of fibers. A very low mass is identical with a lack of contact surface and hence a lack of friction. The friction field is short.

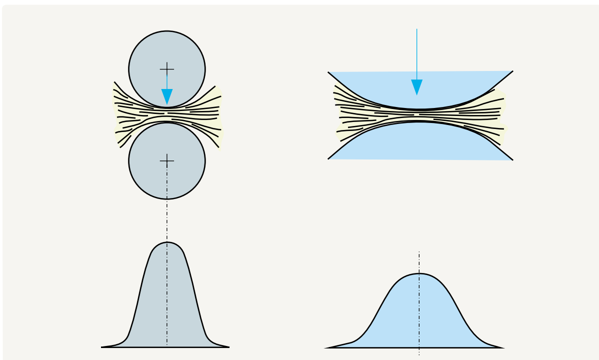


Fig. 48 – Effect of roller diameter on the friction field

High density, i.e. strong compression, facilitates wide spreading of pressure and friction and thus gives a long friction field.
The cross-section of the body of fibers is of decisive importance. A thin strand, which readily moves apart, can take up neither pressure nor friction and therefore does not give a well-defined friction field.
This is a problem in so far as the fibers spread out during each drafting operation; the body of fibers thus becomes gradually broader. Attempts are made to oppose this by compressing the fiber strand within condensers in the drafting arrangement.
However, this is not optimally effective, since undesired delaying forces are produced by friction at the stationary condensing elements, and the resulting broad fiber ribbon is not really rounded but only folded on itself. Only a round cross-section gives the optimum result. Better still is a strand having protective twist, which holds the fiber mass together in a round and compact form (i.e. roving).
If influence is to be exerted on the friction field by adjustment of individual parameters, then it should be borne in mind that strong interactions are found throughout the whole drafting process.

6.5. Distribution of draft

Three-line drafting arrangements, with two draft zones, are generally used in the short staple spinning mill In Asia still four- or five-line drafting arrangements are in use. The task of the draft in the first draft zone (break draft) is simply to prepare the main draft in the second zone. The fibers must be straightened and extended to such a degree that the main draft can immediately cause fiber movements, without still being strongly burdened with preparatory work. In this way, the main draft can be effected with less disturbance.
The extent of break draft normally lies below the critical draft region. In some cases, a higher break draft is needed, however, e.g. in draw frames and ring spinning machines (with drafts around and above 40). In this case, break drafts above the critical figure are selected.
The main draft must be adapted to the drafting conditions, mainly the fiber mass in the drafting zone and the arrangement of the fibers in the strand. The draft can be increased with increasing fineness of the intermediate product, and also with increasing parallelization of the fibers. Since the fibers in card sliver are relatively randomly oriented, the draft in the first draw frame passage should not be too high. Unless there are conflicting reasons, the draft can then be increased at the second passage and so on continually to the ring spinning machine.

6.6. Other drafting possibilities
6.6.1. Mule spinning

If the product to be drafted is firmly held at one end and is moved at the other end away from the fixing point, then drawing apart results, i.e. a draft occurs. Admittedly, auxiliary support is needed.
In order to prevent the thread sliding apart at its weakest point, the thread must be given protective twist (see 5.5.).

6.6.2. Draft at the opening roller

Neither the drafting arrangement nor the mule spinner can draw the fiber strand out into individual fibers. If this is required, opening rollers must be used. The principle is familiar from the licker-in of the card and is today deliberately exploited in new spinning processes, for example, in rotor spinning machines. A small, rapidly rotating roller, clothed with saw-teeth or needles, tears individual fibers out of the slowly moving feed material (sliver). This type of draft cannot be used in all conventional spinning systems, since it not only disrupts parallelization of the fibers already achieved but also completely eliminates the retention of the fibers in a strand. This leads to the necessity for a subsequent collecting device which is also straightening the fibers.

6.7. Additional effects of draft

In addition to the reduction in diameter, draft causes:
- stretching out of the fibers;
- straightening of the fibers;
- parallelizing of the fibers.

All of these represent important operations for spinning.

7. YARN FORMATION

7.1. Assembly of fibers to make up a yarn

7.1.1. Arrangement of the fibers

The characteristics of a yarn are strongly dependent upon the characteristics of its fibers, but they are equally dependent upon the structure of the yarn itself. The following factors are especially significant:

- the number of fibers in the yarn cross-section;
- fiber disposition;
- fiber alignment;
- position of the fibers in the strand (e.g. long fibers inside, short outside);
- binding-in (fully or only partly bound-in);
- overall structure;
- twist.

7.1.2. Number of fibers in the yarn cross-section

This determines, among other things, strength, evenness, handle, insulating capacity, thread-breakage rate, and the spinning limit of the raw material. Accordingly, there are lower limits to the number of fibers in the cross-section, as follows (for normal conditions):

Cotton yarns	ring-spun yarn:	combed	33 fibers
		carded	75 fibers
	rotor-spun yarn:	carded	100 fibers
Synthetic fiber yarns	ring-spun yarn:	carded	50 fibers
	rotor-spun yarn:	carded	100 fibers

The spinning limit can then be calculated approximately by transposition of the equation:

$$n_F = \frac{tex_{yarn}}{tex_{fiber}} \quad \text{to give} \quad tex_{yarn} = n_F \times tex_{fiber}$$

where n_F is the number of fibers. However, this formula does not take into account other parameters, such as fiber length, coefficient of friction, etc., which also affect the spinning limit. If it is desired to ascertain the average fiber fineness in a blended yarn, the following formula can be used:

$$tex_{fiber} = \frac{p_x \times tex_x + p_y \times tex_y}{100}$$

where p represents the proportion of fibers as a percentage, and the index x represents one component and the index y the other.

7.1.3. Fiber disposition

The yarn buyers expect that the yarn they receive is (besides other quality features) even in structure and appearance. However, an even yarn is achievable only by fulfilling some preconditions. These preconditions are very easy to explain, but very hard to obtain: in every yarn cross-section of the whole yarn length there should always be:

- the same number of individual fibers;
- the same number of fibers of every group of the same quality parameter (i.e. length, Fig. 49 a/b), fineness, thickness, etc.

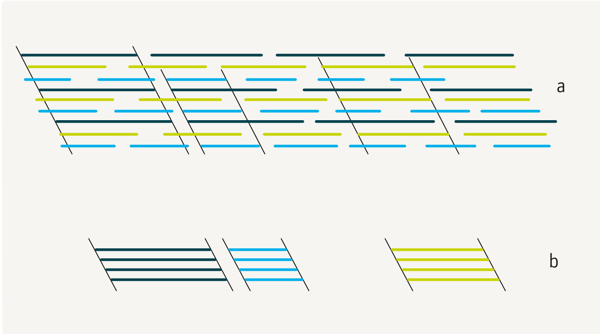


Fig. 49 – The ideal arrangement of fibers of different lengths in the yarn
a, the distribution within the yarn strand;
b, the length groups extracted group-wise from the strand.

7.1.4. The order of fibers within the yarn

Also expected is that the yarn has optimal strength. Nowadays yarns obtain their strength, almost without exception, from twisting. Therefore the strength is, beyond doubt, highly dependent on the height of the twist, but also on a large area of fiber-contact, and that again means for the fibers:

- high degree of stretching-out (straightening);
- highest attainable degree of parallelism;
- binding-in of the whole fiber, including if possible both fiber ends, into the yarn structure.

Furthermore, in yarns which have not been produced by using adhesives, the helical winding of all, or at least some (wrap yarns) of the fibers is of decisive importance, since ultimately the stability and strength of the structure are derived from the pressure towards the interior exerted by fiber windings, which are created by the twist.
One reason for the lower strength of rotor-spun yarn relative to ring-spun yarn is the lower degree of parallelization and the lower degree of straightening (fiber hooks) of the fibers in rotor-spun yarn.

Looking at the first two items, the following operations are responsible for imparting this order:

- Carding (the high degree of longitudinal orientation obtained on the main cylinder is, however, nullified to a large extent by the doffer).
- Combing (here, however, parallelizing is a side-effect, which is not always desired to this extent).
- Drafting (this is the most usual method of imparting order, since each drafting of the fiber masses is accompanied by straightening).
- Floating of individual fibers in a strong air current (for example, in the feed tube of the rotor-spinning machine).
- Deliberate collection of fibers, e.g. in the rotor.

7.1.5. The positions of the fibers in the yarn structure

7.1.5.1. Ring-spun yarns

Owing to the twist, all or some of the fibers take up the required helical disposition. The number of fibers affected by the twist, and the degree of winding, are strongly dependent upon the spinning process. In ring-spun yarns, twisting takes place from the outside inwards. At the periphery (the outer sheath *A*, Fig. 50), owing to the greater degree of winding, the fibers have a lesser inclination, (γ = angle between the fibers and the axis of the yarn) than in the interior of the yarn (the core *B*). Since the fibers become steadily less tightly wound towards the core, ring-spun yarn may be said to have sheath-twist. Under loading, the outer layers will tend to take the radial forces and the inner layers will tend to take the axial forces. However, by increasing pressure inwards, the radial forces reinforce axial resistance to sliding apart of the fibers.

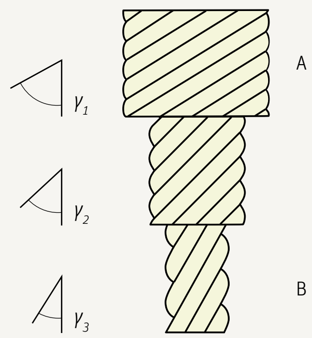


Fig. 50 – The twist structure in ring-spun yarn [22]

Accordingly, fully twisted yarns with sheath-twist have high tensile strength but are not so resistant to abrasion. Under abrasion the outer, highly tensioned fibers are destroyed. Since these fibers hold the yarn together, the strand loses its cohesion. Hairiness on the yarn surface is mainly caused by protruding shorter fibers.

7.1.5.2. Open-end spun yarns

In contrast to ring spinning, twisting during rotor spinning takes place from the inside outwards. The rotating, brush-like open yarn end (*C*, Fig. 51) first catches fibers in the core and then with further rotation gradually takes up fibers towards the periphery. In the interior, where the fibers cannot avoid the twist, the strand becomes more compact but also somewhat harder. On the other hand, towards the exterior, compactness and hardness fall off to an increasing degree, since here the fibers are able partially to avoid twisting-in.

	Ring-spun Yarn		Open-End Yarn		Air-jet Yarn		Wrap Yarn
	classic	compact	rotor spun	friction spun	jet spun, two nozzles, false twist process	vortex spun, one nozzle	filament wrapped
Fiber disposition:							
in the core	parallel, helical	parallel, helical	less parallel, helical	less parallel, helical	parallel without twist	parallel without twist	parallel without twist
in the sheath	parallel, helical	parallel, helical	more random, less twisted	less parallel, helical	6 % of fibers twisted around core in spirals	20 % of fibers twisted around core in spirals	filament windings
Fiber orientation:							
parallelism:	good	very good	medium	low	medium	good	very good
compactness:	compact	very compact, round	open	compact to open	compact	compact	compact
handle:	soft	soft	hard	hard	hard	medium to hard	soft
hairiness:	noticeable	low	very low	low	some	low to medium	very low
stiffness:	low	low	high	high	high	fairly high	low

Table 4 – Shows roughly the differences in structure arising from the spinning process (see also Fig. 54)

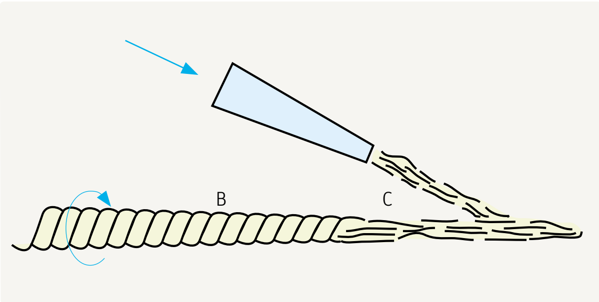


Fig. 51 – Binding-in of the fibers in open-end spinning

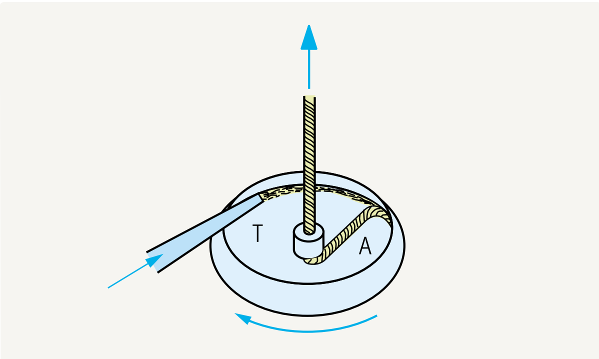


Fig. 52 – Yarn formation in the rotor

Typical characteristics of this so-called core-twist are therefore a harder handle accompanied by a lower strength than is obtained with sheath-twist, since the outer layers have relatively little twist and can thus contribute little to strength. However, abrasion-resistance is often better. Removal of outer fibers due to abrasion has little effect, since these fibers did not create much strength anyhow.
In rotor-spun yarns, this outer layer exhibits other peculiarities. One of these is the presence of wrap fibers. These are fibers which fly directly onto the fully created yarn as the rotor passes under the feed passage. By the further rotation of the yarn in the rotor they are wrapped around the already spun yarn like the band on a cigar. This is a typical characteristic of rotor-spun yarn.
Another peculiarity is a thin outer layer of fibers with hardly any twist, or even with twist in the reverse sense. This arises from the false twist between the navel (Fig. 52, *T*) and the binding-in zone (*A*). In the latter, during each rotation of the rotor, new fibers join on to the already well twisted fiber strand. These latecomers receive only a fraction of the desired twist level. If this low twist is less than the false-twist effect, the fibers are twisted in the reverse sense during cancellation of the false twist (reverse twisting) at the navel, and are thus wrapped around the other fibers with reverse twist.

A further disadvantage of the loose outer layers is their sensitivity to axial rubbing. Since these open layers are not firmly secured in the core, they tend to accumulate in small knots during passage of the yarn over edges, guide elements, etc. As far as possible, open-end spun yarns should not be rewound.

7.1.5.3. Wrap yarns

Wrap yarns consist for the most part of fibers arranged in parallel without any twist (Fig. 53). These form the very thick core. Synthetic filament or staple fiber of the same kind as the core material is wrapped around this core but forms a small proportion of the fiber material. If the thread is wrapped with filament, it will have high strength, since the fibers themselves are stretched out and arranged parallel and are pressed closely together. The filament also contributes some of the strength. Accordingly, for a given yarn strength, fewer fibers are required in the cross-section.

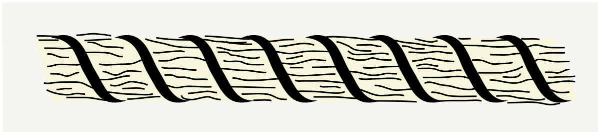


Fig. 53 – Bundled yarns (wrap yarns)

7.1.5.4. Air-jet Yarns

If, the core fibers are wrapped only with fibers of finite length (staple fibers), as in false-twist spinning (air-jet spinning and Dref 3), then the yarn strength is lower than that of ring-spun yarn because the relatively short fibers cannot hold the structure of the yarn together in an optimal fashion. A minimum fiber length is required for production of such threads. At present, therefore, the false-twist process is suitable mainly for the spinning of man-made fibers, blends of cotton and man-made fibers, or combed cotton. Airjet spinning systems using one nozzle, like vortex-spun allow higher percentages of wrap fibers, resulting in better yarn properties and higher productivity.

7.1.6. Yarn structure

One aspect of structure is the visual appearance, created solely by the peripheral layer of the yarn, and a second aspect is the internal and external make-up. Yarn structures are very variable. The differences are partly deliberately caused, depending on the intended use of the yarn, but for the most part they are predetermined by the means available. For example, it is difficult to produce a yarn equivalent to a ring-spun yarn by the new spinning processes

– and the ring-spun yarn still represents the standard of comparison (Table 4).
The yarn structure is dependent primarily upon the raw material, spinning process, spinning unit, machine, machine settings, twist, etc. The structure can be open or closed; voluminous or compact; smooth or rough or hairy; soft or hard; round or flat; thin or thick, etc.
But yarn structure is not simply appearance. It has a greater or lesser influence on:

- handle;
- strength;
- elongation;
- insulating capacity;
- covering power;
- ability to resist wear, damage, strains, etc.;
- resistance to abrasion;
- ability to accept dye;
- tendency towards longitudinal bunching of fibers;
- wearing comfort, etc.

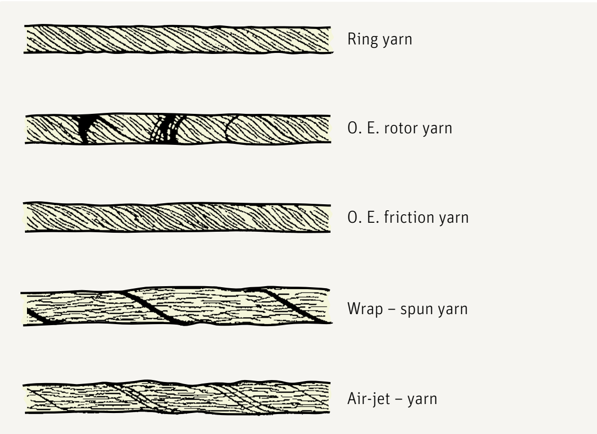


Fig. 54 – Differences in the yarn structure for various spinning processes (drawings without attention to hairiness)

7.2. Fiber migration

Owing to their different characteristics, the fibers take up different positions in the body of the yarn. Grouping arises mostly during drawing. Thus, long fibers are often located in the core, since they exhibit more cohesive friction, and therefore higher resistance to the draft, and remain in the interior. Short fibers are often found on the yarn exterior. This tendency is reinforced by fiber migration (wandering of the fibers), since the fibers do not always stay in the positions they first take up. For example, if any traction of power (even minimal) acts on the yarn, highly tensioned fibers of the outer layers press inward wholly or partly (the fiber ends, for example). In doing so, they press out the lower-tensioned fibers from the interior. Migration takes place from the sheath to the core and vice versa. Such migration is, of course, most prevalent during yarn formation but still occurs after yarn formation is completed. When the smallest forces are exerted on the yarn, e.g. during bending, tensile loading, etc., the persisting tensions in the fibers constituting the yarn lead to continuation of the process of fiber migration even after the completion of yarn formation. For example, the short fibers work their way to the surface and are then partly rubbed off. Moreover, some fibers in the body of the yarn lose their helical dispositions during fiber migration; this effect is more prominent the shorter the fibers and the more random their arrangement.
In addition to its dependence on length, fiber migration is dependent upon degree of elasticity, stiffness, fineness, crimp, etc. Short, coarse, stiff fibers move out towards the sheath while long, fine, flexible fibers move towards the core. Strongly crimped fibers are also found predominantly in the sheath, since they can exert greater resistance to binding-in. Fiber migration should be adequately taken into account in determining the composition of blends.

7.3. Imparting strength
7.3.1. Possibilities for imparting strength

In order to obtain strength in the yarn, which consists of individual fibers of relatively short length, the inherent strength of one fiber must be made wholly or partly transferable to another. In principle, there are two alternatives: adhesives and twist.
Total exploitation of the inherent strength of the fibers can be achieved only by using adhesives, as was done, for example, in the Twilo process. The adhesive effect can be produced by means of adhesive substances or adhesive fibers (polyvinyl-alcohol fibers). Since this process can be used only for a small market segment, twisting of the fiber strand remains the sole possibility for imparting strength, even for the future.
The extension of the fibers that arises during twisting leads, via the associated fiber tension, to increased pressure directed towards the yarn interior, i.e. to an increase in the frictional forces between the fibers and thus finally to the desired, immensely strong coherence of the body of the yarn (Fig. 55).
Fiber strands that are not held together by adhesives cannot completely exploit the inherent strength of the individual fibers.
Staple fiber yarns held together by twist have a degree of exploitation between 25 % and 70 % (normally 30 - 50 %).
Possibilities available for producing the required twist are true twist, false twist and self-twist (as in the Repco process).

7.3.2. True twist
(explained with reference to ring-spun yarn)

7.3.2.1. The direction of twist

Twist is produced with the aid of spindles, rotors, rollers, and so on. Since two twist directions, left and right, are always possible, the fiber windings can also have two directions. The direction of the twist is indicated as Z- or S-twist depending on the transverse orientation of the fibers, i.e. the orientation relative to the diagonals of the letters Z and S (Fig. 56). Z-twist is normally used in short staple spinning, though not to the exclusion of S-twist.

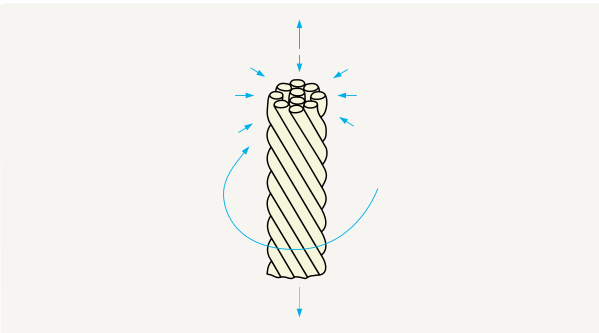


Fig. 55 – Imparting strength to the yarn by twist

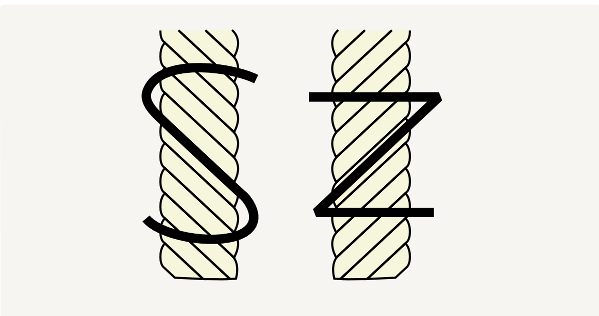


Fig. 56 – Twist directions in spun and twisted yarns

7.3.2.2. Twist and strength

The strength of a thread twisted from staple fibers increases with increasing twist. In the lower portion of the curve (Fig. 57), this strength will be due solely to sliding friction, i.e. under tensile loading the fibers slide apart. Cohesive friction arises only in the middle-to-upper regions of the curve. This is caused by the high tension, and thus high pressure, and finally becomes so considerable that fewer and fewer fibers slide past each other and more and more are broken. This continues up to a certain maximum, i.e. to the optimal exploitation of the strength of the individual fibers, after which strength falls away again. As the two curves show, this maximum – the so-called critical-twist region (at *C*) – is dependent upon the raw material. Normally, yarns are twisted to levels below the critical-twist region (*A* – knitting, *B* – warp); only special yarns such as voile (*C*) and crêpe (*D*) are twisted above this region. Selection of a twist level below maximum strength is appropriate because higher strengths are mostly unnecessary, cause the handle of the end product to become too hard, and reduce productivity. The last effect arises from the equation:

$$\textit{Yarn twist} = \frac{\textit{spindle speed (rpm)}}{\textit{delivery speed (m/min)}}$$

Since the spindle speed is always pushed to the maximum possible limit (and thus may be considered as constant), higher yarn twist can only be obtained through reduction in the delivery speed and hence in the production rate.

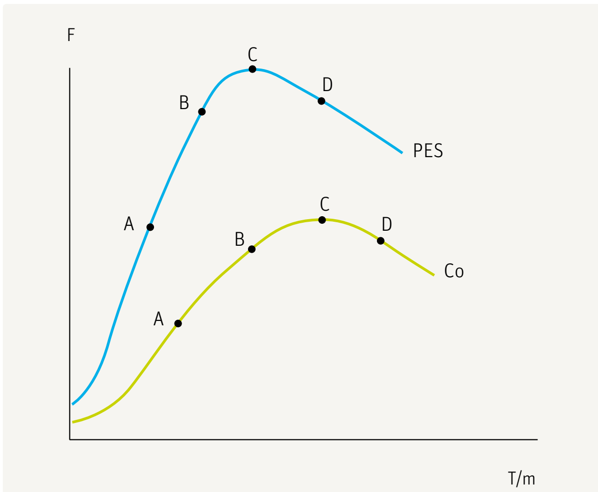


Fig. 57 – Relationship between the number of turns of twist and the strength of a yarn
F, strength; T/m, turns of twist per meter in the yarn;
PES, polyester fibers; Co, cotton fibers

7.3.2.3. Deformation of the yarn in length and width

Fibers can be wound in spirals around other fibers only by increasing their length through exploitation of fiber elongation. When a fiber is extended, its elasticity tries to draw it back. This constant tendency to return to the unextended condition results in a high tension directed towards the core and thus to increase pressure continually towards the yarn interior. These tensions cause the strong compression, and hence great density of the yarn body. The compression leads to a reduction in the diameter of the yarn.

Diameter is thus inversely proportional to twist. However, the tendency to relax also leads to shortening of the yarn (twisting-in, spinning-in). The same effect is produced by the inclined disposition of the fibers relative to the yarn axis. Hence, the length of the spun yarn never corresponds to the delivered length measured at the front roller.
The degree of shortening is also dependent upon the raw material and especially upon the number of turns. Johannsen and Walz [20] indicate that for cotton yarns twisting-in can be derived from Fig. 58 (as an example for Texas cotton).

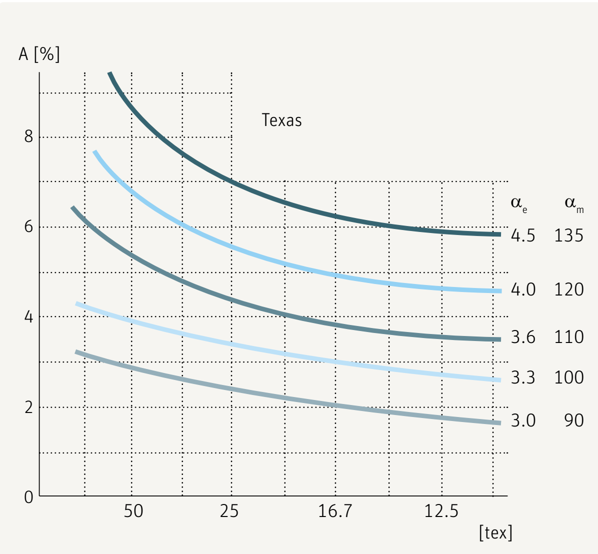


Fig. 58 – Shortening of yarns with different twist coefficients
A, shortening in %; tex, yarn count;
α, twist multiplier (e, english; m, metric)

7.3.2.4. Twist formulas

To elucidate several relationships involved in twisting, two yarns are considered below in a theoretical model. One yarn is assumed to be double the thickness of the other [21]. Consider for each case a single fiber *f* and *f'*, respectively (Fig. 59). Prior to twisting, these fibers lie at the periphery on the lines *AC, A'C'*, respectively.
Assume that the yarns are clamped at the lines *AG (A'G')* and *CD (C'D')* and are each turned once through 360°. Then the fibers take up new positions indicated by the lines *AEC* and *A'E'C'*, respectively. Each fiber can adopt this helical disposition only if its length is increased. However, owing to the greater diameter of yarn *II,* the extension of fiber *f'* must be significantly higher than that of fiber *f*.

The difference becomes clear if the yarns are rolled on a plane, whereupon two triangles (*ABC* and *AB'C'*) are derived, each with the same height *H*. Fiber f has extended from *H* to *l*, while fiber *f'* has extended from *H* to *L*. The greater extension in yarn *II* also implies greater tension and thus more pressure towards the interior. The strength of yarn *II* is considerably greater than that of yarn *I*.

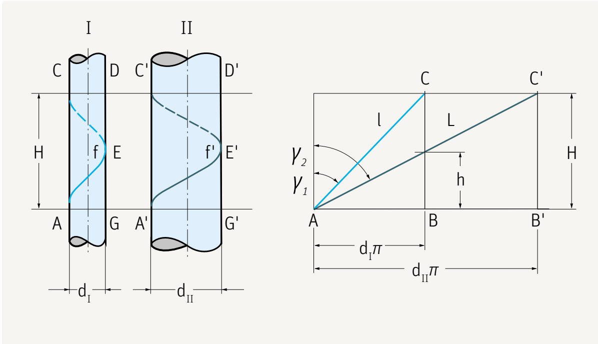


Fig. 59 – Winding of two fibers (f and f') in yarns of different thickness

Fiber extensions in the yarn can be measured only with difficulty, so that they cannot be used as a scale of assessment of the strength to be expected. Such a scale could, however, probably be provided by an angle, for example, the angle γ of inclination to the axis. From the above considerations, it follows that yarn *II* has a higher strength than yarn *I*. Yarn *II* also has a greater inclination angle γ than yarn *I*.
The strengths (*F*) are proportional to the inclination angles:

$$\frac{F_I}{F_{II}} = \frac{\gamma_1}{\gamma_2}$$

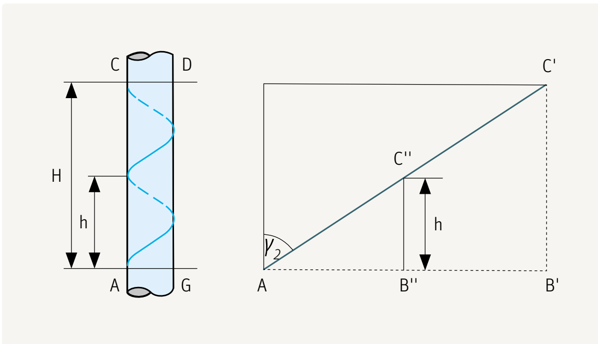


Fig. 60 – Number of turns of twist in thin yarns

In other words, the greater the angle of inclination, the higher the strength. If the two yarns are to have the same strength, then the inclination angles must be the same, so that $\gamma_1 = \gamma_2$ (all other influencing factors being ignored here). This is only possible if the height of each turn in yarn *I* is reduced from *H* to *h*.
In the given example, yarn *I* must therefore have twice as much twist as yarn *II* (Fig. 60).

7.3.2.5. Derivation of the twist equation

If the two yarns are illustrated on a somewhat larger scale, the situation of Fig. 61 is obtained [20]. The following relationships can be derived:

$$\frac{h}{H} = \frac{d_I}{d_{II}} \quad \text{and} \quad \frac{d_I}{d_{II}} = \frac{T_2}{T_1}$$

T = Twist in the yarn.

The mass of a yarn is given by

m = V (volume) x σ (specific mass)

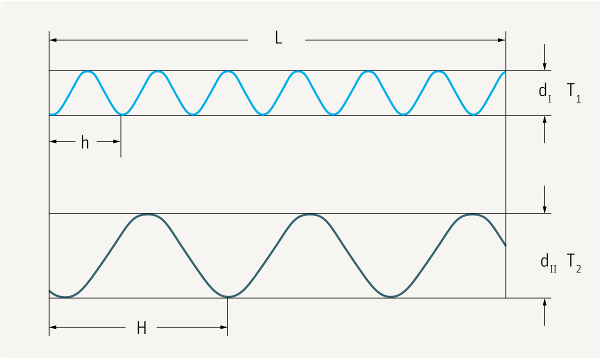


Fig. 61 – Number of turns of twist in yarns of different thicknesses

Since the volume is given by

V = A (surface area in cross section) × L (length),

and the area

$$A = d^2 \times \frac{\pi}{4}$$

the mass of the yarn is

$$m = d^2 \times \frac{\pi}{4} \times L \times \sigma$$

The masses of the yarns I and II are:

$$m_1 = \frac{d_I^2 \times \pi}{4} \times L \times \sigma$$

$$m_2 = \frac{d_{II}^2 \times \pi}{4} \times L \times \sigma$$

If these masses are inserted in the count formulas of the English system, the following results are obtained:

$$Ne_I = \frac{L}{m} = \frac{L}{\frac{d_I^2 \times \pi}{4} \times L \times \sigma} = \frac{4}{d_I^2 \times \pi \times \sigma}$$

$$Ne_{II} = \frac{L}{m} = \frac{L}{\frac{d_{II}^2 \times \pi}{4} \times L \times \sigma} = \frac{4}{d_{II}^2 \times \pi \times \sigma}$$

Here the yarn counts are related by the formula:

$$\frac{Ne_I}{Ne_{II}} = \frac{\frac{4}{d_I^2 \times \pi \times \sigma}}{\frac{4}{d_{II}^2 \times \pi \times \sigma}} = \frac{d_{II}^2 \times \pi \times \sigma}{d_I^2 \times \pi \times \sigma}$$

which reduces to

$$\frac{Ne_I}{Ne_{II}} = \frac{d_{II}^2}{d_I^2}$$

The diameters are related by the formula:

$$\frac{d_{II}^2}{d_I^2} = \frac{Ne_I}{Ne_{II}} \quad \text{i.e.} \quad \frac{d_{II}}{d_I} = \frac{\sqrt{Ne_I}}{\sqrt{Ne_{II}}}$$

but, since also

$$\frac{d_{II}}{d_I} = \frac{T_1}{T_2} \quad \text{we therefore have} \quad \frac{T_1}{T_2} = \frac{\sqrt{Ne_I}}{\sqrt{Ne_{II}}}$$

Expressed in an alternative form:

$$\frac{T_1}{\sqrt{Ne_I}} = \frac{T_2}{\sqrt{Ne_{II}}} = \frac{T_3}{\sqrt{Ne_{III}}} = \frac{T_n}{\sqrt{Ne_n}} = Constant = \alpha$$

This constant can be arbitrarily designated, for example, as α, and the following generally valid formula can then be derived:

$$\frac{T}{\sqrt{Ne}} = \alpha_e \quad .... \quad T = \alpha_e \sqrt{Ne} = \text{turns/inch}$$

The twist coefficient α_e is derived in accordance with the English count system, and for cotton yarns it takes the following values:

Yarn type	Short staple	Medium staple	Long staple
Knitting	–	2.5 - 3.0	2.1 - 2.6
Weft	3.3 - 3.8	3.0 - 3.5	2.5 - 3.0
Semi-warp	3.7 - 4.0	3.5 - 3.8	3.0 - 3.4
Warp	4.0 - 5.0	3.8 - 4.5	3.4 - 3.9

For the other count systems, the following formulas apply:
Turns per meter:

$$T/m = \alpha_m \times \sqrt{\frac{100}{tex}}$$

$$= \frac{\alpha_{tex}}{\sqrt{tex}}$$

Conversion factors are:

$$T/inch = T/m \times 0.0254$$

$$\alpha_e = \alpha_m \times 0.033$$

$$\alpha_e = \frac{\alpha_{tex}}{958}$$

7.3.3. False twist
7.3.3.1. Operating principle

If a fiber strand (Fig. 62) is held by two clamps K_1 and K_2 at two spaced points and is twisted at some point in between, the strand will take up the same number of turns on each side of the twisting element (*T*), but with opposite twist directions. In the example above, Z-twist is shown on the right and S-twist on the left (seen vertically). If the clamps are replaced by rotating cylinders (Z_1 and Z_2) and the yarn is made to run past the cylinders during twisting, the same thing happens – but the conditions are now different. With a stationary thread, as first assumed, both thread portions were untwisted at the start. With a running thread, however, the thread entering path section *b* is already twisted with the number of turns imparted to it in path section *a*. In the given example these are turns of Z-twist.
The twisting element, however, is creating S-twist in the left-hand path section, so that each turn of Z-twist imparted in the first section *a* is cancelled by a turn of S-twist imparted in the second section *b*. The strand therefore never has any twist between the twisting element and the delivery cylinder. In a false-twist device, twist is found only between the infeed cylinder and the twisting element. This principle is used in false-twist texturing.

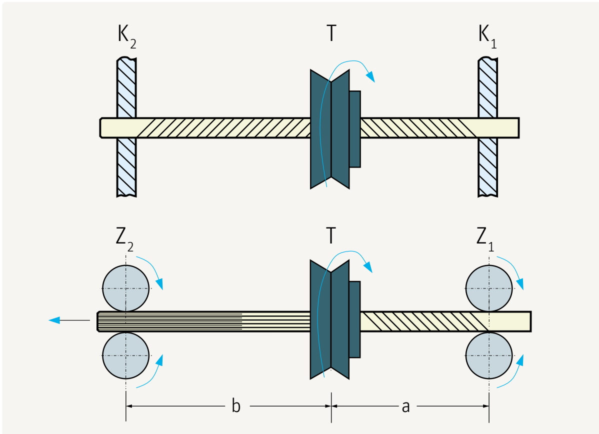


Fig. 62 – Creation of false twist
(above) in stationary condition; (beneath) in through-flow condition

7.3.3.2. Imparting strength by false twist

As described, the strand leaving the false-twist unit consists of parallel, untwisted fibers (Fig. 63). This twist principle is therefore normally unsuitable for imparting strength to a yarn. Nevertheless, threads are currently spun by this process — but with modification of the system. For example, the fiber strand fed by cylinder Z_1 has to be very wide as it passes into false-twist zone *a*. The result is that, owing to this substantial width, a considerable number of edge fibers can avoid the twisting effect.

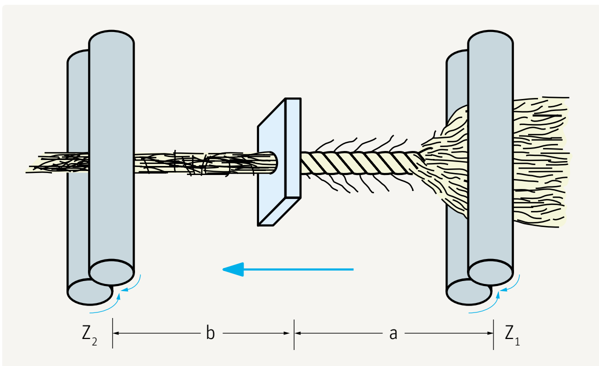


Fig. 63 – Forming a yarn by means of false twist

In contrast to the operation described in the preceding section, the fiber strand entering the twisting element is no longer fully twisted. Instead, only the core is twisted, and the sheath fibers have no twist or only a low twist level, with the core still representing by far the greater part of the fibers. The opposite twist now imparted by the twisting element cancels all twist in the newly arriving strand, in particular the turns in the core.

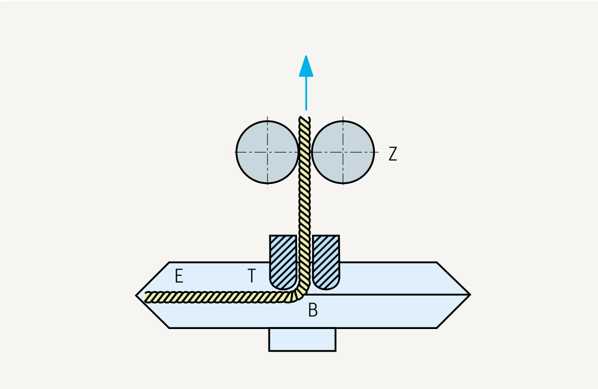


Fig. 64 – Creation of false twist in the rotor

Twist in the opposite direction is, however, imparted to all those fibers which were untwisted on arrival, i.e. the fibers in the sheath.
These are now wrapped around the core fibers so that a bundled yarn is produced. The Murata jet system operates in a similar, but not completely identical fashion and there are slightly greater differences in the Dref 3 system.

7.3.3.3. False twist at other places in the spinning process

The creation of false twist is not limited to the example given before. False twist arises, whether or not it is wanted, at various other points in the spinning process; for example, at the crown of the flyer in the roving frame and at the rotor navel in the rotor spinning machine.
At any point where a twisting element is operative between two clamping points, false twist will be produced. The clamping points can be stationary as in the example given (e.g. the yarn contact point *E* in the rotor and the withdrawal rollers *Z*, as shown in Fig. 64), and the twist element (the navel *T*) can rotate, as described in Section 7.3.3.1. Alternatively, the twisting element (*T*) can be stationary, as actually occurs in rotor spinning, and the thread can be continuously rolled on the contact surface of the navel owing to the movement created by the rotor revolution at the point *E*. The effect is the same. False twist occurs between *E* and *T*. Without this false twist effect, it would probably not be possible to operate with the high rotor speeds that are normal today.

7.3.4. Self-twist

If the strand is passed forward (by the delivery movement) between rubbing rollers (*N*), which are also moving to and fro, then it will be continuously twisted with alternating Z- and S- twist over successive short portions (Fig. 65 and Fig. 66). The counter-torque created in the yarn will, however, eliminate this twist immediately after the yarn leaves

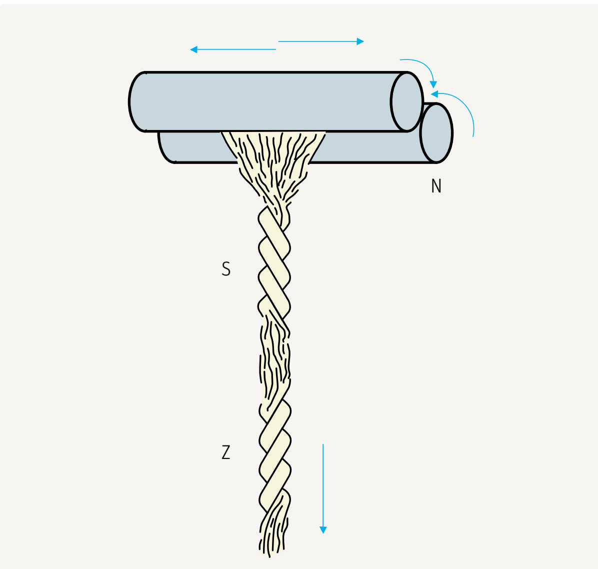


Fig. 65 – Self-twist

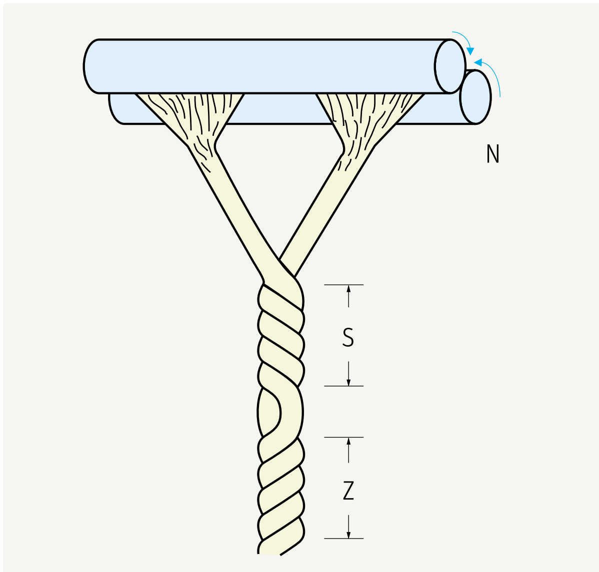


Fig. 66 – Forming a yarn by means of self-twist

the roller nipping line. If – instead of one strand – two fiber strands are passed through while arranged parallel and very close to each other, then the counter-torque can no longer operate solely on one yarn. It must operate on both, and causes twisting of the two threads around each other. A plied thread is created with continually varying twist direction – Z-twist where S-twist is present in both yarns and S-twist where the yarns had originally Z-twist. In most cases, the strength of the self-twist thread made in this way is not quite sufficient because of the untwisted pieces between the twisted portions – it must be additionally twisted subsequently.
In worsted spinning, its sole field of application, self-twist spinning (also known as Repco spinning) has been in use for several years, although not on a very large scale.

8. HANDLING MATERIAL

8.1. Carriers for material

8.1.1. Material carriers and transport

A spinning mill is less a production plant than a large-scale transport organization. Certainly, this assertion is somewhat exaggerated – but it contains an element of truth. When the quantities of material and the distances over which they have to be moved are considered, the comparison becomes obvious. Storage and transport of material are substantial cost factors in the spinning mill. Furthermore, they often exert a quality-reducing influence. Transportability always requires a taking-off operation at the preceding machine, and a feeding-in operation at the subsequent machine. These operations are frequently not carried out precisely in practice.
Furthermore, the necessity for winding up is a handicap to performance in many machines. Thus, for example, the ring spinning machine is scarcely capable of much further development simply because of the winding of cops (by travelers).
Material handling and transport are therefore significant problems in a spinning plant – problems that the machine designer and mill personnel must always take into account. In this complex problem, it is always necessary to find the new optimum and to seek the most appropriate means.
In relation to material carriers, it is important that they:

- take up as much material as possible;
- can be filled or wound in an uncomplicated manner;
- permit simple removal of material;
- protect the material;
- facilitate transport (in full or empty condition);
- take up little room;
- are economical to procure; and
- are well designed ergonomically.

8.1.2. Package forms

8.1.2.1. Classification

Three groups of packages are used for the intermediate and end products of the spinning mill [18]:

- Containers into which the material is made to run; for example, cans. This package form provides a high degree of protection for the material, but in the empty condition it occupies the same amount of space as when it is full.
- Take-up formers, such as cylinders, spindles, tubes, cones, etc., on which the material is wound. They provide less protection for the material, but they are easy to transport, are well suited to unwinding the product at high speeds in a controlled and trouble-free manner, and occupy little space when empty. They are therefore used where many production units are operated in confined spaces. For example, the ideal infeed for the ring spinning machine is still the roving bobbin.
- Unsupported packages, which consist only of the material. These are bumps, cakes, strands, hanks, etc. They are only usable for special purposes.

8.1.2.2. The most widely used package forms with internal formers

ROVING BOBBINS
The individual, closely adjacent windings are formed as so-called parallel windings.
The formers are plastic or wooden tubes. In order to prevent falling away of the upper and lower layers, the ends of the packages are made conical. The wound height is up to 16 inches. Not much tension is produced during winding. Accordingly, this is a suitable package form for weaker products such as rovings (Fig. 67).

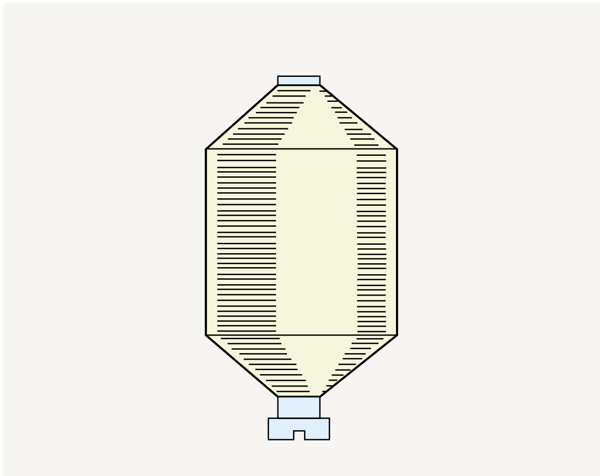


Fig. 67 – Roving bobbin

PACKAGES WITH FLANGED BOBBINS
These also have parallel windings but with constant wound height (Fig. 68).
Their take-up capacity is therefore greater, but the material tends to jam under the flanges and to be scraped off on the rough flange edges.
This type of package is therefore not used in short-staple mills.

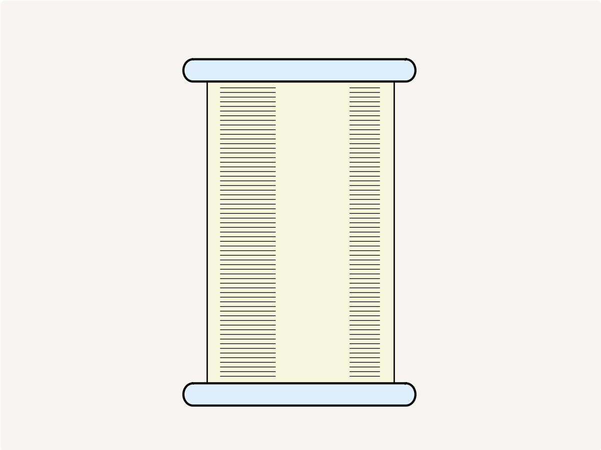


Fig. 68 – Package on a flanged bobbin

COPS (see also Fig. 81, Fig. 83)
The windings are not laid down in parallel layers but in conical layers (Fig. 69). Each conical layer, and therefore the wound height, is much shorter than the tube length. The layers are laid one on the other by continual raising of the winding device (the ring rail) by small amounts.
The windings are formed on plastic or paper tubes with lengths of up to 300 mm.
As far as winding is concerned, this type of operation is not favorable, because:

- the winding mechanism is complicated;
- continual tension variation is created in the yarn during winding;
- a traveler is generally required to form the winding;
- and this limits the performance of the machine.

With regard to unwinding, however, the conical arrangement of the layers is optimal since it permits high withdrawal speeds.

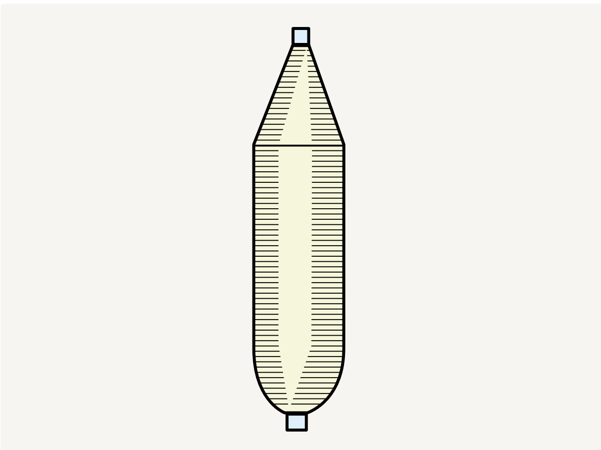


Fig. 69 – Cop

CONICAL CROSS-WOUND PACKAGES
By means of a traversing operation, the yarn is moved crosswise from one side to the other on the paper, or plastic tube (Fig. 70). Cross-wound packages take up a great amount of material and are ideal where adequate space is available for both winding and unwinding. In both cases, high speeds can be obtained. Conical cross-wound packages are used with cone angles α of 9° 15′, 5° 57′, 4° 20′, 3° 30′, and 2°.

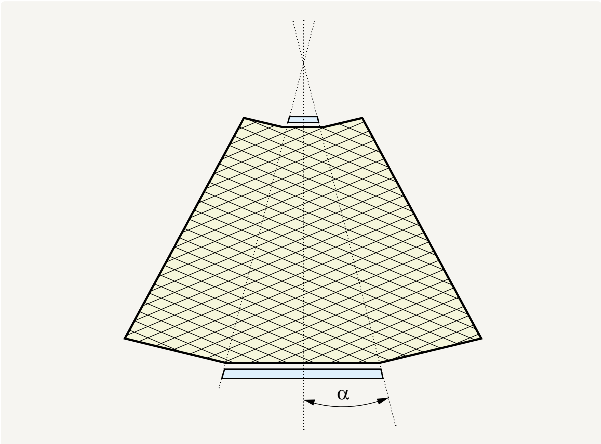


Fig. 70 – Cross-wound cone

CYLINDRICAL CROSS-WOUND PACKAGES
These are made up in cheese form and are easy to produce (Fig. 71).

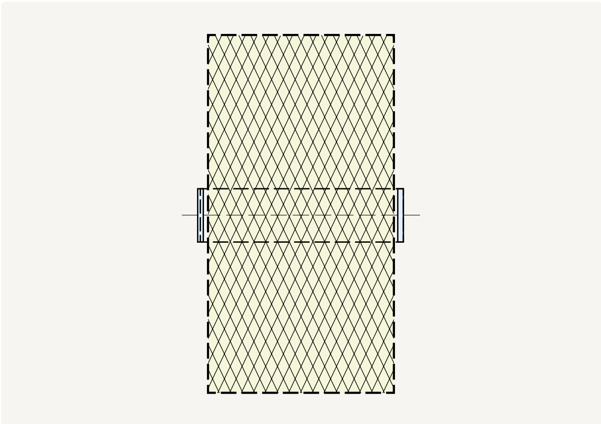


Fig. 71 – Cylindrical cross-wound package

SHORT-TRAVERSE CHEESES (SUN-SPOOLS)
These are also cylindrical coils, but they are considerably narrower than cylindrical packages, rather resembling discs (Fig. 72). When used as feed material in twisters, for example, they allow donning of two packages behind each other, so that preceding plying becomes superfluous.

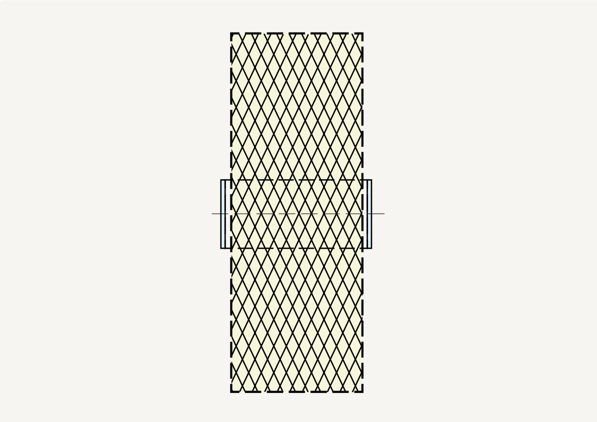


Fig. 72 – Short traverse cheese

8.2. Laying down in cans
8.2.1. Laying down of sliver

Cycloidal deposition of sliver has proved to be the most advantageous method of filling a can (Fig. 73). In this process, two shifting movements of the deposition point are carried out simultaneously. The rotating plate *R*, with its guide passage *L*, draws the sliver away from the delivery cylinders *D* and continuously deposits it on a circle. However, since the turntable can plate C continually rotates the can, the deposition point of the circle is constantly shifting. A helical arrangement of the circles is produced within the can (Fig. 74).

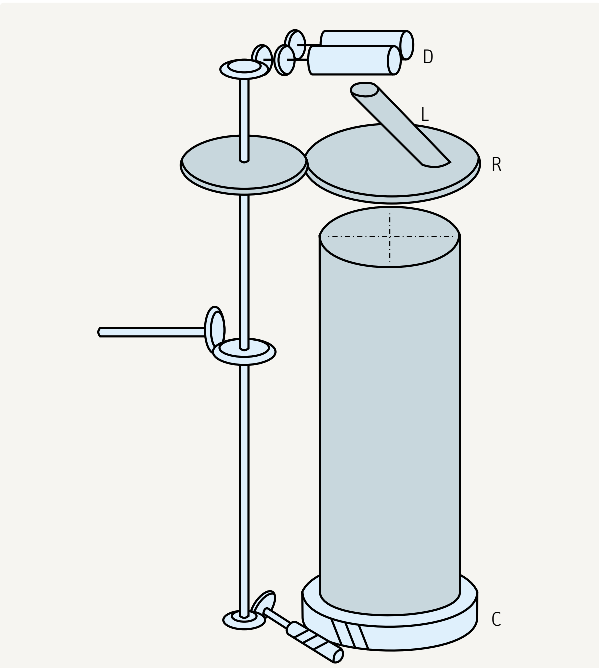


Fig. 73 – Can filling device (coiler)

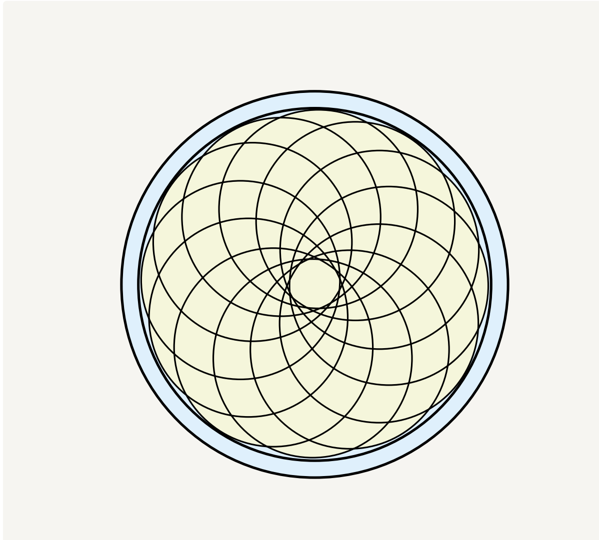


Fig. 74 – Laying down sliver in cans

In many coilers, the cans are no longer rotated. In this case, both movements must be induced from above. The delivery plate rotates at higher speed in a second larger plate, which is also rotating but at a lower speed. This also leads to shifting of the circles and hence to cycloidal deposition. In all cases, the sliver must be so deposited that a hollow space is created from top to bottom in the middle of the can. The space is required to ensure that the sliver layers do not overlap completely in the middle of the can. This avoids formation of a central pyramid-shaped column of material, leaving the side portions of the can half-empty.

8.2.2. Large and small coils

The hollow space can be obtained with large coils (Fig. 75, over-center coiling), or with small coils (Fig. 76, under-center coiling). With small coils, the diameter of the sliver coil (d_B) is less than the radius of the can (r_C). With large coils, the sliver-coil diameter is greater than the can radius. Large coils are generally used in small to medium-sized cans and small coils generally in large cans. The diameter relations should be approximately

$$\frac{d_C}{d_B} = 1.45 \quad or \quad \frac{d_C}{d_B} = 2.5$$

Large coils are better with small to medium-sized can diameters because lower plate speeds can be used for the same circumferential speed (reduction of force, noise, and wear). Moreover, the can capacity is 5 - 10 % higher.

With large cans, however, it is more advantageous if the plate is kept as small as possible, since then less mass has to be rotated.

A speciality is the coiling into rectangular cans as they were developped for optimal space usage.

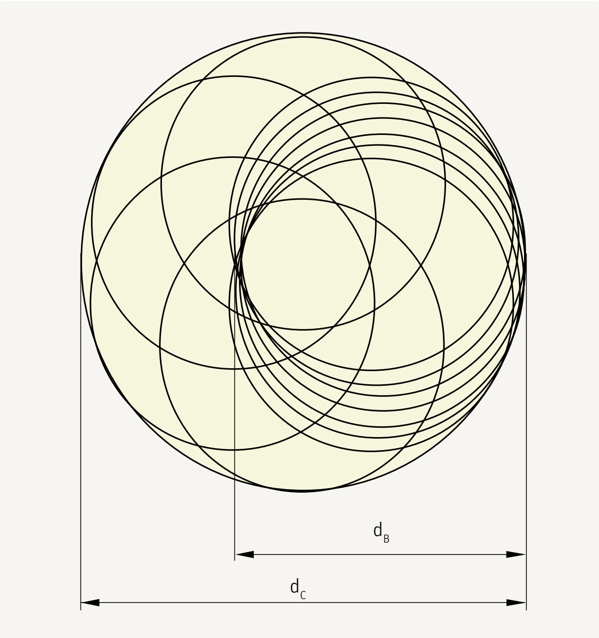


Fig. 75 – Laying down of sliver in large coils (over-center coiling)

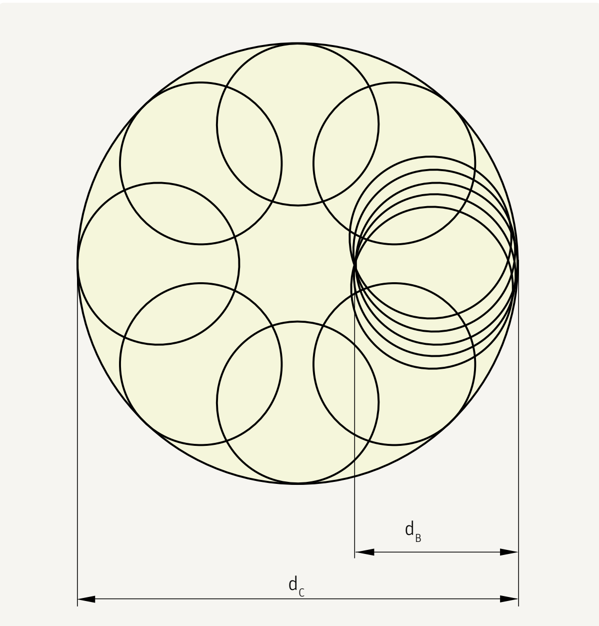


Fig. 76 – Laying down in small coils (under-center coiling)

8.2.3. Twisting of the sliver

Cycloidal deposition of sliver has several advantages, but it also has disadvantages. It creates twist in the sliver. Mostly this is insignificant because only a few turns are created. However, in the processing of man-made fibers, it can lead to disturbances.
Since both the plate and the turntable are rotating, twist can arise at both these places. The turns created at the plate are not permanent: they are subsequently detwisted when pulling-out the sliver from the can. On the other hand, the turns caused by the turntable remain.
The turntable creates no turns during deposition of the sliver, and there is only a shift in the position of the deposition point. The sliver twists during withdrawal when it has to follow the helical coils in the can.

8.3. Winding by rolling and lap forming

In this type of winding operation, a product of substantial width, such as a lap or a web, is wound up over its full width on a mandrel or a tube (Fig. 77). A traverse mechanism is unnecessary since the width of the product is the same as that of the receiving tube. In this case, winding is a very simple procedure. However, unwinding is not always so easy. It can happen that the individual layers of the lap do not separate cleanly.
They cling to each other, tear apart, or scale apart and thus produce disturbances. This will occur all the more readily if the lap does not form a closed, self-isolating separating layer. A random arrangement of fibers on the lap surface separates the individual layers from each other substantially better than an arrangement with a high degree of parallelization.
This can often be seen clearly in the raising of hairs on the ribbon lap machine in combing.

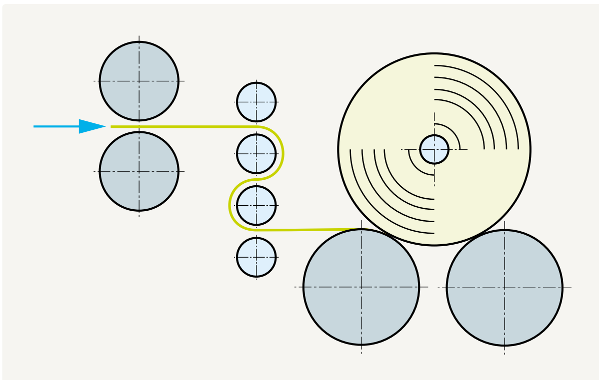


Fig. 77 – Winding of lap layers on a mandrel

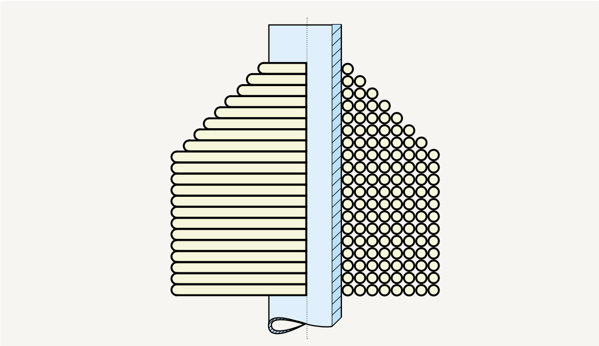


Fig. 78 – Build of roving bobbin in sections

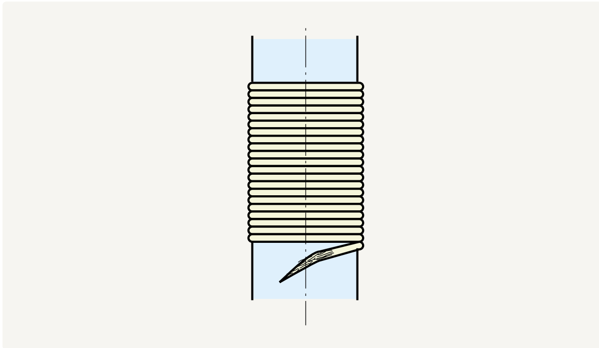


Fig. 79 – Laying wraps next to each other

8.4. Winding on flyer bobbins
8.4.1. Build-up of the package

Laying down of roving in the package is effected in parallel layers, i.e. each wrap is laid on the tube closely adjacent to the neighboring wrap (Fig. 78 and Fig. 79). In order to be able to wind over the whole length of the tube, the winding point must be continually shifted.
In principle, this is possible by adjusting the position of the press finger through raising and lowering the flyer or by up-and-down movement of the tube. However, the appropriate up-and-down movement of the flyer cannot be implemented in practice because it would result in continual variation of the spinning geometry – the inclination and length of the thread path from the drafting arrangement to the head of the flyer. The only practical method is the more complex continual raising and lowering of the packages together with the bobbin rail.
Since the first winding layer is formed on the bare tube, its diameter and hence its circumference (length of wrap) are both small. The second layer of wraps lies upon the first, i.e. the circumference of the wraps is already larger. However, since the individual wraps must be located very close to each other, so that the package takes up as much material as possible, the package (as a unit with a bobbin rail) must be moved more slowly for this second winding layer than for the first. For the third layer, it must be moved still more slowly, and so on. The speed of the bobbin rail, and also of the bobbin itself, must be continuously reduced.
A second change of movement is required insofar as the bobbin rail must perform continually shorter strokes. This is necessary because of the lack of end limitations in the form of flanges. If the stroke were held constant, i.e. the package ends were made straight, then the individual layers would fall away at the ends. In order to prevent such falling away, the ends are made conical, and consequently the stroke of the bobbin rail has to be reduced after each layer.

8.4.2. Speed relationships

One assembly, the flyer (spindle), is needed to twist the roving, but two assemblies are needed to wind it, namely, both the flyer and the bobbin. Winding is effected only when the difference between the speeds of these two assemblies is equal to the delivery speed. In terms of design, such a difference can be obtained very easily if one of the two assemblies does not rotate. Such a design, how-

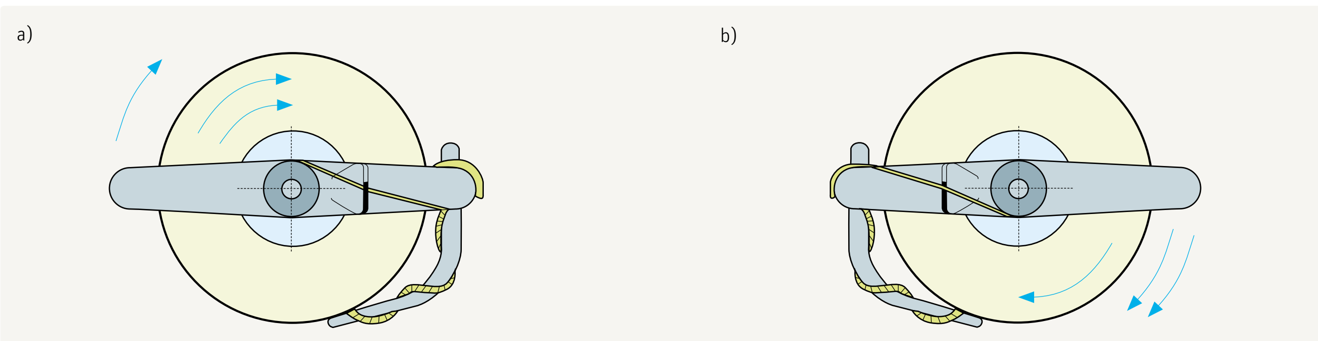


Fig. 80 – Winding on flyer bobbins
(a) with a leading bobbin; (b) with a leading spindle

ever, would impede the fulfillment of an additional task of the flyer, namely twisting of the roving. With a non-rotating flyer, there would be no turns in the product; with a non-rotating package, there would be too few – only one twist per wrap. A bobbin diameter of 106 mm leads to one twist per circumference (= 333 mm), i.e. only three twists per meter instead of the required 40 - 60 twists.
In order to fulfill both tasks, winding and controlled twisting of the roving to a selected degree, the two assemblies must have the same direction of rotation. However, the bobbin must rotate faster than the flyer or the flyer faster than the bobbin. This is referred to operations with a leading bobbin or with a leading spindle (flyer) (Fig. 80).
A leading spindle has the advantage that, with a pre-set fixed spindle speed, the operation can be run with lower bobbin speeds – lower than the spindle speed.
Nevertheless, all modern short staple roving frame designs use the principle of the leading bobbin. It provides significant advantages, as follows:

- Fewer roving breaks or faulty drafted places at the winding point, because the drive transmission path from the motor to the spindle is short, whereas that to the bobbin is long. Furthermore, the drive transmission to the bobbin includes a slip position, the cone belt transmission. When the roving frame is started, the spindle starts up immediately, but the bobbin follows with a delay. With a leading spindle, the roving would tear at the press finger, and a drafting fault at the finger would be created. With a leading bobbin, there are no such effects.
- No unwinding of the layers. Unwinding of the roving would arise on a roving break with a leading spindle, because the roving is moved against air-resistance in the rotational direction of the bobbin. On the other hand, with a leading bobbin, the air-resistance tends not to lift the roving off the bobbin but rather to press it back against the bobbin.
- Speed reduction with increasing package diameter. With a leading bobbin, the bobbin speed must be reduced slowly with increasing bobbin diameter, i.e. with increasing mass to be moved. This is advantageous in terms of power consumption. On the other hand, with a leading spindle, the bobbin speed must gradually be increased, which is not altogether sensible.

8.4.3. The winding principle

As already mentioned, winding can occur only when there is a difference between the circumferential speed of the bobbin and that of the spindle (flyer). At each instant, this difference must correspond to the delivery speed, since the length delivered and the length wound up must be the same. As roving layers are deposited on the bobbin, however, their diameters increase. Hence, in the absence of intervention, the circumferential speeds (and finally their difference) would increase. There would be a constant increase in the length wound up, and a roving break would occur. To avoid this the bobbin speed must continuously be reduced in a precisely controlled manner in order to maintain the speed difference continually equal to the constant delivered length. The following general principle can therefore be derived. If the circumferential speeds (*bo* = bobbin, *spi* = spindle) are given by:

$$v_{bo} = d_{bo} \times \pi \times n_{bo}$$
$$v_{spi} = d_{spi} \times \pi \times n_{spi}$$

then, since delivery is given by:

$$L = v_{bo} - v_{spi}$$
$$L = d_{bo} \times \pi \times n_{bo} - d_{spi} \times \pi \times n_{spi}$$

The bobbin diameter and the spindle diameter are equal, since in this context only the winding point at the press finger is significant. Hence we obtain:

$$L = d \times \pi \times n_{bo} - d \times \pi \times n_{spi}$$
$$L = d \times \pi \, (n_{bo} - n_{spi})$$

By transforming the equation, the bobbin speed corresponding to any given bobbin diameter can be derived:

$$(n_{bo} - n_{spi}) \times d \times \pi = L$$

which gives

$$n_{bo} = \frac{L}{d \times \pi} + n_{spi}$$

8.5. Winding of cops
8.5.1. Build of cops
8.5.1.1. Form of cops

The cop (Fig. 81) consists of three visually distinct parts – the barrel-like base *A*, the cylindrical middle part *W*, and the conically convergent tip *K*. It is built up from bottom to top from many conical layers (Fig. 82), but constant conicity is achieved only after the formation of the base. In the base portion itself, winding begins with an almost cylindrical layer on the similarly almost cylindrical tube. With the deposition of one layer on another, the conicity gradually increases.

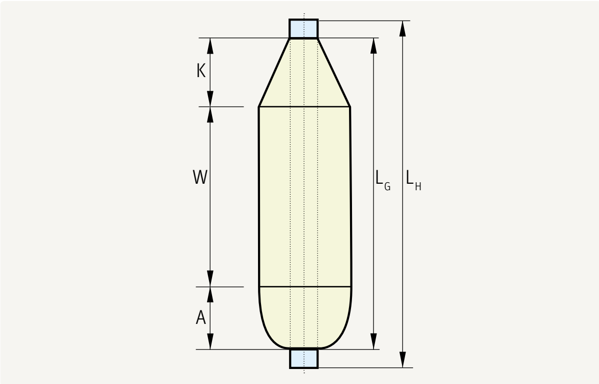


Fig. 81 – The cop as a yarn package

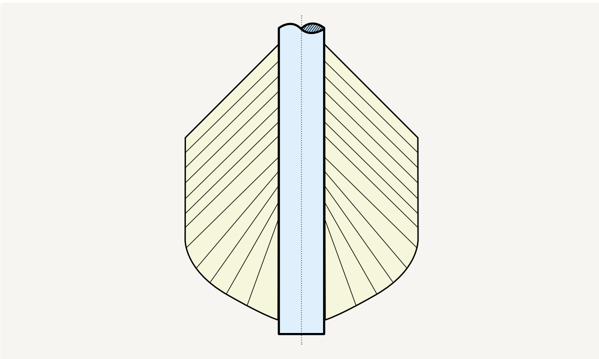


Fig. 82 – Building up the cop in layers

Each layer consists of a main layer and a cross-layer (Fig. 83). The main layer is formed during slow raising of the ring rail, the individual wraps being laid close to each other or on each other. The main layers are the effective cop-filling layers. The cross-layers are made up of widely separated, steeply downward inclined wraps of yarn and are formed during rapid lowering of the ring rail. They form the separating layers between the main layers and prevent the pulling down of several layers simultaneously when yarn is drawn off at high speed in winding machines. In the absence of such separating layers, individual yarn layers would inevitably be pressed into each other, and layer-wise draw-off of yarn would be impossible.

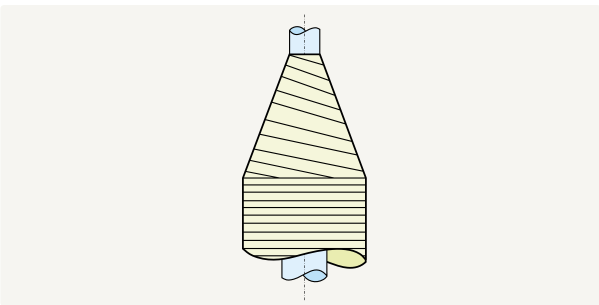


Fig. 83 – Main layers and cross layers

Raising and lowering of the ring rail are caused by the heart-shaped cam and are transmitted by chains, belts, rollers, etc., to the ring rail (Fig. 84). The long, flatter part of the cam surface forces the ring rail upwards, slowly but with increasing speed. The short, steep portion causes downward movement that is rapid but occurs with decreasing speed.

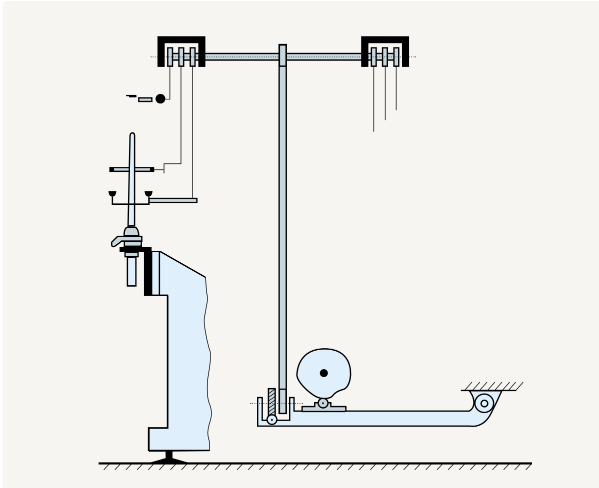


Fig. 84 – The winding mechanism

8.5.1.2. The formation of the base

The creation of the typical cop form is explained as follows by Johannsen and Walz [20].
The heart-shaped cam and the delivery cylinder are coupled together by the drive gearing. Thus the quantity delivered for each revolution of the cam, and hence per yarn double layer, is always the same. The volumes of the individual double layers are therefore also equal.

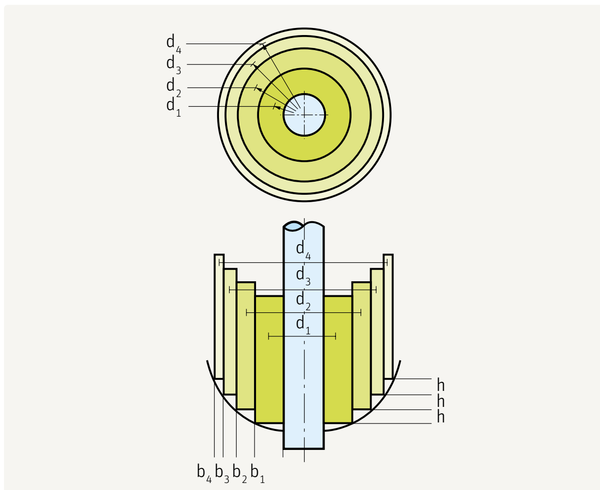


Fig. 85 – The formation of the curvature at the cop base

Deposition of double layers on the tube begins with a small average layer diameter, d_1 (Fig. 85). The average diameter increases gradually with each newly deposited layer.
With constant layer volume, this can have only one result, namely a continual reduction of the layer width from b_1 to b_2 to b_3, and so on.
Since the ring rail is also raised by a constant amount h after each deposited layer, it follows that a curve, rather than a straight line, arises automatically in the base portion, at the bottom.

8.5.1.3. The formation of the conical layers

It has already been mentioned that the ring rail is not moved uniformly. Its speed increases during upward movement and falls during downward movement. At the tip of each layer the speed is higher than at the base of the layer, i.e. the ring rail does not dwell as long at the tip as it does at the base: less material is wound, and the layer is thinner at the tip. If it is assumed by way of example that the ring rail is moving twice as fast at the top of its stroke as at the bottom of the stroke, the first layer would be half as thick at the top as at the bottom, i.e. b_1 ½ instead of b_1, (Fig. 86).

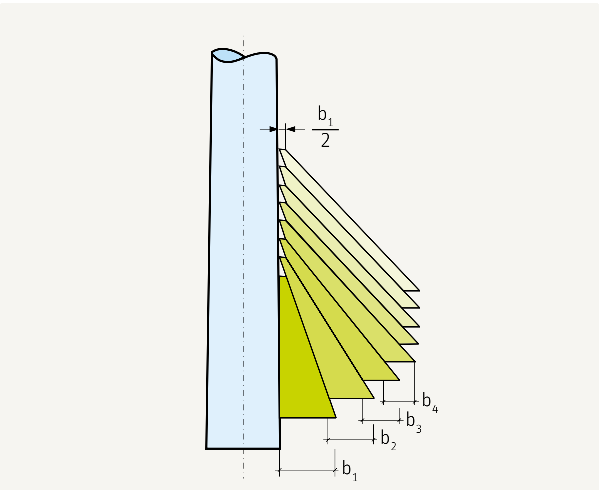


Fig. 86 – The formation of the conical layers

The first layer would correspond to a trapezium with the side b_1 at the bottom and the side b_1 ½ at the top. This is followed by the deposition of the second layer. Owing to the constant, short-term lifting of the ring rail, the upper portion of the new layer would again be deposited on the bare tube.
The average diameter at the top would be the same as that of the first layer, and the volume, and hence the thickness, would also be the same, that is b_1½. Each newly deposited layer will have this thickness of b_1½ at the top. At the bottom, however, the winding diameter is increasing continually so that the layer thickness is declining from b_1 to b_2 to b_3 to b_4. Accordingly, continually narrowing trapezia are produced.
At some stage, the trapezium will become a parallelogram, i.e. the lower side will be the same size as the upper side: both will be b_1½. Since all other winding conditions now remain the same, no further variation can now arise in the layering. One conical layer will be laid upon the other until the cop is full, i.e. when the cylindrical portion of the cop is formed.
The gearing change wheel has little influence on this sequence of events. If too many teeth are inserted, the final condition of constant conical layers will be reached too soon, and the cop will be too thin. It will be too thick if the ring rail is lifted too slowly.

8.5.2. The winding process
8.5.2.1. The winding principle

As in the case of the roving frame, two assemblies with different speeds must be used in order to enable winding to occur. One assembly is the spindle, the other is the traveler representing the remnant of the flyer. Furthermore, the speed difference must be equal over time to the delivery length at the front cylinder. In the roving frame, each assembly has its own regulated drive. In the ring spinning frame, this is true only for the spindle. The traveler is dragged by the spindle acting through the yarn. The speed of the traveler required to give a predetermined speed difference arises through more or less strong braking of the traveler on the running surface of the ring. Influence can be exerted on this process by way of the mass of the traveler. For winding with a leading spindle (see also 8.4.2.), the following relationships apply. The delivery is given by:

$$L = v_{spi} - v_T$$

where v_T is the traveler speed. Thus we have:

$$L = d \times \pi \times n_{spi} - d \times \pi \times n_T \quad \text{and} \quad L = d \times \pi \, (n_{spi} - n_T)$$

The required traveler speed is then:

$$n_T = n_{spi} - \frac{L}{d \times \pi}$$

As in the case of the roving frame, the diameter d is the diameter at the winding point.

8.5.2.2. Variation in the speed of the traveler

In contrast to the roving frame, the winding diameter in the ring spinning frame changes continually with raising and lowering of the ring rail, since the winding layers are formed conically (Fig. 87).

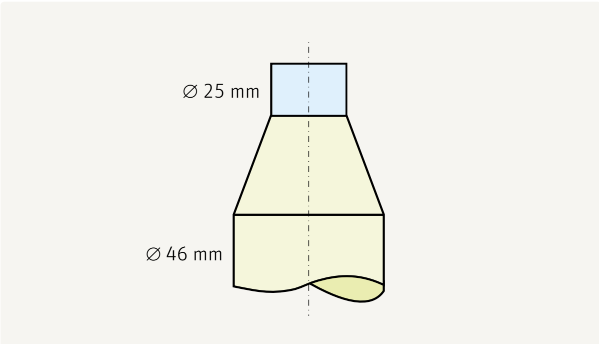


Fig. 87 – Different winding diameters

The traveler must have different speeds at the base and the tip. Assuming, for example, a spindle speed of 13 500 rpm, the layer diameters given (as in Fig. 87), and a delivery speed of 15 m/min, the traveler speed at the base will be:

$$n_{TB} = 13\,500 - \frac{15\,000}{46\pi} = 13\,500 - 104 = 13\,396\ min^{-1}$$

and at the tip it will be

$$n_{TS} = 13\,500 - \frac{15\,000}{25\pi} = 13\,500 - 191 = 13\,309\ min^{-1}$$

In comparison with the constant speed of the spindle, the traveler has a changing speed difference of 0.77 to 1.41 %.

8.5.2.3. Variation in yarn twist

The equation

Twist/m = Spindle speed (rpm)/Delivery speed (m/min)

is generally used to calculate the number of turns in the yarn. As just established, this is not wholly accurate, since the turns arise from the traveler and not from the spindle. In the given example, 104 turns per minute are missing at the base of the winding on the cop (larger diameter), and 191 turns per minute at the tip (smaller diameter). However, these missing turns are a theoretical rather than a practical problem for two reasons. Firstly, the inaccuracy of measurement in the estimation of yarn twist by test instruments is greater than this twist variation.

Secondly, the yarn finally receives its full twist in any case. This happens as soon as the yarn is drawn off the cop over the end, since each rotation of the yarn around the tube (1 wrap) leads to the insertion of an additional turn in the yarn. The compensation of the missing turns can then be explained easily.

If 191 turns per minute are missing at the tip, and 15 m of yarn has to be wound up in this period, the result is

T_m *(missing) = 191 turns/min / 15 m/min = 12.73 turns/m*

During unwinding, each yarn wrap on the cop (one circumference) produces one additional turn. At the tip (cop diameter 25 mm), we have:

T_a *(additional) = 1 000 mm/m / 25 mm × π = 12.73 turns/m*

that is exactly the number of turns previously missing. It must, however, be ensured that cops are always unwound over end, even during twist tests.

8.5.3. Force and tension relationships during winding by using travelers

8.5.3.1. Preliminary remarks

In the following explanations, certain inaccuracies have been deliberately accepted; for example, representation exclusively in two dimensions when the actual process is three-dimensional.
The intention is not to present either exact scientific theory or a detailed basis for calculations. Rather, the aim here is to provide the textile specialist involved in everyday practice with an understanding of the interrelations and in particular to bring out the interplay of forces. For this purpose, simplified models have been used; there is much literature available on scientifically exact usage [18, 20, 21].

The whole treatment is based on the parallelogram of forces, the normal "school" presentation of which is repeated here briefly for completeness (see Fig. 88).

If a carriage is to be moved forward on rails, it can be pulled directly in the direction of the rails (as F_T).

In this case the whole of the force contributes to the forward movement. This is no longer true if the force is directed with a sideways inclination (pulling in direction F_F). Now only a part of the total force exerted (F_F) will contribute to the forward movement (F_T).

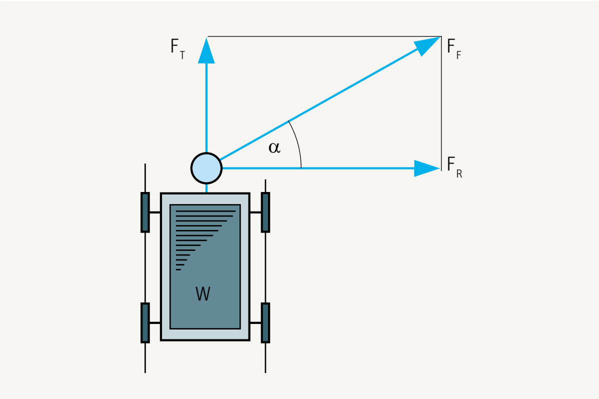


Fig. 88 – Resolution of forces in the force parallelogram

Part of the force F_F (i.e. the force F_R) will press the carriage against the rails at an angle of 90° to the direction of movement. This component is lost as far as forward motion is concerned. The pulling force F_F can therefore be resolved into two components, the tangential force F_T, which draws the carriage forward, and the radial force F_R. Accordingly, if the carriage is to be moved forward with the required force F_T and the pulling force is effective at an angle α, then the pulling force must have the magnitude F_F (friction forces being neglected here). These forces can be represented graphically and measured or calculated in accordance with the formula:

$$F_F = \frac{F_T}{\sin\alpha}$$

8.5.3.2. Conditions at the traveler in the plane of the ring

The following forces act on the traveler (1) in the plane of the ring (2) (Fig. 89):

- A tensile force F_F, which arises from the winding tension of the yarn and always acts at a tangent to the circumference of the cop (3).

- A frictional force F_H between the ring and the traveler. In the stationary state, i.e. with constant traveler speed, this braking force F_H is in equilibrium with the forward component F_T of the yarn tension F_F. Hence we have:

$$F_H = F_T \text{ or } F_H = F_F \times \sin\alpha$$

A force F_N normal to the surface of the ring (pulling the traveler in the direction of the cop, diminishing the friction of the traveler at the ring created by the centrifugal force F_Z). The frictional force F_H arises from this normal force in accordance with the relation:

$$F_H = \mu \times F_N$$

Where μ is the coefficient of friction.

- A centrifugal force F_Z, which is the largest force acting on the traveler. This force can be calculated in accordance with the relations [20]:

$$F_Z = m_L \times \omega^2_L \times d_R/2$$
$$\omega_L = n_{spindle} \times \pi / 30$$

where m_L is the mass of the traveler, ω_L is the angular velocity of the traveler, and d_R is the diameter of the ring.

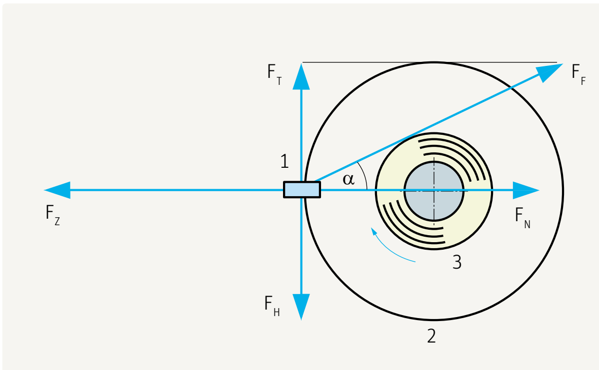


Fig. 89 – The forces acting at the traveler

Professor Krause (ETH, Zurich) identifies the following relationships between these forces, solved for the tensile force:

$$F_F = \frac{\mu \times F_Z}{\sin\alpha + \mu \times \cos\alpha}$$

$$F_F = \frac{\mu \times m_L \times \omega_L^2 \times d_R}{2 \times (\sin\alpha + \mu \times \cos\alpha)}$$

For a rough estimate, the term $\mu \times \cos\alpha$ can be ignored. Approximately, therefore, we have:

$$F_F = \frac{\mu \times m_L \times \omega_L^2 \times d_R}{2 \times \sin\alpha}$$

8.5.3.3. Changes in the force conditions

Continuous variation of the operating conditions arises during winding of a cop. This variation is especially large with regard to changes in the winding diameter, i.e. when wraps have to be formed on the bare tube (small diameter), and then on the full cop circumferences (large diameter). This occurs not only at the start of cop winding (formation of the base); such changes arise at very short intervals in each ring rail stroke as demonstrated by the example illustrated in Fig. 90.
It has already been mentioned that tensile force F_F must be assumed tangential to the cop circumference because it arises from the winding point. Frictional force F_H undergoes only small variations; it can be assumed to be the same in both cases.
The components F_T of the yarn tension are then also equal. However, owing to the difference in the angle α the tensile forces F_F are different. The same dependence of the tensile force F_F on the angle α can be seen from the formulas given above.
The result is that the tensile force exerted on the yarn is much higher during winding on the bare tube than during winding on the full cop diameter because of the difference in the angle of attack of the yarn on the traveler. When the ring rail is at the upper end of its stroke, in spinning onto the tube, yarn tension is substantially higher than when the ring rail is at its lowest position. This can be observed easily in the balloon on any ring spinning machine. If the yarn tension is measured over time, then the picture in Fig. 91 is obtained.
The tube and ring diameters must have a minimum ratio, between approximately 1:2 and 1:2.2, in order to ensure that the yarn tension oscillations do not become too great.

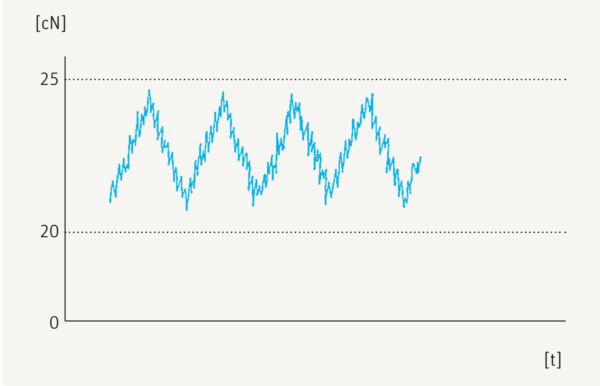


Fig. 91 – Continual changes in yarn tension due to winding on larger and smaller diameters

8.5.3.4. Conditions at the traveler in the plane through the spindle axis

These conditions were formulated by Professor H. W. Krause and Dr. H. Stalder, of ETH, Zurich.
The influence of the yarn on the traveler can be expressed in terms of two forces (see Fig. 92). One of these is tensile force F_F, acting at an angle α to the x-axis. The other is a force F_B, which arises from the balloon and can be assumed as tangential to the balloon curve. This force draws the traveler upwards at an angle γ to the y-axis.
Thus the traveler is drawn upwards at an inclination by the resultant force F_L of the two components ($F_B + F_F$). As the ring rail goes up and down, the angle σ therefore undergoes substantial variations.
Furthermore, the traveler is subjected to the forces F_Z (centrifugal force) and F_N (normal force). The weight of the traveler can be ignored here.

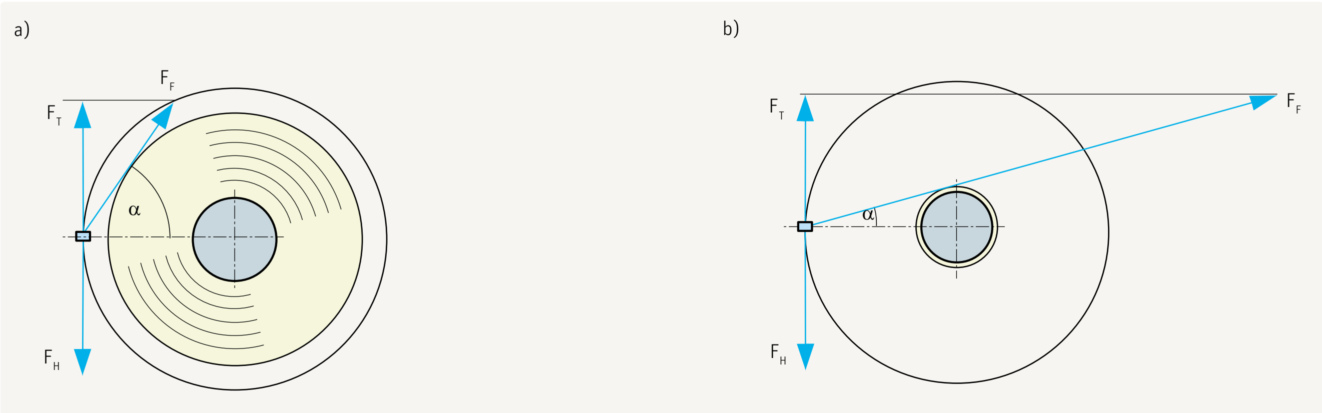


Fig. 90 – The tensile force (F_F) on the yarn
a, with a large cop diameter; b, with a small cop diameter (bare tube)

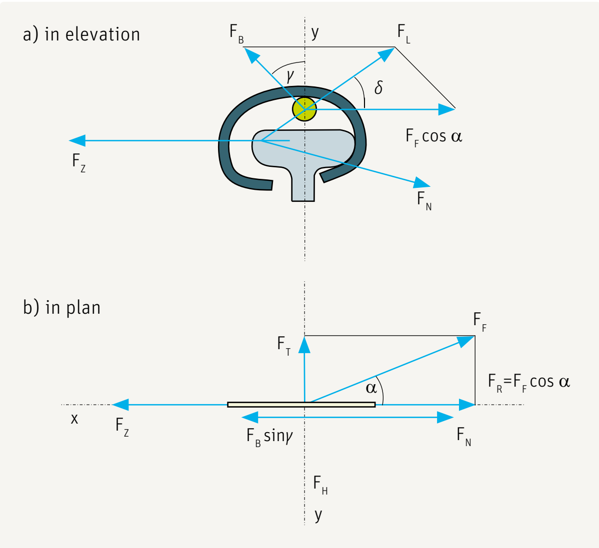


Fig. 92 – Resolution of forces at the traveler: a, in elevation; b, in plan

At constant traveler speed, the three forces F_L, F_Z, and F_N are in equilibrium, i.e. they intersect at point *P* and form a closed triangle (Fig. 93).

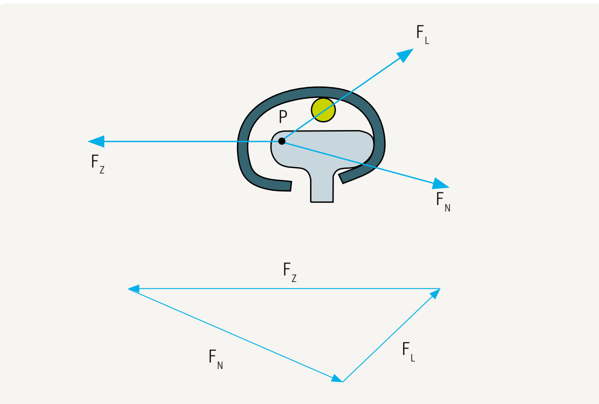


Fig. 93 – The resultant tensile force F_L on the yarn

8.5.3.5. Changes in the conditions

The forces F_F and F_B and the angle δ are subject to substantial variation during one stroke of the ring rail. This implies corresponding variation in force F_L. The point at which the yarn passes through the traveler also varies, however, with the magnitude of the tensile component F_L, and the angle of attack. When the ring rail is at the top of its stroke (small cop diameter, Fig. 94 a)), yarn tension is high, the yarn acts on the traveler at a position only slightly above the ring, and it draws the free end of the traveler upwards on the left-hand side.

The traveler straightens up. When the ring rail moves down, the tensile forces are reduced, the balloon widens out, and the yarn slips towards the middle of the curve in the traveler. The free end of the traveler tilts slowly downwards on the left-hand side.

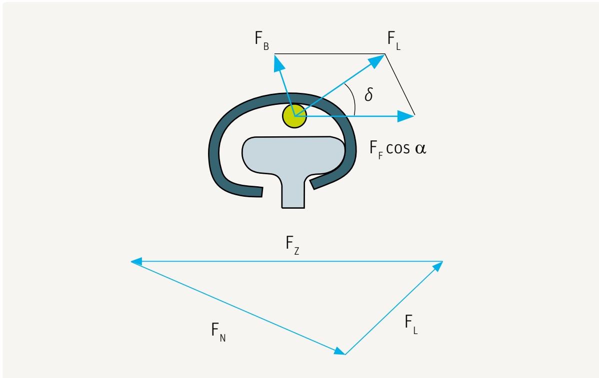


Fig. 94 a) – Raising and lowering of the traveler
raising, caused by the greater force F_L

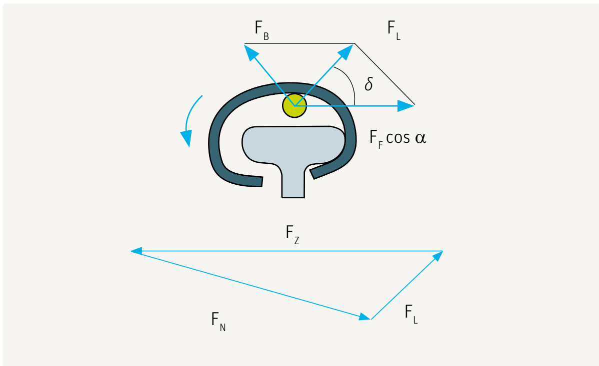


Fig. 94 b) – Raising and lowering of the traveler
lowering, caused by the reduced force F_L

In addition to these tilting movements, the traveler also performs a so-called rolling motion. If the yarn moves upwards in the traveler (Fig. 95 b)), the point of attack of the yarn on the traveler moves away from the contact surface with the ring. The yarn acts on the upper portion of the curve in the traveler, which is thereby drawn out of the vertical with an inclination to the left. In the reverse effect, when the yarn in the traveler approaches the ring more closely during upward movement of the ring rail, i.e. as the yarn moves downwards relative to the traveler, the latter straightens up again (Fig. 95 a)). This variability in the movement of the traveler is not good in terms of friction conditions; on the other hand, the traveler needs this freedom to enable it to adapt to the varying forces and to take up impact.

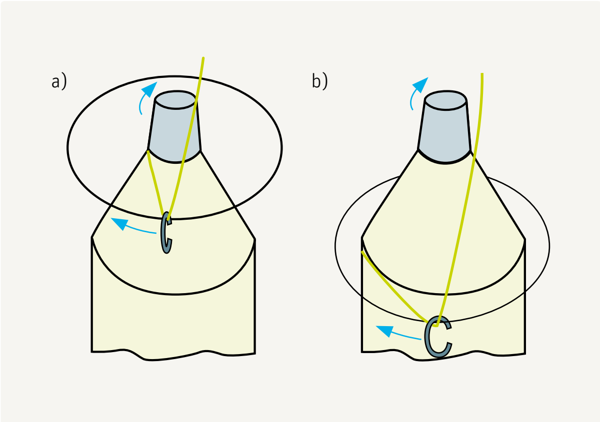


Fig. 95 – Varying inclination of the traveler on the ring
a) upright; b) inclined

8.5.3.6. Conditions at the traveler in the tangential plane

The yarn does not run absolutely vertically, i.e. in the plane of the spindle axis. It follows a curve caused by the air resistance created by the balloon rotation. The balloon tension F_B does not therefore act as a vertical pulling force, as previously assumed in the simple representation. Its effect is actually inclined upwards at an angle. An exact formulation would require three-dimensional representation and a corresponding analysis. Even without this, however, it can be seen from the drawing that the balloon tension can be resolved into two components (Fig. 96), namely, a component F_C, which presses the traveler upwards against the ring, and a component F_A, which acts as a restraining force on the traveler and slightly reinforces the restraining force arising from the friction appearing between the ring and traveler. Component F_A is relatively small and can be ignored. This is true also of the air resistance of the traveler.

8.5.3.7. Balloon tension

The yarn tension in the balloon (F_B) is the tension which finally penetrates almost to the spinning triangle and which is responsible for most of the thread breaks in practice. It is reduced to a very small degree by the diversion of the yarn at the thread guide. An equilibrium of forces must be obtained between yarn tension F_F and balloon tension F_B. Since the yarn is diverted at the traveler and friction arises there, this equilibrium is given [20] by:

$$F_F = F_B \times e^{\mu\xi}$$

where e is the base of natural logarithms (2.718), μ is the coefficient of friction between the yarn and traveler, and ξ is the angle of wrap of the yarn on the traveler. The value of $e^{\mu\xi}$ generally lies between 1.2 and 1.8. The balloon tension F_B is therefore a little more than half the winding tension (F_F).

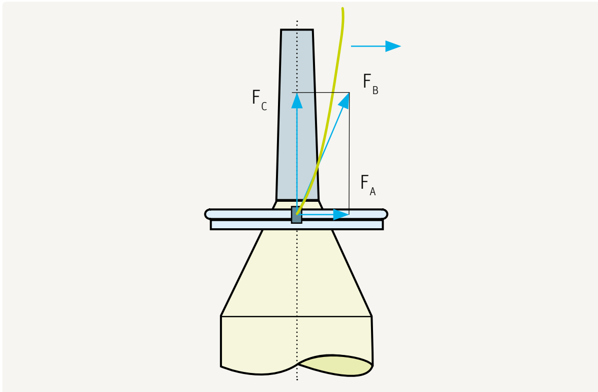


Fig. 96 – Resolution of forces with an inclined balloon

Yarn tension F_V (Fig. 97) at the point of maximum diameter in the balloon can be derived approximately from the following formula given by Professor Krause:

$$F_V = k \times \omega_L^2 \times H^2 \times \sigma$$

where ω_L is the angular velocity of the traveler, H is the height of the balloon, σ is the specific mass of the yarn, i.e. (yarn mass/yarn length) ≈ tex, and k is a constant. Thus, for a given yarn count, the yarn tension in the balloon is strongly dependent upon the traveler speed and the height of the balloon. High traveler speeds, and greater balloon heights, lead to very high yarn tensions in the balloon.

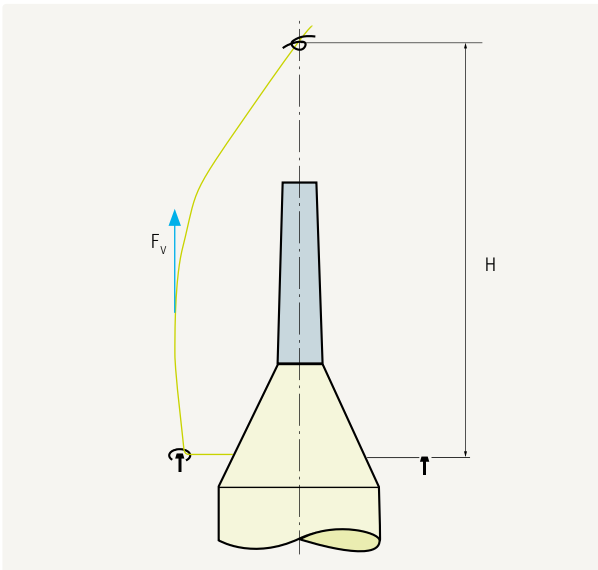


Fig. 97 – The balloon tension

8.5.4. Effects on the traveler

All of the forces mentioned here act on the traveler. Since the forces themselves and their angles of attack are constantly changing, the attitude of the traveler on the ring is also changing. These analyzable variations are reinforced by sudden sharp forces arising from the balloon or from the friction conditions between the ring and the traveler. Quiet, uniform, stable running of the traveler is therefore impossible. This is one of the great problems in ring spinning.

A still bigger problem is the development of heat. Since the traveler has no drive of its own but has to follow the spindle, its movement must be braked. However, braking without generation of heat is not possible. Accordingly, very high temperatures arise in the traveler. They reach more than 400°C. The problem here is actually not so much the generation of heat as its dissipation. The mass of the traveler is too small to enable it to transmit the heat to the air or to the ring in the time available.

These various explanations show that it is not easy to achieve considerable improvements in the interplay of the ring, traveler, and yarn under present conditions. Even with complete new designs of ring and traveler as introduced by the Rieter company, the traveler speed is limited to about 50 m/s (180 km/h).

9. QUALITY ASSURANCE

9.1. The necessity

Running high-tech spinning plants without the requisite technological knowledge is not possible, but it is also not possible without the required management expertise. In addition to many other subjects, this expertise includes the ability to ensure constant, long-term product quality.
One tool for ensuring virtually total process security is the Mill Information System (MIS). Besides ensuring quality, this also has a very important second advantage, namely considerably reducing production costs by:

- enabling the precisely required quality to be produced;
- optimizing raw material utilization;
- increasing productivity;
- improving personnel efficiency.

The wrong tool for high-tech spinning plants in respect to quality is the time-honored "Statistical Quality Control Office". By the time it is able to react to faults in production, enormous damage has occurred because high-performance machines such as cards, draw frames, etc., produce huge amounts of intermediate products within a very short time. This can be illustrated by a simple example: in only one minute, a draw frame operating at a speed of 800 m/min produces sliver for about 55 to 60 cops of yarn, sufficient to manufacture 25 shirts. The volume of rejects if anything goes wrong at any production unit in the mill is equally high. More than ever the following slogan is valid:

"FAULTS SHOULD BE AVOIDED, NOT CORRECTED"

Meeting this requirement calls not only for competent quality management, but also for an overall control, monitoring and information system with control devices at all relevant points of the material through-flow, either individual or group-wise.
The system has to start at the point where the first intermediate product is created, and has to continue to the end of the process, i.e. to start at the process infeed of the card, and to end at the winding machines. As sensors are installed nowadays in any case at all important points on nearly all machines, it makes sense to equip these control units additionally with data collecting and data evaluating systems in order to have the necessary tools not only for quality management, but also for mill management.
Fortunately, systems referred to as "Mill Information Systems" to control the process in terms of both quality and economy are now available from some machine manufacturers, one of which is the Rieter Company. The advantage of the Rieter system (SPIDERweb) is that it controls the entire mill from the blowroom to the winder, whereas many other systems control only specific machine groups.

9.2. The structure of the Mill Information System (MIS)

These systems mostly feature a three or four-level structure, starting at the lowest level, i.e. the level at which sensitive sensors are installed directly at special control points on the machines. They pick up the incoming figures and transmit them to the second level, the machine level. At the machine level, simple computers collect, transform and evaluate the signals arriving from the sensors. The summarized result is often indicated in a simple manner on a panel at the machine, informing the personnel responsible and enabling them to react immediately.

The third level is the level of the PC workstation, where the data collected at the machine level is selectively evaluated and informatively displayed in the supervisor's office, often also in graphic form (Fig. 99). The top level of the MIS is usually a commercial host computer.
Here again, all information arriving from the third (or perhaps second) level is collected in a condensed and compatible form by a local network and selectively evaluated in an easy-to-use form, e.g. as diagrams (Fig. 98). The detailed analysis of the second, third and fourth level enables immediate action to be taken if the slightest deviation occurs.

9.3. The Rieter "SPIDERweb" Mill Information System (Mill Monitoring System)

SPIDERweb is a user-oriented data system based on Windows. Its modular design permits the interconnection of any number of machines, and can be extended to include additional machines at any time. It permits control and monitoring of the entire mill from bale lay-out to the winding machines.
It enables production data, e.g. weight per time unit, efficiency, stop events, down-times, etc. and quality data, e.g. CV values, spectrograms, Classimat data, etc., from every machine to be logged and analyzed according to the requirements of the mill. A very important feature of this system is the inclusion of an alarm system. The moment any controlled item at any point within the mill crosses a preset limit specified by the mill, this is indicated immediately, and the fault can be eliminated at once.
SPIDERweb is a very modern and important management tool. It relieves management staff of time-consuming routine work, and allows it to concentrate fully on exceptional events, one of the requirements of competent management.

SPIDERweb provides responsible personnel with all necessary data to run the mill without major problems. The initial data required are available from Rieter, but can also be elaborated by the mill itself.

A further advantage of these systems is the potential for constant improvement of quality and productivity due to the following effect: when the alarm record indicates a deficient production unit, the reason for this deficiency can be eliminated, thus enabling the alarm limit to be lowered. The resulting new alarm schedule enables improvements to be made at the next deficient production unit, and so on. Improvement becomes increasingly difficult with each improvement step, of course, and will end when the effort required is greater than the result achieved.

9.4. Comment

If these systems are not purchased together with the machinery at the outset it has to be kept in mind that:

- a mill information (monitoring) system is essential sooner or later;
- machines purchased now will become part of such overall systems later;
- these machines have to fit into the MIS;
- management‘s failure to take this into consideration would create insoluble problems.

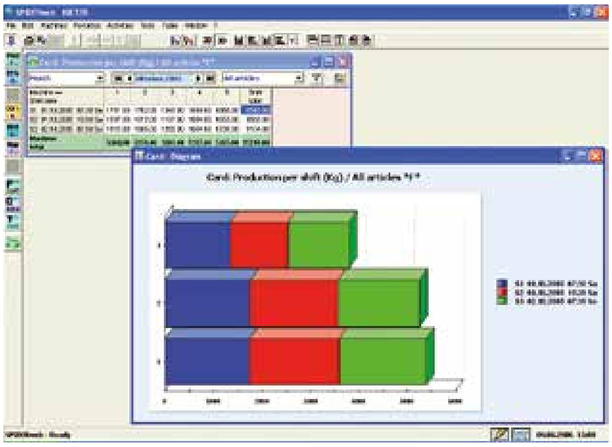


Fig. 99 – Diagram of SPIDERweb

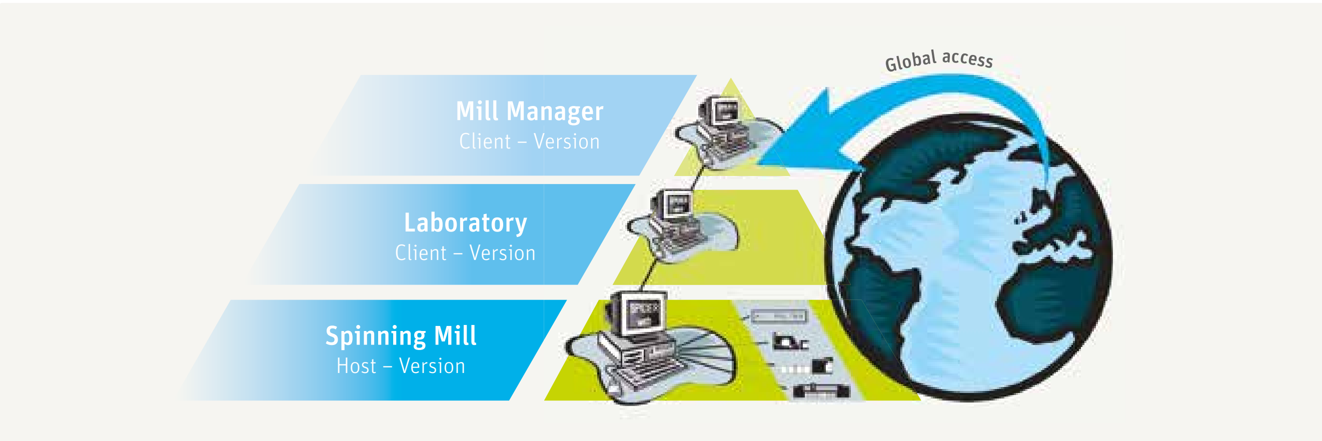


Fig. 98 – The different levels of the SPIDERweb system

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ILLUSTRATIONS

The Rieter Manual of Spinning

Volume 1 – Technology of Short-staple Spinning

This first volume in the series of The Rieter Manual of Spinning deals with the basics, and therefore generally valid, technological relationships in short-staple spinning. The following volumes in this series will be organized according to machines or machine groups. Generally valid basic principles will thus be kept separate from ongoing developments in machine design and construction.

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

Rieter India Private Ltd.
Gat No 134/1, Vadhu Road
Off Pune-Nagar Road, Koregaon Bhima
Taluka Shirur, District Pune
IN-Maharashtra 412216
T +91 2137 308 500
F +91 2137 308 426

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

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