3

Common principles

3.1 Introduction

Many principles relating to yarn production apply across the range of processes. For example, eccentric or deformed machine elements can produce periodic errors in filament yarns just as much as in staple yarns. An understanding of the common principles is vital to the comprehension of the technologies involved. The spectrum covers many technologies and yarn production systems. It includes the mechanics of drawing, doubling, and twisting. For reasons of economy, it is useful to discuss some of these common principles before dealing with the details of each process. Readers unfamiliar with the industry will find reference to Appendices 1 and 2 helpful.

3.2 Twist in strands

3.2.1 Purpose of twist

In the present discussion, the words 'twisted strand' encompass any yarn or intermediate product that is twisted. Staple yarns or rovings are twisted to induce lateral forces. Friction created by these forces acts to control fiber slippage in a strand under tension. A simple experiment can demonstrate this. Take a length of sliver and it will be found that fibers can be withdrawn from the ends with ease. If the sliver is now twisted tightly, it will be observed that the diameter decreases as the twist is added. Lateral forces act to compress the strand and bring the fibers closer together. As the fibers are pressed together, it is harder for the fibers to slip and it will be found that it is difficult to break the twisted sliver. If the sliver is then untwisted, it becomes weak again; failure is caused by fiber slippage.

A yarn is false twisted when a torque is applied to a running yarn, and the consequences are highly significant. Examples include texturing, rotor spinning, ring spinning, roving production, and yarn splicing. Distinctions between real and false twist will be drawn in the following text and the importance of each will be discussed.

3.2.2 Twist direction

It is necessary to define the direction of twist before continuing. Referring to Fig. 3.1, the direction of twist can be determined by matching the visible surface fibers to the center portion of the letter S or Z, whichever is appropriate. The convention is to refer to S twist or Z twist according to the direction. It is also conventional to spin single yarn in the Z direction but to ply in the S direction.

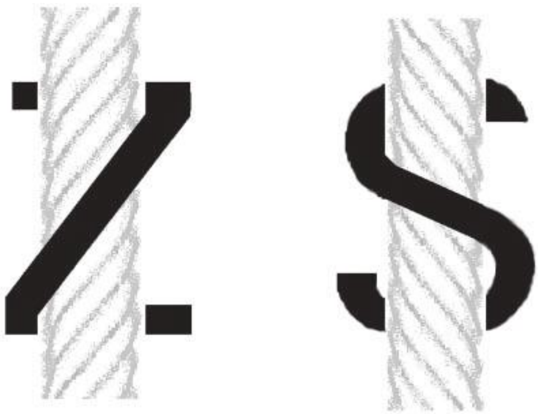


Fig. 3.1 Twist direction

3.2.3 Twist and flow

Twist multiple and linear density are the most important parameters in determining the character of a twisted yarn made from a given fiber. However, in setting up a spinning machine, the linear velocity of the strand and the rotational speed of the twister must be set in their correct proportions to produce the required yarn. The relative speeds are controlled by a transmission system consisting of gear trains and belt drives. In practice, a single gear (called a twist gear) is changed to alter the velocity ratio, which gives the required rate of advancement of the strand for the given spindle speed. The rest of the transmission is typified by a twist constant for the machine. Twist density is often measured in twists/inch (tpi), which is calculated from the ratio of the twist constant and the number of teeth in the twist gear. Twist density can also be measured in the metric system. Some simple examples of such calculations are given in Appendix 2.

3.2.4 Effect of twist on a staple yarn

Consider a simplified model of a staple yarn where a number of fibers at a given radius exist in a roughly helical configuration. Each fiber is under tension and a series of resultant forces acts towards the center of the fiber bundle (see Appendix 5). Taking all the fibers at a given radius, there is a sort of tube of fibers, all of which press inwards on the bundle of other fibers inside the tube. If a sufficiently high pressure is maintained on the inner fibers, there can be little fiber slippage and the whole structure becomes capable of bearing load. This requires that at least the outer shell of fibers should be kept under tension. One way to do this might be to tuck in the ends of each of the outer fibers rather in the manner of cord ends tucked in when whipping the end of a fishing rod. Although this is impracticable for yarn production, it serves to show a principle. In fact, the actual process of spinning causes portions of the outer fibers to be entrapped in the inner structure. Fiber migration is the name for this phenomenon and it causes the whole of the structure to interlock. In an ideal yarn, if the fibers were totally unbreakable, the strength of the yarn would increase with twist in the manner indicated by the cohesion curve in Fig. 3.2. Yarn failure occurs because the fibers slip over one another. On the other hand, in a yarn where the fibers cannot slip but must break, the strength would decline with twist. This is because of the reduced components of fiber tension resisting breakage as the twist angle increases[1]; it is shown as the obliquity curve in Fig. 3.2. 'Strength' is usually quoted in normalized units; it is then referred to as 'tenacity'. Tenacity is the quotient of force and linear density. The linear density is often quoted in tex and the units commonly used for tenacity are mN/tex. It has the virtue that the value is similar for all staple yarns made from a given fiber and twisted to the optimum degree, irrespective of linear density. It is, therefore, a useful comparative measure of the strength of the yarn. As will be discussed later, twist is usually quoted for this purpose as twist multiple (TM). The manner of calculating TM is dealt with in Appendix 1. This is also a normalized value and the yarn characteristics vary little for a given fiber length. Thus, diagrams similar to Fig. 3.2 serve as models for all staple yarns made from fibers of a given length and strength.

Real yarns are made from fibers that can be broken and which do slip. The strength of a twisted bundle varies, as shown in the lower curve of Fig. 3.2. It will be seen that twist weakens a fiber bundle by making the fibers oblique with respect to the yarn axis; too much twist seriously weakens the yarn. This eventually overwhelms the increased cohesion at twist levels above the optimum. The so-called obliquity curve refers to fibers oriented at an oblique angle. The yarn strength has an optimum value that is less than the sum of strengths of all the fibers in a cross-section. Above the optimum twist, the yarn fails by fiber breakage and a distinctive snap can be heard when the yarn breaks. If there is appreciable fiber slippage during the breakage because the twist is well below optimum, no snap can be heard. Sometimes, where strength is unimportant, yarns are produced at less than the optimum twist for economic

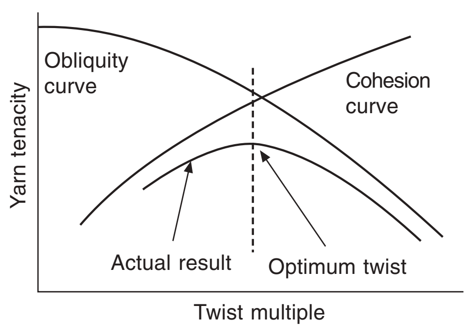


Fig. 3.2 Effect of twist on yarn strength

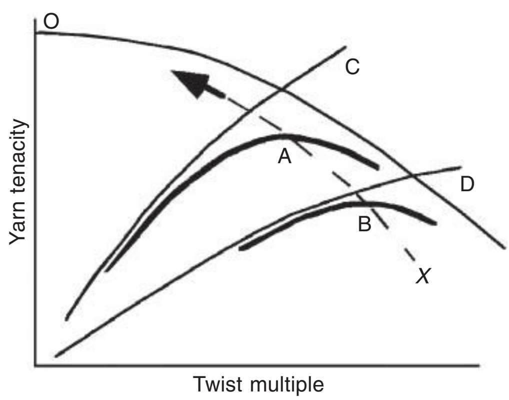
1 Simple trigonometry shows that the component of tension contributing to strength = $T \cos \beta$, which indicates that the helix angle of the fiber (β) is very important in determining the strength of the yarn. When β is very small, as in the case of some filament yarns, an anomaly arises because of maldistribution in loads between fibers. The yarn tenacity at zero twist may be slightly less than that achieved when the yarn has producer twist.

reasons. Sometimes the twist used is below optimum to give a soft hand to the product.

The cohesion curve can be changed by altering the staple length, l, of the fiber or by altering the effective coefficient of friction, μ. The latter is altered by varying the fiber lubricant (i.e. fiber finish) or the crimp level of the fiber. If l or μ is increased, the cohesion curve moves from curve D to curve C along path x in Fig. 3.3. The actual tenacity curve also alters to reflect these changes. Providing the obliquity curve remains the same, the optimum moves from point B towards point A. It will be seen that the optimum twist level is reduced and the maximum tenacity is improved by increasing the staple length or the interfiber friction. This explains why a premium is placed on the longer staple fibers and why short fibers are often removed from the material to be spun. As will be discussed in Chapter 8, there is a limit to how long the fibers can be before there are processing difficulties. However, there is another limit; fibers beyond a certain length add very little to the resistance to fiber slippage.

For indirect count systems twist density = TM $\sqrt{N}$ and in the direct systems twist density = TM/$\sqrt{n}$ both measured in twist/unit length.[2] The symbols 'N'and 'n' stand for indirect yarn count and the direct yarn count (or linear density) respectively as defined in Appendix 1. Some people use alpha to describe the metric version of direct twist multiplier.

Since TM describes the nature of the yarn, it does not vary greatly within a units system (see Table 3.1). It will be realized that the twist density required (tpi) is strongly dependent on yarn count. Thus, to set up a spinning machine to make a certain class of staple yarn, it is necessary to know the specified TM and count of the yarn before the twist density can be calculated. The need for twist rises with count; this is why fine yarns are more expensive than coarse ones (the adage 'twist costs money' comes to mind).



NB O = Obliquity curve
C = Cohesion curve 1 D = Cohesion curve 2
A = Actual curve 1 B = Actual curve 2
X = Path of optimum tenacity

Fig. 3.3 Optimum twist

2 ASTM D861 uses twist density in t/cm rather than t/m.

Table 3.1 Typical twist multiples

System	Length	Use	N_e cotton count	N_m metric count	N_w worsted count
Cotton	Short	Warp	4.0–5.0	120–150	–
		Filling	3.2–3.8	110–115	–
		Hosiery	–	–	–
Cotton	Long	Warp	3.4–3.8	100–115	–
		Filling	2.5–3.0	75–90	–
		Hosiery	2.2–2.6	65–80	–
Wool	Long	Warp	–	65–75	1.8–2.0
		Filling	–	55–65	1.5–1.8
		Hosiery	–	45–55	1.4–1.5

3.2.5 Ply twist

Where durable and pliable yarns are required, it is the practice to twist several yarns together and this is called plying. A singles yarn might, when relaxed, tend to take up a shape sketched in Fig. 3.4(a). It is then termed twist lively. It is usual to ply in the direction opposite to that in which the component strands were originally twisted so that the resulting plied yarn is no longer twist lively. Fibers on the outside of the ply normally appear to be roughly parallel to the axis of the yarn. Such a yarn produces a result similar to that in Fig. 3.4(b). If the amount of ply twist used is just sufficient to remove any residual torque (i.e. the plied yarn is non-twist lively, or 'dead'), the yarn is said to be balanced. Such balanced plied yarns are useful in reducing difficulties in handling the yarn during any post-spinning processes, as well as in lessening distortion of knit fabrics.

Twist structure is normally described in shorthand fashion. A singles yarn of count $N_e = 20$ is usually written as 20/1 (or 20s). When two such yarns are twisted together to make a plied yarn, the equivalent count[3] is 10_{equ}. The ply yarn is described as a 20/2 (but in some areas it is described as 10/2, which is meant to indicate $10_{equ}/2$). If four 20/1 yarns are plied, the result is a 20/4 yarn that has an equivalent count of 5_{equ}. The designation 'equ' stands for equivalent and it is usually omitted, which is confusing. It is useful to check the context before working with yarn numbers for plied or cabled yarns. With worsted yarns, the order of the numbers is usually reversed; if two yarns

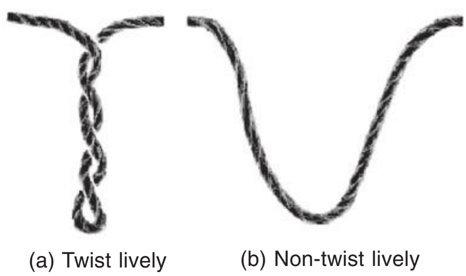


Fig. 3.4 Twist liveliness

3 See Appendix 1 for calculations. There are alternative designations to indicate that the number refers to equivalent count.

of N_w = 40 are plied together the result is designated $2/20_{equ}$ or 2/40. The ply twist multiple is calculated on the equivalent count.

When plied yarns are twisted together to produce a complex structure, this is referred to as a cable. Such cabling has a structure that is much more flexible than a simpler one. An example will illustrate how the twist structure is designated: if six 20/2 yarns are twisted together, the result is a cable, which is sometimes described as 20/2/6; the equivalent count is 10/6 = 1.66s. In some areas, the numbers are written in a different order. With cables, there could be an ambiguity and care should be taken to check the context.

3.2.6 Twisted filament yarns

It is unnecessary to twist continuous filament yarns to impart strength; nevertheless, some small amount of twist is inserted merely to control the fibers. An untwisted bundle of filaments is difficult to handle because odd filaments and loops project from the surface of the bundle. These tend to catch up in guides, tangle with adjacent yarns, or otherwise cause difficulty. Some man-made fibers tend to balloon out quite severely because they accumulate electrical charge. Filaments or loops protruding from the yarn are often called wild filaments. Even a low level of twist in the yarns helps to reduce the number of these wild filaments; twist inserted for this purpose is called producer twist.

Filament yarns are sometimes twisted to a fairly high level to break up the luster of the yarn or to impart some other attribute to the yarn for effect purposes. However, high twist levels reduce the tenacity of the yarn and make the yarn leaner (i.e. have a smaller diameter).

Another use of twist in filament yarns is to create texture. A false twisted yarn will coil or snarl if it is subject to the correct sequence of twist, set, and untwist. If properly relaxed, these textured yarns become bulky and have many desirable features. A major advance was made when it was realized that the process of false twisting provided the opportunity to carry out such a sequence in a continuous manner. To understand how that works, it is necessary to be knowledgeable about false twist.

3.3 Twist insertion

3.3.1 Real and false twist

So many practical cases involve false twist that it is thought desirable to discuss it in its own right. It is necessary first to discriminate between real and false twist. First, let the word ‘strand’ be used to widen discussion. It is used here to include not only yarns, but also rovings and possibly other forms of intermediate strands. We return now to the subject of false and real twist. Real twist is created when a ‘crankarm’ of a strand is rotated about an axis to insert twist and the material delivered to the take-up package retains all the twist, as shown in Fig. 3.5(a). The theoretical twist remains constant from the point A until the yarn is wound onto the package at a level $\tau = U/V$, where τ = strand twist in tpi, V = linear speed in inches/min, and U = rotational speed in r/min.[4] Some of the practicable means of achieving this are described later.

4 Fig. 3.5(a) does not show a balloon or yarn package so that the diagram may also cover two-for-one twisting.

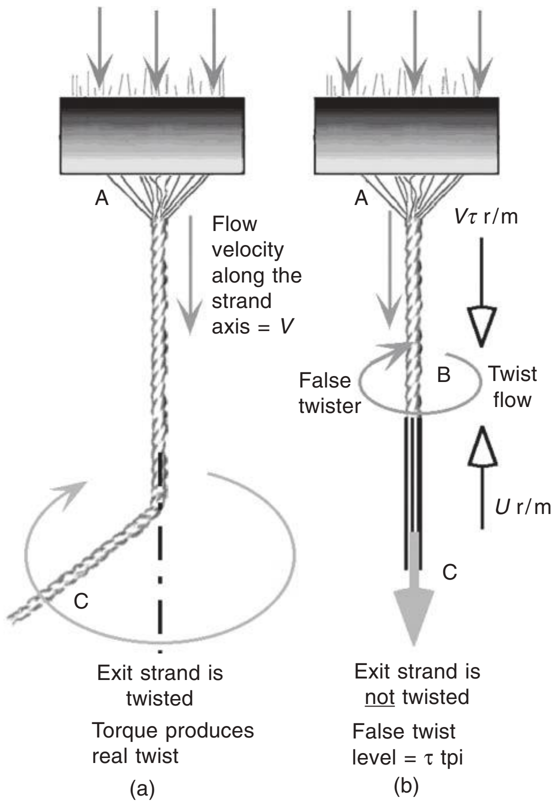


Fig. 3.5 Real and false twist

A typical example of this mode is in ring spinning, where the point C is in the upper reaches of a yarn balloon. The yarn package (not shown) rotates at a speed similar to that of the yarn in the balloon. In consequence, real twist extends over all the length AC.

False twist is created when a strand flows through the torque producing means. No twist exists in the strand delivered and the false twist is locked in the system above the twister while the strand continues to run. Systems involving both forms of twist are possible, in which case there is twist in the strand delivered but it is different from the value upstream.

3.3.2 Mechanics of false twist

In the simplest form of false twisting, neither the supply nor take-up packages are rotated to insert twist. Thus, the net twist in the delivered strand is zero and twist is trapped upstream. To explain how false twisting works, consider Fig. 3.5(b). A is just below the nip of the feed rollers, B is the point at which twist is applied, and C is the nip of the take-up. Twist carried downstream from B by the yarn is $-V\tau$ twist/min, the amount projected by the twister is $+U$ twist/min, and the twist delivered is the sum of them. The difference in sign is because the false twister generates S twist on one side and Z twist on the other. Twist flow input to zone AB is U twist/min and the loss is $V\tau$ twist/min.

Thus the total twist in zone AB of length L is $\tau L + (U - V\tau)t$, where t = time. $(U - V\tau)$ must be zero, otherwise the twist level would change and the system would not be stable. The input to zone BC is $-(U - V\tau)$ twist/min, which results in no twist in zone BC. Thus, the running false twisted yarn behaves as if twist was inserted at A and removed at B.

3.3.3 False twist insertion

Only examples of false twisting may be discussed at this stage. Some are by design and some are involuntary. Some uses are aimed at texturing the yarn and some are aimed at temporarily strengthening the strand during processing. For brevity, only one example will be given of each.

In texturing, twist is deliberately inserted by stacks of discs. The shape of the filaments and the structure of the twisted yarn are frozen and then the twist is removed, leaving the fibers in a stressed condition. The fibers are separated and the stress is relaxed, which causes the filaments to texture themselves to create a bulky or stretchy structure.

In roving, rubber grommets are used at the top of the flyer to provide a combination of false and real twist in the weak strand leaving the drafting system and entering the twister. The rubber surface grips the roving, which is in contact with the inner top surface of the rotating grommet and they move at different speeds. The shear from this pumps twist into the section between the drafting system and the grommet; this is in addition to the twist generated by the rotation of the flyer (discussed in Chapter 6). In this case, the outgoing twist is similar to that determined by the rotational and linear speeds; however, this does not imply that the structure of the strand is unaffected by the false twist. Often of major importance is that the twist in a vulnerable zone is enhanced and the strand is temporarily strengthened. The effect reduces end-breakages with beneficial economic consequences.

3.3.4 Real twist insertion

Ancient systems of twist insertion were discontinuous; the yarn did not flow through the machine in the steady and continuous manner employed by modern systems. However interesting these ancient systems might be, space limitations preclude any discussion of them. Conventional systems have endured for some 200 years and they are very well developed as commercial processes. They appear in several forms. Commercial twisting is always carried out as the textile material passes from the supply to some sort of twisting. Where twisting is the sole objective of the operation, either up-twisting or down-twisting may be used. It is usual to use down-twisting when other operational phases are involved in the process (such as drafting).

Two of the most common forms of down-twisting are flyer spinning and ring spinning. As the first example (Fig. 3.6), consider the production of singles staple yarn. A stream of fibers is supplied from a drafting system, then twisted, and the resulting yarn is wound onto a bobbin situated inside the yarn balloon. The second example is of up-twisting, where yarn is withdrawn from a package before further processing (Fig. 3.7).

Alternatives capable of economic exploitation have been sought and some of these newer developments are discussed later. There may or may not be another process involved. One of these involves two-for-one twisting as shown in Fig, 3.8 (discussed

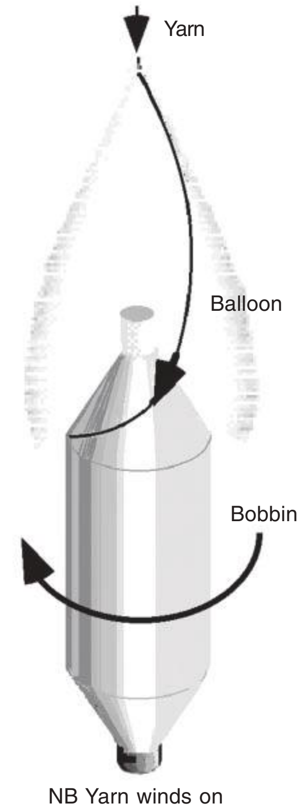


Fig. 3.6 Down-twist (down-twist is used to wind yarn on to a package)

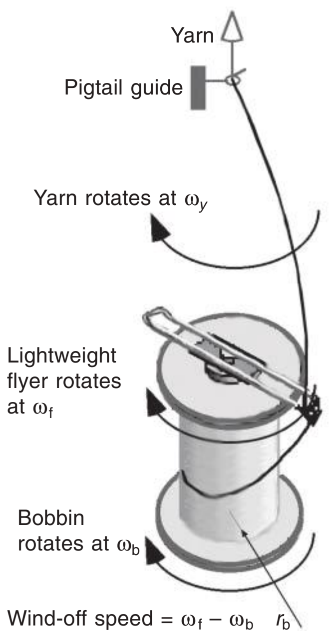


Fig. 3.7 Up-twist (up-twist is used to wind yarn from a package)

in Section 3.3.5); one yarn to be twisted is taken from a package situated inside the two concentric yarn balloons and is wound onto another one after twist has been inserted. An extension to this is found in plying (doubling), where the input consists of two or more yarns and the output is a single composite strand in which the input yarns are twisted together. The twisted yarn is usually wound onto a cheese or cone and this gives an economic advantage.

Now let us consider the twisting as an abstract idea somewhat remote from the supply and take-up systems. With conventional technology it is necessary to rotate a package about the axis of the yarn to insert the twist. Depending on whether the upstream or downstream package is rotated, we have either up-twisting or down-twisting. In such cases, it is normal to have a common axis for both the rotating package and the yarn balloon, as shown in Figures 3.6 and 3.7. By having a common axis, it is possible to wind yarn onto (or to unwind yarn from) the rotating package with the same motion used to put in the twist. This makes a very neat design of machine but it requires that the yarn package inside the balloon be small in diameter and limited in height. Also, the yarn has to be laid in organized layers as nearly parallel as possible to its neighbors; this is important if the process is to run smoothly at high speed.

Down-twisting is the most commonly used of the choices enumerated. The restrictions imposed by the balloon are substantial. (The details appear in Appendix 9 because the analysis is rather complicated.) To make the system work, there must be not only a twisting system but also a system to control the build of the package. Control is often applied by the motion of the ring-rail as discussed in Chapter 7. The element that is changed to alter the build is called a lay gear.

Up-twisting combines twisting with winding and results in a change of package shape. In up-twisting, the package from which the yarn is drawn is rotated to insert the twist. The receiving package is rotated only to wind the strand; thus there is a beneficial separation of winding and twisting. Control of the yarn leaving the package is necessary, otherwise the rate of unwinding might vary with the consequence that the yarn tension would vary. Ideally, a constant tension is required so that a stable and uniform yarn cheese or yarn cone is built. Physical control of the yarn balloon can be achieved by use of a ring and traveler or by a tiny wire flyer such as that sketched in Fig. 3.7. The flyer or traveler rotates at a speed slightly different from that of the bobbin. The wind-off speed = $\pm (\omega_f - \omega_b)\, r_b$ inches/min, where ω_f = flyer speed in rads/min, ω_b = bobbin speed in rads/min and $r_b = (1/2) \times$ diameter of bobbin in inches. The idea is somewhat similar to that used in down-twisting.

3.3.5 Two-for-one twisting

The foregoing cases relied on at least one package being rotated to put in twist. However, there is a possibility that requires no package rotation to insert twist. Consideration of the case sketched in Fig. 3.8 will show how this may be done. If the yarn is doubled back on itself to make a loop, which is rotated, then one turn of A inserts one turn of twist in each of legs B and C. Furthermore, the direction of twist is the same in each with the result that the twists add together. With this arrangement there is no need to rotate either package to twist the strand; one revolution of the spindle puts in two turns of twist. Such machines are known as 'two-for-one twisters'. The problem is that the large package has to be held inside the yarn balloon.

The concept first started to be used for tire cords in the 1930s, but it was a further

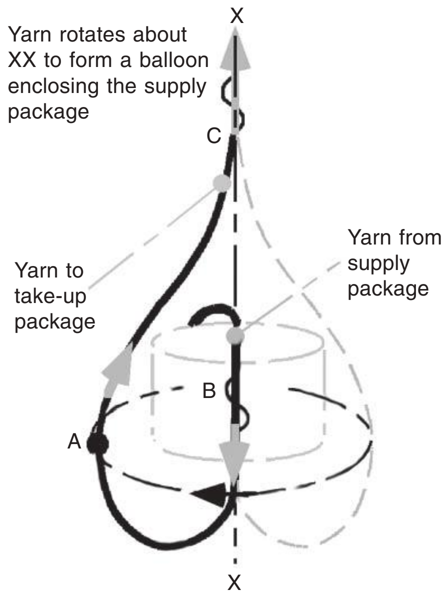


Fig. 3.8 Two-for-one twisting

20 years before it came into commercial use for staple yarns. Penetration of the short-staple market took another 20 years. These machines are now used for carpet, industrial, and other yarns, as well as for sewing threads. The attraction is that, with a two-for-one twister it is not necessary to rotate a large, heavy package to insert twist; consequently high twisting speeds can be used. However, the problem of suspending a non-rotating yarn supply package inside the yarn balloon leads to some mechanical design difficulties. It also leads to a certain awkwardness in piecing up because of the relatively complex threadline path. It is normal to use a compressed air system to blow the new end through the fairly complicated passageway. A tension control disk, coaxial with the package(s), gives stability to the large balloon (see Chapter 9).

It could be inferred that high speed yarn balloons of large diameter are needed. However, high yarn tension results from various combinations of large balloon diameter and high speed. The result is that two-for-one twisters are normally used for twisting relatively strong strands. Some machines are used for plying, in which case two yarn cheeses may be mounted coaxially inside the balloon. The reader is referred to a review by Lorenz [1]

3.3.6 Wrap spinning

The direct cabling machine has one sort of wrapping spindle arrangement; other sorts are based on the ring frame in which a hollow spindle is used.

In wrap spinning, one or more small strands are wrapped around a core yarn. Basically, one or more yarns are wrapped around a core yarn so that the fibers in the outer sheath differ from those in the core. The wrapping may be a strong filament or yarn to enhance the yarn strength or the wrapping might create a texturing effect. The core often has inferior properties and the system offers financial incentives as well as possibilities of enhancement of the technical or visual properties of the yarn. One sort of wrapping machine has an arrangement based on the two-for-one principle. Another is based on a ring frame in which a hollow spindle is used.

3.4 Confined and non-confined systems

The means of twisting so far considered have required that a package be confined within a yarn balloon. There are several systems that are not so restricted and these will be discussed next.

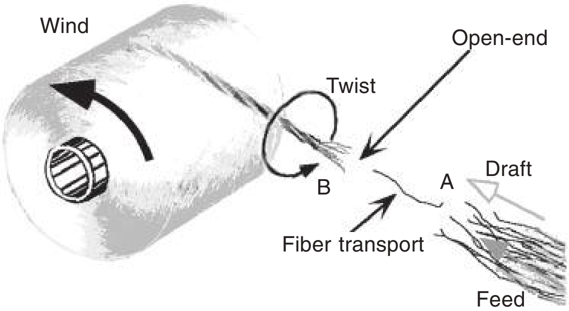
3.4.1 Open-end spinning

If the number of fibers in the flow cross-section is sufficiently reduced as they flow from one package to the other, it is possible to create a so-called open-end. Such an open-end may be rotated about the axis of the yarn to put real twist in the yarn without great interference from the incoming fiber. It is no longer necessary to rotate either package to twist the yarn. This is known as open-end (OE) spinning.

The process involves the separation of fibers by a severe drafting action, followed by re-condensation. This is discussed further in Chapter 7. In OE spinning, the staple fiber flow is separated by drafting so that individual fibers (or small clumps of fibers) are added to the 'open-end' of the forming yarn (shown diagrammatically in Fig. 3.9). A rotor is normally used to collect these fibers and support the open-end. This is discussed in Chapter 7 and Appendix 10. Yarn can be spun providing there is a steady flow of clean fibers into the moving rotor and the yarn is continuously removed. There is no significant yarn balloon; there is neither ring nor traveler. The result is that the package size is limited only by the ability to wind the package. Also, the speed is not limited by a traveler. Consequently, an OE spinning machine is capable of high production rates. In fact, an OE 'spindle' is capable of producing up to ten times as much yarn per hour as a ring spindle and, as a result, this process has become very important.

3.4.2 Alternating twist systems

It is possible to insert twist into one or more parallel strands by using a pair of plates



Discrete fibers are detached from the feed at A by the drafting system, transported and then added to the open-end of the yarn being made at B.

Fig. 3.9 Open-end spinning

pressed into contact with a strand, as sketched in Fig. 3.10. Alternatively, a pair of rolls can be made to move parallel to their axes to produce a similar effect. If the process is to be continuous, the plates or rolls have to oscillate in the direction of the arrows.

In the case of woolen yarns, the strand is called a roping. The twist cancels after passing through the reciprocating rolls but sufficient cohesion between the fibers is generated by the process to give the strand enough strength to carry it to the next stage of processing.

In the case of self-twist yarns, the rolls are called ‘shuffling rolls’. They rotate to deliver yarn and at the same time they oscillate parallel to their axes to produce two (or more) strands, each of which now contains alternating twist. The component yarns are in close proximity to one another. A length of newly twisted yarn has an unbalanced torque (i.e. it is twist lively). If two such strands of the same twist direction are brought together in close contact along their length and are given freedom to rotate about their common axis, they will ply themselves in the opposite direction to relieve the unbalanced torques. The resultant ply tends to be balanced.

The shuffling roll in the self-twist machine puts in twist that alternates from Z through zero to S, back through zero to Z, and so on. Two such strands placed together so that the Z twist is opposite Z twist and S twist is opposite S twist, ply themselves to give S ply through zero ply to Z ply and so on. The result is a ply yarn in which the direction of the ply alternates. Again, twisting and winding are separated with the result that large packages of unbroken yarn can be made. A much higher processing speed can be attained than with other devices, because there is no conventional spindle or rotor.

3.5 Twist evenness

3.5.1 Torsional stiffness

An uneven yarn has a varying torsional stiffness; if a torque is applied to a length of such yarn, some portions will become more twisted than others. Torsional stiffness of a yarn is dependent on the yarn diameter, the disposition of the fibers in the cross-section, and the torsional stiffness of the fibers. (Torsional stiffness of the fibers depends on their cross-sectional shape and their modulus of elasticity.) The torque might remain constant along the length but there can be rotation of one segment with respect to a neighboring one, which is controlled by the torsional stiffness; the result is shown in Fig. 3.11. This phenomenon is known as twist migration; the perception

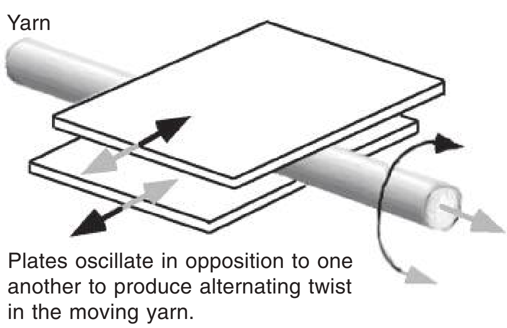


Fig. 3.10 Alternating twist

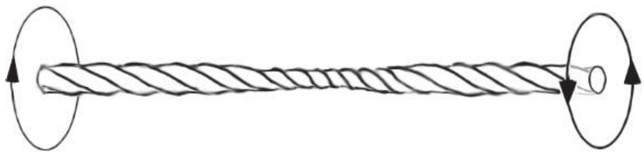


Fig. 3.11 Twist distribution in an uneven yarn

is of twist running to the thin spots (which is largely true, but changes in torsional stiffness can produce similar effects).

3.5.2 Variation in behavior of twisted strand

Clearly, an uneven twisted strand, such as roving, has varying diameters and hardness; consequently it has variable behavior as it goes through a drafting system, which results in variable twist densities. This is a particular problem with roving. where highly twisted compact portions of the strand (called 'hard ends') enter the drafting system of a ring spinning machine and cause slubs and end-breaks because of the conditions just described. Two means of controlling this problem in ring spinning are (a) to obtain as even an input strand as possible, and (b) to use as low a roving twist as possible. Too low a twist will not run on the spinning system concerned. Also, in texturing, migration of twist can disrupt the structure and create faults.

3.6 Tension control

3.6.1 Axial movement

Moving strands are nearly always under tension and the tension needs to be controlled. If the strand is flowing along its axis, there are two main simple alternatives for the creation of extra tension for control purposes. One is to use an additive tensioner (Fig. 3.12(a)), and the other to use a capstan tensioner (Fig. 3.12(b)). A device can use both methods. In the additive system, the drag from the tensioner is simply added to the existing upstream tension. In the capstan system, the wrapping of the yarn over

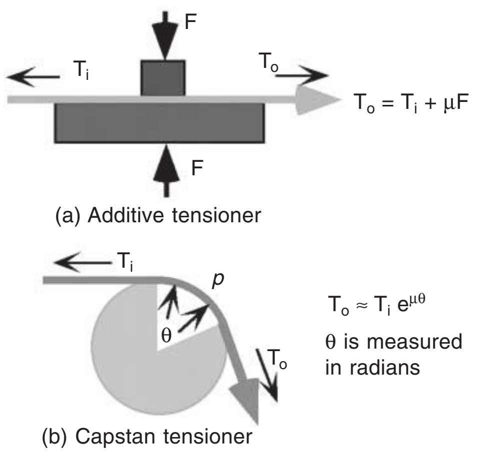


Fig. 3.12 Tension controllers

the segment of subtended angle, θ, produces a transverse pressure, *p*, and creates a frictional restraint to flow. The appropriate equations are given in the diagram.

Note: T = tension, μ = coefficient of friction, θ is the angle subtended by the yarn, and e = 2.718 (the base of naperian logarithms), and the subscripts i and o refer to the input and output respectively. It must be pointed out that the coefficient of friction, μ, is not a fixed value and varies according to the velocity of sliding. Various factors have an effect and these include: (a) temperature of the surfaces, (b) moisture content of the fibers, (c) additives applied to the fibers, (d) hairiness of the yarns, (e) condition of machine surfaces, and (f) presence of contamination.

3.6.2 Orbital movement

If a yarn orbits an axis it is subjected to centrifugal force that makes it 'balloon'. This is a complex subject that is addressed in Appendix 9. The tensions created are lessened by coaxial control rings, which confine the balloon. In some applications, such as rotor spinning, the rotating element supports some of the fibrous assembly.

3.7 Drawing

3.7.1 Terminology

Historically, the term 'drawing' was used in connection with the drawframe in staple spinning. 'Drafting' was used regarding roller drafting systems in roving and ring spinning. Upon the appearance of man-made fibers, the term 'drawing' was also used to describe the elongational process to improve the molecular orientation of the filaments. Custom still insists on the use of the historically founded words but in essence there is little fundamental difference between drafting and drawing.

Linear density is defined as mass per unit length of a strand or along the flow path of a stream of fibers.

3.7.2 Purposes of drafting or drawing

Drafting occurs when a stream of fibers passes through an acceleration zone[5]. The place where the acceleration occurs is called a 'draft zone' and it is necessary to control the fiber flowing through it. The solutions to the problem of fiber control are diverse and only a few examples can be given to illustrate the importance of mass flow control by passive devices.

There are two major reasons for drafting or drawing, which are (a) to better orient the molecules or fibers in the strand, and (b) to change the cross-sectional area of the strand[6]. In the drawing of polymers, one very important objective is to orient the long-chain molecules to give the filament better properties. In staple processing, an important objective is to orient the fibers within the strand by causing them to slide over one another to give the strand better properties. It should be noted that improved orientation can only be achieved by drafting the strand to give a smaller output cross-section.

5 Conversely, when a stream of fibers passes through a deceleration zone, condensation occurs.
6 In staple spinning, drawing is sometimes considered to include doubling.

There are cases that are not always regarded as drawing but which really are. For example, in extrusion, the linear density of the molten polymer approaching the spinneret is higher than the sum of the linear densities of the output filaments even before conventional drawing. The speed of the output material is faster than that of the input. While an extruder is not regarded as a drawing machine, it always is.

3.7.3 Control of flowing material

Both polymer and staple drawing and drafting have instabilities in flow. Control is exercised by imposing restraints on the systems. With polymer in the solid state, control is exercised by hot pins or the like. Heat flow from the control surface permits control of the local visco-elastic constants of the polymer in such a way as to promote stability. In the case of staple processing, the variable frictional forces between the flowing fibers are a strong factor in producing the instability, which reduces their value in both yarn and fabric forms. These instabilities produce quasi-random errors in the product. The addition of an external retarding force to the flowing fiber reduces the instability.

3.7.4 Principle of drafting or drawing

Consider a sample of the input material before and after discontinuous drafting or drawing. If there were no losses in the process, the mass of the input sample would be the same as it is after drawing. Let ρ be the packing density (not to be confused with linear density), a the cross-sectional area, l the sample length, $\rho_i a_i l_i$ be the mass in the input sample, and $\rho_o a_o l_o$ be the mass after drafting. It follows that:

$$\rho_i a_i l_i \approx \rho_o a_o l_o$$

and if the packing density is constant,

$$a_i l_i \approx a_o l_o \qquad [3.1]$$

For the purely theoretical case, the change in cross-sectional area is inversely proportional to the change in length. This is discontinuous drafting. However, in production, the process of elongation takes place continuously with the input and output mass flows nominally constant. Thus, the formula of Equation [3.1] can be restated to say that the cross-sectional area is inversely proportional to the speed ratio. In practice, this is modified by changes in the packing density and small losses have to be taken into account, but it forms the basis of all drafting and drawing.

3.7.5 Drawing in staple fiber processing

In staple spinning, the material flows through the drafting or drawing zones of the equipment. (The term 'drawing' is often used to describe the particular overall process but it is common to refer to the components that carry it out with the adjective 'drafting'. Thus we speak of drafting rolls and draft in a drawframe which seems odd, but that is the common usage.)

Fibers are accelerated as they pass through each zone. Also fibers can, and do, migrate with respect to one another along the direction of flow. Conventional theory has been mainly restricted to roller drafting, in which there are fiber acceleration zones within the spaces between two consecutive sets of rollers. (A similar idea applies to filament drawing but godets are used rather than rollers. Godets are cylinders about which a yarn is wrapped to grip the yarn for the purpose of elongating it.) However, fundamentals merely require that the exit material moves at a greater velocity than the entry material. The theory in Appendix 8 seeks to include the case where fibers are drafted by toothed rolls.

3.7.6 Cumulative draft

It is not possible to achieve sufficient drafting or drawing in one step; consequently most systems use multiple, consecutive draft or draw zones (Fig. 3.13). As shown in Appendix 1:

$$\Delta = \Delta_1 \times \Delta_2 \qquad [3.2]$$

where Δ = total draft ratio
Δ_1 = draft ratio in stage 1
Δ_2 = draft ratio in stage 2.

NB The term draft ratio is technically correct but it is frequently shortened to 'draft'.

In staple spinning, there are usually two zones. The first (or break-draft zone) has the function of breaking frictional bonds which form in roving (or other strands) due to (a) setting, (b) fiber migration, (c) fiber crimp, or any combination thereof. Newly drafted material is easier to draft immediately after such an operation even if the break draft is small because the crimp gets set over time, and the fibers no longer slide over one another as smoothly as freshly drafted material. The break draft varies according to the type of fiber and the linear density of the strand; it usually varies between 1.1 and 1.4. Overall draft is the product of the break and main drafts and it varies from about 6 to 30 according to the machine concerned. In polymer drawing, there is often more than one stage of drawing (perhaps using different machines) to complete the total process and the mathematical treatment is the same as for drafting in a staple process. However, one would use the term drawing rather than drafting. Nevertheless, for simplicity the explanation will be expressed in terms of draft.

Normally, it is arranged that there is little change in fiber characteristics, to prevent the need to change the draft program and hence unnecessarily escalate costs.

For more than one stage, all the drafts are multiplied together to give the overall draft. In staple spinning, the process starts with a bale laydown that might be regarded as an extremely thick strand (a linear density of perhaps a billion (10^9) tex). The yarn leaving the mill may have a linear density of less than 10^2 tex. (1 tex = 1 g/km or 1 mg/m as discussed in Appendix 1.) The mill can be regarded as a gigantic complex

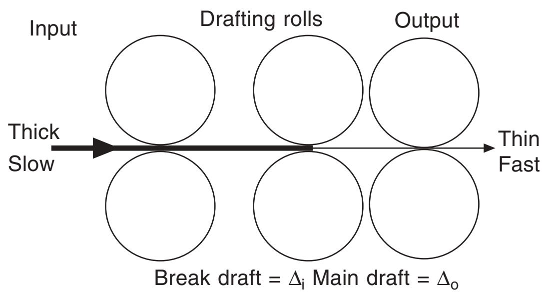


Fig. 3.13 Draft distribution

drafting system and it is clear that a drastic amount of drafting is needed over all the various machines in the production line. Although the foregoing has been explained for staple spinning with roller drafting, much of it is equally applicable to toothed drafting (as in an opening line). Some machines, like cards, have draft ratios of roughly 100, whereas machines such as drawframes, roving frames, and ring frames usually have overall drafts of the order of 10. A large number of stages of drafting are required including those that precede the card.

3.7.7 Effects of roller errors

It is essential that the operating surfaces of all rolls, gears, and other cylindrical elements should be perfectly round and concentric if periodic errors are to be avoided. It might be noted that the operating surface of a gear is at its pitch-circle diameter.

An eccentric element produces a sinusoidal error. If a drafting system is left standing with the pressure acting on the soft cushion rolls, deformations might be developed in the rubber. Such deformations cause periodic errors in the textile product, which contains fundamental and harmonic components. Even though an elliptical roll is a rarity, it is useful to demonstrate the effects. Therefore consider an elliptical roll in a simple four-roll staple system such as is shown in Fig. 3.14. (Other deformed rolls will produce somewhat similar effects, irrespective of the type of system.) The bottom front (delivery) roll has been drawn as excessively elliptical for the purposes of illustration. All the other rolls are perfectly round and concentric; the back rolls deliver material at V inches/s. The elliptical bottom front roll rotates at ω radians/s and the surface velocity is $V_1 = \omega r_1$ inches/s, where r_1 is radius of the roll at the point of contact. The middle diagram refers to the bottom front roll after it has turned through 90°. The active radius is now r_2 and the velocity is $V_2 = \omega r_2$ inches/s. Meanwhile, the back roll speed, V, remains unchanged. Consequently, the draft changes from V_1/V to V_2/V as the front roll moves through 90°. As the elliptical roll rotates, there is a periodic change in draft, which in turn causes a periodic change in linear density of the output strand. In this case, the periodic wavelength is half the circumference of the deformed roll. A similar effect would have occurred if the roll had been round but off-center (i.e. eccentric). In this case, however, the error wavelength would have been the whole circumference of the deformed roll. Any deformity of the roll produces an error and, as mentioned earlier, a common cause of such errors is deformation of the top rolls (which are normally rubber covered). The rubber is used to improve the grip on the fibers but it is visco-elastic and will deform if the load is left on while the machine is stationary. It might be added that the rubber coverings harden unevenly with time and use. The result is that the deformation of the rubber also becomes uneven. Even if no geometric error is present, an uneven strand is produced because the rubber deforms in a cyclic fashion. These problems are controlled by using special tools to measure roundness, concentricity, and rubber hardness on a regular basis.

There is a further complication. The nip-to-nip distance changes, as shown in Fig. 3.14(c), when an elliptical or any other non-round roll meshes with another. At the given angle of the bottom front roll, the setting has changed by δL. In effect, there is a cyclic variation in setting that not only produces a cyclic error of its own but actually magnifies it. Consequently a great deal of trouble is taken to keep the rolls, and other elements, round and concentric. The spectrogram is useful in this regard because out-of-true rolls generate a spike at a wavelength λ_o, which can be used to

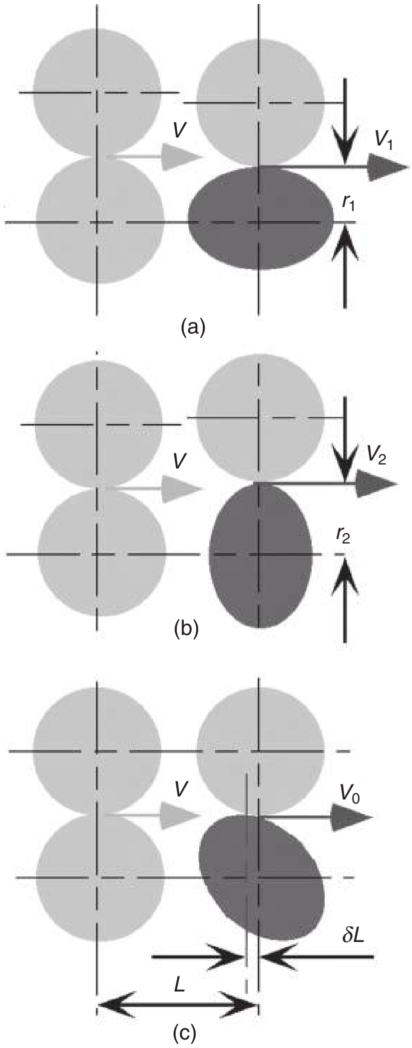


Fig. 3.14 Deformed rolls

diagnose the source of the error. Further, any error produced upstream is elongated by the drafting to be Δ times as long, where Δ is the overall draft. Consequently, the spectrograph can show multiple sources of error. (An actual example is given later, in Fig. 3.18.)

In symbols:

$$\lambda_o = \lambda_1 \times (\Delta/k) \qquad [3.3]$$

where λ_o = error wavelength in strand measured
λ_1 = circumference of bad roll
Δ = draft between bad roll and point of offtake of the material measured
k = a factor which is an integer that takes into account how many lobes are on the bad roll.

λ_o and λ_1 must have the same units of measurement.

3.7.8 Drawing a filament

Filaments are made to grip the surface of the drawing elements (godets) by the simple expedient of wrapping the filaments several times round the godet as shown in Fig. 3.15. The pins, P, lie at an angle; this merely serves to separate the turns on the godet. The wrap friction effect is the same as is used in a capstan winch; indeed it is sometimes referred to as capstan friction. Yarn is wrapped round two godets rotating at different surface velocities, and the draw ratio is calculated from the velocity ratio. It is important that the surfaces of the godets are concentric with the axis of rotation, and round, otherwise errors similar to those described earlier will occur. A common reason for problems arises from irregular deposits of finish and debris on the operating surfaces.

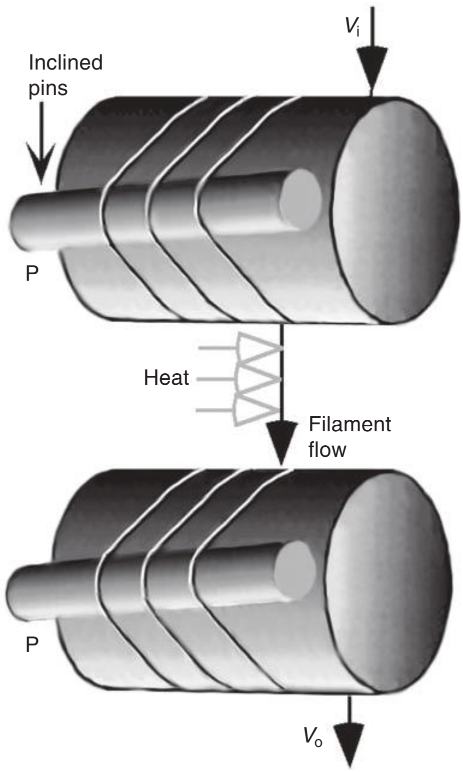


Fig. 3.15 Filament drawing

3.7.9 Drawing a sliver (staple processing)

In the drawing or drafting of staple fibers, pairs of rollers are caused to grip the strand as shown in Fig. 3.16. Weighting by deadweights, springs, or pneumatic systems is used to press the rollers together and prevent slippage between the fiber and the rolls. Normally, one roll is made of metal and is fluted; the covering of the other is usually made of synthetic, elastic material (i.e. it is a cushion roll or 'cot'). As previously indicated, the cushion rolls should not be left under pressure, otherwise the rubber becomes deformed and produces mechanical errors in drafting. Fiber condensers are necessary to gather the fibers and introduce enough fiber migration to give the sliver cohesion. Drawframes are made to facilitate easy access to the elements, for example,

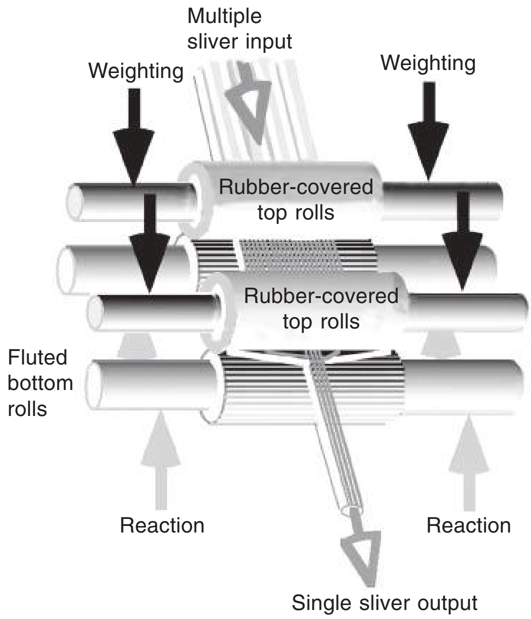


Fig. 3.16 Staple fiber drafting

easy removal of parts liable to fairly rapid wear (such as the cots). They are also designed to give a direct fiber flow path to minimize chokes.

A sliver is an untwisted rope-like strand of loosely aggregated fibers that are held together solely by interfiber entanglement. To make good yarn, it is desirable that the fibers be aligned as well as possible, and this is one of the purposes of drawing. However, alignment or orientation of the fibers lowers the strength of the sliver. Sliver becomes weak if it is drawn too much or has too low a linear density. Thus, there is a limit to how much a sliver can be drawn and there is a limit to how fine it can be drawn before it is too weak to handle. The minimum linear density is affected by the degree of fiber orientation and crimp. Therefore, it is normal to set the mechanical draft to be about the same as the number of slivers fed. This limits the draft for one 'passage of drawing'. The term 'passage' refers to a sliver passing through a drawframe a single time.

3.8 Consequences of roller errors on the textile product

3.8.1 Periodic errors

Roller or godet defects such as those previously described translate into periodic errors in yarn, roving, sliver or tow, which are sharply defined. Not only does the linear density of the material vary in consequence but so also does the structure of the material strand.

3.8.2 Random errors

Textile strands also contain random errors with a very wide spectrum of errors.

3.8.3 Cumulative effects of drafting

Where there is a number of drafting stages, the results are cumulative and the range of error wavelengths can be very large. Yarns show not only an extremely large range of error but these errors translate into faults in the fabric. The end result of these irregularities is that the fabrics made from the yarns show undesirable patterning known as moiré or barré, which reduces their value.

3.9 Control of irregular flow in drawing or drafting

3.9.1 Irregular polymer flow in drawing

An experiment with an undrawn nylon monofilament, or a strip of undrawn or partly drawn nylon sheet, will show that the draw does not always proceed as expected. The strand or strip tends to neck as indicated at Fig. 3.17(a) but the process of necking is not always stable. The thin portion consists of oriented strong material, whereas the thick portion is largely amorphous and capable of plastic flow. As the draw continues, material flows from the thick to the thin portion in regions and becomes oriented as it does so; the flow causes local heating, which tends to localize the flow. A partially drawn material may have 'lumps' in it if several necks form during the draw, as shown in Fig. 3.17(b); clearly this is undesirable.

Polyester, nylon, acrylic and some others fibers are drawn during normal processing to improve their molecular orientation, but various materials, such as the cellulosics have a limited potential for improved molecular orientation by drawing. In the following discussion, the narrow class of textile materials capable of benefiting from drawing will be called 'polymers' for simplicity even though the term 'polymer' really covers a very much wider range.

The flow of polymer in the drawing operation absorbs energy and the temperature of the strand rises as it is drawn at high speed. A change in temperature changes the characteristics of the polymer. To control the mechanical flow, it is necessary to control the heat flow; hence the use of the hot pin mentioned earlier (see, Fig. 2.13, p 45). The heat flow and mechanical drag caused by the pin are intended to keep the neck in its proper position. A polymer has a natural draw ratio, which is a function of the degree of molecular orientation and the draw becomes unstable if the machine draw ratio differs from this. The position of the neck will advance or retreat according to whether the machine draw ratio is lower or higher than the natural draw ratio. If the machine draw ratio is too high, the tensions rise to the point where the filament breaks. If it is too low, the system is unstable and the product consists of a mixture of drawn and undrawn lengths. In a continuous flow process, the position of the neck has to be stabilized; without such stabilization, the neck is likely to move in one direction or the other in respect to the godets. (There is an exception when the

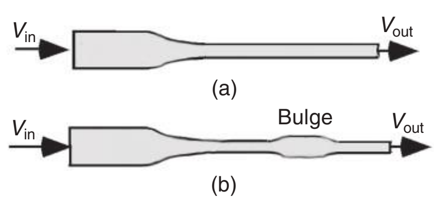


Fig. 3.17 Unstable polymer flow in 'neck'

mechanical draw ratio is the same, numerically, as the natural draw ratio.) The neck retreats or advances until it reaches a godet, where the strand will then break. Any oscillation of the position of the neck tends to give uneven filaments and therefore great care has to be taken in the design and operation of the drawing system. This is especially true if the filaments have to be dyed at a later stage; variations in draw cause corresponding variations in polymer morphology, which give rise to barré in fabrics.

3.9.2 Drafting waves in staple systems

The problem of uneven polymer flow in drawing a polymer has its counterpart in staple spinning. In drafting staple fibers, the *effective* length of the fiber is an important factor. Fibers supplied to a drafting system in normal practice vary in length, fineness, crimp, and finish, natural fibers being more variable than man-made ones. Each of the variables mentioned alters the force that can be transmitted by a fiber under these circumstances; the force may be taken as a measure of the effective length of the fibers. A perfectly smooth fiber behaves as if it were much shorter than it really is. A crimped fiber is physically shorter than its fully extended length but it engages neighboring fibers because of the crimps. Thus, the question of fiber length is far from an easy one. For simplicity, the following discussion will refer solely to the effects of length variation.

Irregular flow of the fibers changes the position of fibers relative to their expected positions after drafting and creates unwanted variations in linear density. With natural fibers, length is quite variable and the error is distributed. The variation produces a 'hill' typical of this type of error, as shown in the actual distribution in Fig. 3.18(a) and it is easily distinguished from a mechanical error (Fig. 3.18(b)), which shows up as spikes like those at A and B (also there are less easily distinguished peaks such as shown at C). The first of these types is often called a 'drafting wave' and it is a fiber-borne error. Fig. 3.18(a) shows two hills, which indicates that two different drafting waves were created, one from a rearward drafting zone and a large wave from a forward one. Since a difference between the roll setting and effective fiber length is an important factor, variations in fiber length can produce undesirable results, which show up as blotchiness or streakiness in the fabrics.

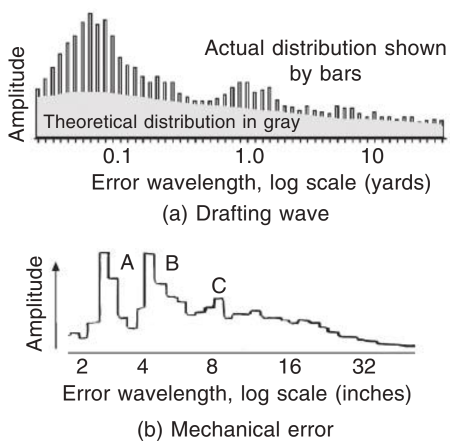


Fig. 3.18 Actual and theoretical variance distributions in a drawframe sliver

Not only is control of fiber length an important matter, but so is the maintenance of correct roll settings. There are thousands of drafting zones in a normal mill, and the aim is to set all of them to standard values appropriate to the material being processed. Changing the ratch setting (i.e. the distance between the nip lines of successive pairs of rolls in a drafting system) throughout a mill is a major operation. Settings of all the drafting systems must be maintained within close tolerances to the values standard in the particular mill. Also the fiber purchasing agent must seek to acquire fibers within a standard range of fiber length distributions. These are management and maintenance problems; changes are not made lightly. Once set up, the ratch settings are usually maintained until the next maintenance period. Thus, it is useful to constrain the variability in the fiber population by blending and careful stock control.

3.9.3 Control of fibers by mechanical restraint

The evenness of the final product, which is usually yarn, can be gravely affected if these errors just discussed are not kept under control. This is true even when the faulty drafting is in an earlier process. On the other hand, if the fiber movements could be constrained to minimize drafting waves, the distribution would approach the theoretical value as shown in Fig. 3.18(a). In the example, to the left of the picture there is a significant hill and in the center there is a minor one. The large one came from the main draft zone and the small one from the break draft (back) zone or an earlier process. Obviously there must be concern about the irregular flow through the front draft zone where the draft ratio is the largest.

Fortunately, there are some design features in modern machines that help to restrain the unwanted relative fiber movement. These features work by adding frictional forces, which tend to keep floating fibers at a speed at or near that of the back rolls. These floating fibers within the draft zone are not gripped by either nip. In drawframe design it is normal to incorporate a pressure bar (Fig. 3.19(a)) or some other device to restrain these floating fibers. In a ring frame or roving frame, aprons are commonly used to fulfill a similar function (Fig. 3.19(b)). Aprons are pairs of relatively wide flexible bands. They are pressed together sufficiently to restrain most fibers so that they move at the apron speed until the leading ends of the fibers are trapped by the delivery rolls. The linear speed is usually close to the surface speed of the back roll.

The use of aprons has helped staple spinners achieve remarkable improvements in yarn quality in this century, by greatly reducing the unstable fiber flow through the drafting system. The aprons are pressed together by pressure P (Fig. 3.19), merely to restrain the floating fibers and to allow them to slip without gripping them sufficiently to cause fiber breakage. This is in contrast to the rollers, which are pressed together by forces F to eliminate, as far as possible, fiber-to-roll slippage. The aprons press on the floating fibers and add their influence to the competing effects of the fibers. The competing forces arise from the frictional contact between the fibers and the front and back rolls. The concentration of fibers is greatest at the nip of the back rolls and the surface speed is greatest at the front rolls. As mentioned before, the aprons retard any premature accelerations of the floating fibers but they must be maintained in good condition to work properly.

If the draft is too high or the linear density of the strand is too large, the wear rate of the aprons increases markedly. Aprons are not normally used in sliver drawing because of the high wear rates. For roving frames it is normal to use long bottom

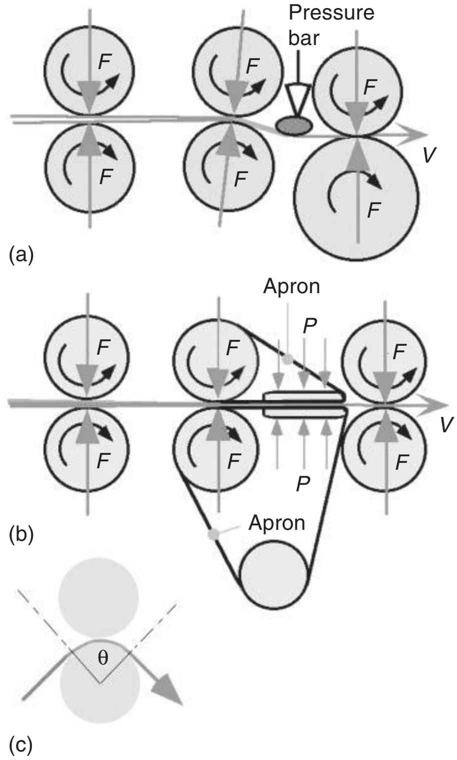


Fig. 3.19 Fiber control in a drafting system

aprons, such as those shown, to prolong their life, whereas simple short aprons might suffice in ring spinning. However, many modern ring frames also use long aprons for the reasons cited. The setting of the forces *F* and *P* is critical to good performance. If *F* is too small, defects are created in the output strand, whereas if it is too high, the rubber rolls quickly become damaged. Setting *P* is part of the art of spinning.

There is a choice of roll layouts but it is usual for the first drafting zone met by the sliver to be the break draft zone. The second operational zone is the place where the main draft occurs. Aprons in the break draft zone have been found to wear quickly and have never gained a foothold in practice. The roll layouts are referred to as '3 over 3' or '4 over 4' according to the number of rolls involved. A 3 over 3 system implies a system similar to that sketched in Fig. 3.19. A 4 over 4 system has four top and four bottom rolls but there are still only two drafting zones. The reason cited for this design by the makers is that it is beneficial to have a rest zone between the two draft zones, but additionally, the extra spacing insulates one drafting zone from the worst effects of fiber slippage from the other.

In a conventional ring frame, which has roller drafting, the draft might well be up to 30, and in certain cases much higher drafts have been used. This applies especially to air-jet spinning, where the width of the ribbon of fibers presented to the twisting device is wider than normal. Also, some sliver-to-yarn systems are capable of handling remarkably high drafts (up to 80). Properly designed high draftframes yield higher yarn strengths, the yarn is more even, and the productivity is higher than with conventional frames. Increased precision in setting the high draft machines is required because high drafts are often associated with increased short-term error.

Condensers are also used to help control the flowing fibers by forcing them through an orifice (or other constraint) with a narrow throat, which compresses them. Compression of the fibers approaching the draft zone keeps the fibers together and prevents so-called 'cracking' of the fiber sheet. It is possible thereby to obtain a smoother and more even drafting action.

3.9.4 Prevention of fiber slippage over driving surfaces

If the input strands are unequal in size, some may be gripped by the rolls more firmly than others and the loosely gripped portions may be pulled forward from the feed prematurely, causing a fault. If the input strands are cored, the outside sheath of fibers may be improperly gripped by the roller pair. (Cored slivers have a hard central core. See Section 5.10.4) In such cases, slippage between the rolls and the fiber occurs, which leads to irregularities in linear density of the output product. A pair of rolls clamping a strand does not have a simple line contact because the fiber assembly squashes as shown in Fig. 3.20(a). There is a distribution of pressure in the nip zone, but a leading fiber end is free from the direct influence of the nip before it arrives at the compression zone, and the trailing end comes free after it has left. The size of the compression zone varies according to how thick and compressible the strand is. The effective ratch setting is thus different from the theoretical value, and the difference depends on the material being processed. The setting differential just mentioned is a function of the linear density of the strand being processed and the type of fiber. For example, the ratch setting in a drawframe should have a greater differential than that in a roving frame. Another factor also intervenes. The effective length of the fiber increases during the drafting processes because hooks and fiber-crimps are pulled out and the fiber is generally straightened. It is therefore not surprising to find, in practice, that the best ratch settings are often determined by trial and error. If there is fiber loss or slippage between the fibers and the rolls, the actual draft becomes slightly reduced.

Perhaps more important is what happens when the amount of slippage varies with time or position. Obviously, if the slippage varies with time, there are corresponding variations in linear density of the output strand that constitute a degradation of yarn quality. Such time-dependent variations can be caused by variations in agglomeration of the input material. For example, in ring spinning, twist in the roving input tends to concentrate in the thin spots and this makes so-called 'tight spots' more difficult to draft. The fiber tensions in the draft zone rise and this, in turn, causes slippage between the fibers and the back rolls. In drawing, the use of slivers of different linear densities in the creel causes the 'thinnest' ones to slip, as demonstrated in Fig. 3.20(b). Strands 1, 3, and 4 are compressed by the forces F and the resistance to slippage in each of those cases is μF where μ is the coefficient of friction. Strand 2 is too small to be gripped and slips under any applied tension. Even if Strand 2 is gripped, but to a lesser extent than the others, errors still arise. Highly irregular input slivers produce similar effects. The same type of condition can often be found in a comber lap machine in which many parallel slivers are combined side by side and are drafted to form a comber lap.

Extra control can be obtained by wrapping the fibers partially around any rotating surfaces with the intention of restraining fibers movement (Fig. 3.19(c)). A partial wrap design improves the grip between the back rolls and the flowing material. The wrap idea is also sometimes applied at the front rolls and permits some control of the

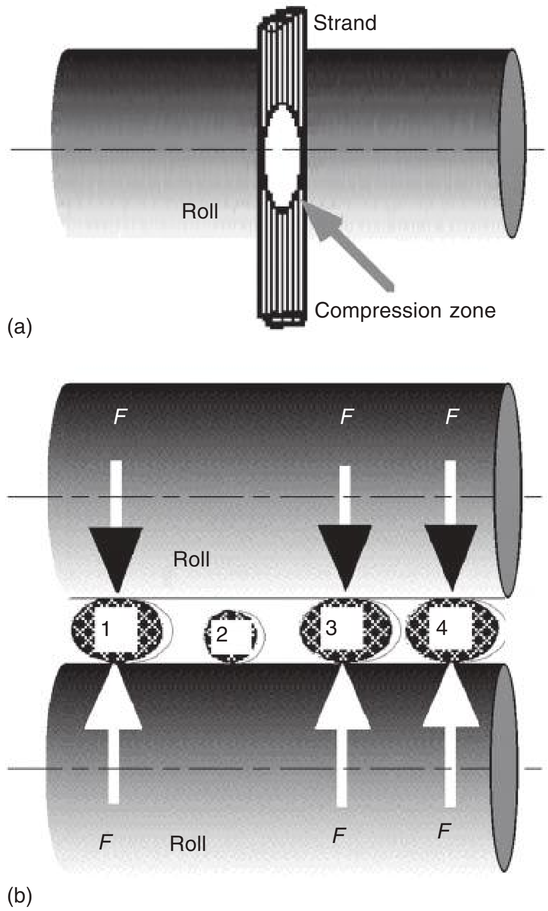


Fig. 3.20 Unequal compression of strands in a nip

fibers passing through the twist triangle on the output side. Wrapping a strand around a roll to get a better grip is common to both staple and filament processing.

In filament processing, the use of godets to grip the filaments is very common. A pair of rolls squeezed together on an incompletely solidified filament would cause flats on the surface, which would be undesirable under most circumstances. The use of a number of wraps around a large diameter godet roll produces much less surface stress for a given gripping power. There is a similarity in concept between this and the partial wraps just mentioned. However, when multiple wraps are used, it is necessary to keep the coils separated. This is achieved in a very elegant fashion by the inclined pins shown in Fig. 3.15. Also in the godet system, the resistance to slippage is a function of the cumulative wrap and the coefficient of friction (μ) between the fiber and the metal. In these cases it is important to ensure that an adequate number of wraps is used and that the surface of the godet roll is free from contaminants, which would affect μ. In the production of filament yarn, each spinning head produces only one yarn. However, when tow is being produced, there is more ambiguity in the load distribution between the component feeds and consequently there is a greater chance of error. The filament length is virtually infinite and problems associated with longitudinal fiber migration do not arise.

3.10 Doubling

3.10.1 The principle of doubling

If *m* similar streams of fiber converge, the theoretical variance of the total combined stream is theoretically reduced to 1/*m* of that of the individual input streams. The theoretical coefficient of variation (CV) is reduced by a factor of √(1/*m*), where CV = St dev/mean and St dev = √Variance. The same applies if *m* similar strands of sliver (or other strands) are laid in parallel in the feed to a machine. This combining of multiple fiber streams is known as doubling. An example is where slivers are placed in the creel of a drawframe; they are combined into one during and after the drawing phase of the operation. (A ‘creel’ is that portion of a machine where a multiplicity of input strands are removed from their packages and are delivered to the strand processing device. An example is shown later in Fig. 6.1.)

Other cases exist of placing streams of fiber or strands in parallel and combining them. Many errors are created in processing; consequently, even if the material is delivered to the process evenly, the output contains variation. Sometimes doubling is used to offset the errors and the theory works reasonably well providing the errors are random. (Strictly speaking, the mean values and variances of each strand should be similar for the theory to apply.) The actual CVs are higher than the theoretical values.

When doubling and drawing are combined, the input materials are doubled to reduce the long-term errors; however, new errors of shorter wavelengths are added as a result of the process of elongation. There is an exchange of relatively long-term for short-term error.

3.10.2 Combinations of drawing or drafting with condensation

Doubling occurs in some processes that are not widely regarded as a form of doubling. For example, in filament tow production, parallel streams of filaments are combined before they are chopped or otherwise separated into staple fiber. The multitude of parallel streams reduces the total error in the output material. The collection of the cut material also creates a further doubling effect because of the mixing that takes place as the stream of cut fibers is condensed into the bales. In condensation, deceleration causes the incoming product stream to fold and produces multiple doubling of adjacent elements. The effect is a reduction in variance which, although it is somewhat less than the theoretical value, is still substantial.

Drafting in the early stages of staple fiber processing is always followed by a condensation stage because of the need to control the flow of several machines in series. Doubling occurs in every condenser, chute feed, blending machine or any other place where the fiber flow rate is slowed down and the fibers accumulate. In fact, if it were not for this doubling, the drafting problems in the opening and carding would be noticed more. As it is, the increases in variance caused by the toothed drafting in the opening line are mostly offset by the large doubling factors that also prevail. This is not to say that the extra variance did not exist.

3.10.3 Homogenizing multiple streams of a nominally similar product

Another valuable aspect of doubling is that it can be used to offset variabilities from one set of equipment to another. Each set of equipment tends to produce a product with different characteristics according to its state of maintenance, setting, and design. If a downstream machine were always fed from the same source, there could be differences in product that would show up in the fabric, in the form of barré. This is called channeling. The effects are greatly reduced if the product is properly distributed to all the downstream machines in a systematic way that avoids patterning.

According to Uster [2,3], the CVs of linear densities of sliver from the card, 1st drawframe, and 2nd drawframe sliver for the top 10% of yarn makers were 3.4%, 3.5%, and 3.6%, respectively in 1982. For the bottom 10%, the respective CVs were 5.7%, 7.5%, and 7.2%. This means that the gains due to doubling at the drawframe are just about offset by the losses in regularity caused by drawing. One purpose of doubling is to blend product streams. The implication is that it is not just the linear density of the product stream that is important, but so are all the other aspects of homogeneity of the stream. In the case of filament processing, this might be represented by differences in polymer morphology. In staple processing, it might be represented by differences in fiber attributes other than linear density. Some practical results for cotton processing are shown in Table 3.2. In this case, the CVs of short fiber content after carding rose slightly when compared with the average value in the appropriate bale slice, whereas the CV of fiber fineness dropped considerably.

3.11 Effects of shear

3.11.1 Definition of shear

Shear may be defined as trapezoidal deformation or relative movement of elements in a structure, which causes the elements to slide over one another. When a visco-elastic body is stressed, some dislocations in the structure remain after the external stress is removed. There is often a residual stress pattern too. Such dislocations and residual stresses form the basis of a number of phenomena that are exploited in yarn manufacturing. They can be considered at the molecular and at the fiber levels, the former relating mostly to texturing and the latter mostly to staple yarn processing.

At the molecular level, the elements are segments of long-chain molecules; the movements are measured in microscopic units and it seems suitable to describe these movements as dislocations. In many solid materials, crystalline areas are separated by amorphous areas and the ‘crystals’ can, and do, move with respect to one another under stress.

In staple fiber processing, fibers migrate and the composition at any cross-section of the material undergoing drawing changes because of that processing. The phenomenon can still be regarded as visco-elastic but obviously the elastic forces are proportionately less than those in polymer molecular dislocations. The relative movements of fibers

Table 3.2 Fiber attributes

	Linear density %CV	**Fiber fineness micronaire %CV**	**Short fiber content %CV**
Bale slice	–	4.2	15.5
Sliver	3.1	2.2	17.3

can be quite large and, historically, the term migration has been applied; therefore it is proposed to extend that practice here in respect of other fiber movements.

3.11.2 Molecular dislocations

The visco-elastic properties of polymers change when heated, especially at the transition temperatures, i.e. softening point (T_g) and melting point (T_m). Above T_g, many of the bonds between molecules are broken and relative movement of segments of the molecules occurs. When the temperature drops below T_g, new bonds are made with the molecules in their new shapes and relative positions. This makes possible the heat setting of filaments into desired yarn textures suitable for commercial use.

When two polymers are involved, as in bicomponent yarns, differential stress patterns caused by the cooling polymer cause filaments to curl, coil, or loop. Also, the visco-elastic constants of a layer along the length of yarn can be altered to produce similar effects. The edge-crimp method is one such example, where the filament is dragged over an edge to produce a disoriented layer and that is sufficient to make the fiber deform significantly (see Chapter 4).

Similar behavior can be found in staple yarn processing, where the result is not at all desirable. Fibers are dragged over sharp teeth in a number of machines and they stand a chance of becoming edge-crimped. Fine fibers that are stressed by this kind of action can form into tiny tight balls called neps (which are a cause of loss of quality).

3.11.3 Lateral fiber migration

At the fiber level, most of the phenomena discussed relate to relative movement of one fiber with respect to its neighbors. For example, in ring spinning, segments of some fibers are subject to higher stresses than others in the twist triangle, and they move radially within the structure of the yarn. Highly tensioned fibers tend to move to the core and slack fibers move to the outer perimeter. In consequence, fibers thread their way between what would otherwise be concentric layers and stabilize the structure to make it self-locking. This is called fiber migration but it really should be called lateral fiber migration or some such term. In air-jet texturing, segments of filaments are forced across the yarn structure so that they, too, form an interlocked stable structure. Interfiber friction is the medium by which the structures become locked. A useful analogy to these effects is the common knot.

3.11.4 Longitudinal fiber migration

As explained in Appendix 8, fibers flowing through a draft zone do so irregularly; there is shear between the fibers and some have a higher mean velocity through the drafting system than others. Generally, shorter fibers accelerate from the nip of the back rolls in a drafting zone earlier than longer ones that enter at the same time. The relative motion between two fibers delivered by the device is called 'longitudinal fiber migration'.

$$\text{Maximum longitudinal fiber migration} = (\Delta - 1) \times (L - S) \qquad [3.4]$$

where Δ is the draft, L is the length of the long fiber, and S is the length of the short fiber.

The ratch setting is usually set a little larger than L and the longitudinal migration of fibers varies between zero and the amount given in Equation (3.4). The fiber population of a given cross-section of the entering material differs from the population of the corresponding zone in the emerging material; it becomes difficult to predict the performance of the fibers in drafting because of these changes in fiber population.

3.11.5 Effect of migration on evenness

The longitudinal fiber migration just described has an important effect on the evenness of the strand. To demonstrate the mechanism by which the evenness is degraded, consider the following example. The strand shown in Fig. 3.21(a) has two components and the composite strand has been leveled by some mechanism such that the evenness of the composite is perfect and the linear density of it is constant at n_{av} units. However, component B has a thick spot, which is compensated by a conforming thin spot in component A. A normal autoleveling device cannot discriminate between the relative natures of the two components and can only make its adjustments based on the total linear density. Two conjugate intervals are marked by hollow headed arrows. The component A is now moved to the right by some means. Figure 3.21(b) shows how the linear density changes near the blend anomaly. The marked intervals do not change their heights but they become separated. Bearing in mind that the height of the diagram represents linear density, it will be observed that the strand is now uneven. The linear density now ranges within the limits $n_{av} \pm n_1$. Variations in fiber length along the strand are converted into variations in linear density. If the concentration of short fibers varies (as was shown earlier), then the longitudinal fiber migration varies and the result is that a perfectly leveled strand can become uneven after passing through the process stage. Thus, for example, a roller drafting system converts variations in fiber content into variation in linear density. It can be seen that irregular blending produces some undesirable side effects.

3.12 Integration of sub-processes

3.12.1 Historical examples of process integration

As will be detailed more exactly in Chapter 5, the development of cotton card sliver production in the twentieth century provides an example of the integration of a variety of machines arranged in serial fashion in a process line. This is the first case.

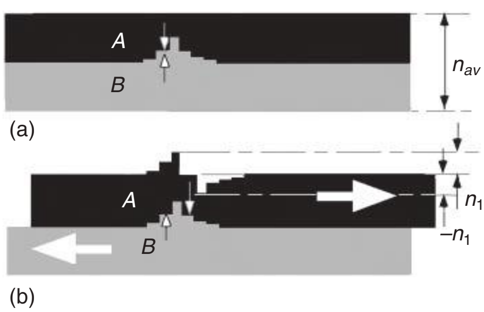


Fig. 3.21 Longitudinal fiber migration and strand evenness

In the 1950s, each machine was free standing. The fiber transfers, to and from the machine, were executed by manual labor and were also controlled manually. By the close of the century, the transfers were automatic and so was the control. Very little labor is involved in the operation of the series of machines that open, clean, and blend the fibers taken from the bale. No appreciable labor is needed until the sliver emerges from the card. In contrast, the subsequent stages (in which the card sliver is converted into yarn) still involve considerable manual work. This is the second case. Various schemes of automation are being applied, but not universally. The first case shows a mature system and the second one shows a system developing in a somewhat similar direction. Integration and automation of process lines are a theme common to all phases of yarn production.

3.12.2 The driving force behind process integration

Competitive pressure mandates economical means of production. Since labor costs have been much of the total cost of yarn, there has been a powerful motive to reduce the amount of labor needed. This pressure is offset by the costs of capital needed to implement technical solutions. Consequently, not every solution is adopted by industry and those that are adopted are put in place with considerable caution. In the first case just cited, the solutions adopted involved relatively modest amounts of capital and yet, over the years, have yielded significant reductions in the labor costs involved. The linking and automation of the next series of processes require investment and the savings are relatively modest; thus progress is relatively slow. Another aspect of reducing labor costs in spinning is the need to deal with end-breakages. There is a contrast between the initial and final processes that helps explain the dilemma. In the blow room there are normally only two or three production streams, whereas in spinning there are many, many parallel streams. Consequently, the acceptable capital cost per stream is relatively low in the last case and this hinders the development of process integration. Nevertheless, there is movement in this direction and future generations will see it mature.

Filament yarn production seems to be less affected because of the shortness of the process line, but it is not immune to the pressures. For example, extrusion, texturing, and drawing were originally separate operations in series, but now draw-texturing is well established with little or no increase in capital cost. The relatively small labor cost was reduced. The development of the use of partially oriented yarn (POY) was responsible for that commercial advance, rather than some mechanical solution. Thus it can be seen that there is no single route to increased process integration, but the economic pressures ensure that progress in that direction will continue.

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