Module 4

Staple Spinning and Filament Texturing

Overview

Several staple spinning systems are being used in the textile industry. Table 1 indicates the major systems, the fibres used by each system, and the selected end-uses of these spinning systems.

Table 1: End-products of yarns produced by major spinning systems (Krause 1985)

SPINNING SYSTEMS Fibres used	RING All	OE ROTOR Short staple	OE FRICTION All	AIR JET All
Selected end-use examples				
Shirting	✓			✓
Bedding	✓			✓
Outerwear	✓	✓		✓
Sports wear	✓	✓	✓	
Blankets	✓	✓	✓	
Knitted goods	✓			
Stretch garments	✓			
Carpeting	✓		✓	
Woollen goods	✓		✓	
Worsted goods	✓			
Industrial textiles	✓	✓	✓	
Waste processing	✓	✓	✓	

Obviously, ring spinning is the dominant method of yarn production. It can process all fibres and ring spun yarns are used for a wide range of applications. It is also the system that produces a quality yarn against which other spinning systems' performance is evaluated. But ring spinning is the least productive system amongst the major spinning techniques listed in Table 1. In addition, ring spinning uses roving as feed stock, while other spinning systems use slivers as feed stock, thus eliminating the roving stage.

Ring spinning is the only method used in the worsted sector that uses long staple fibres such as virgin wool. In the short staple section, yarns for apparel applications are produced on several spinning systems - ring, rotor, and air jet.

Table 2 shows the share in total spinning capacities by the three short staple spinning systems.

Table 2: Share of different short staple spinning systems

Total Spinning Capacities Major Short Staple Spinning Technologies				
	1992		**2000 (Est.)**	
	World	**USA**	**World**	**USA**
Ring Spinning	69%	51%	63%	39%
Rotor Spinning	30%	45%	35%	55%
Air jet Spinning	1%	4%	2%	6%

(Source: Helmut Deussen, "Rotor spinning technology", 1993, p3)

All spinning systems involve the following three basic steps:

- Drafting
  To attenuate the feed roving or sliver

- Twisting
  To hold fibres in the yarn together

- Winding
  To take up newly formed yarn

The way in which these three steps are carried out varies from one spinning system to another. This is discussed separately in the following topics:

Topic 1: Ring spinning
Topic 2: Rotor spinning
Topic 3: Friction spinning
Topic 4: Air jet spinning

Synthetic fibres have become an integral part of our daily life. While the production of manufactured fibres has been covered in the introduction to fibre science and textile technology unit, the processing of manufactured fibres has not been discussed yet. Therefore, topic 5 is devoted to filament yarn processing, the texturing process in particular. Emphasis has been placed on the commonly used false twist texturing and air jet texturing systems. A brief account is also given to the filament intermingling process.

Ring spinning

Introduction

Ring spinning has been and will continue to be an important spinning system for making staple spun yarns from different fibres. Since its invention in 1828, little has changed in terms of the principle of ring spinning. Furthermore, the principle of ring spinning for short staples such as cotton and for long staples such as wool is exactly the same. So the discussion in this topic applies to both short staple and long staple ring spinning. This topic discusses the three basic stages of ring spinning, the physics of ring spinning, and the developments as well as limitations of ring spinning. The detailed differences in machine design for long staple and short staple ring spinning are beyond the scope of this topic.

Objectives

At the end of this topic you should be able to:

- Explain the basic principle of ring spinning
- Know the features of ring spun yarns
- Understand the theory of yarn balloon and its implications
- Appreciate the advantages and disadvantages of ring spinning

The principle and process

A schematic diagram of a ring spinning process is shown in Figure 1.1. It consists of a roller drafting unit, a ring and traveller assembly, and a bobbin mounted on a spindle (driven by a tape). A yarn guide (pigtail guide) is also used to guide the yarn. To start ring spinning, a seed yarn (on an empty bobbin) is threaded through the traveller and the pigtail guide. It is then brought to the nip of the front rollers where a thin strand of fibres emerges. As the bobbin/spindle rotates, the seed yarn is twisted and the twist flows upwards to trap the thin strand of fibres emerging from the front rollers. A continuous twisted strand of fibres (i.e. the yarn) is thus formed. The newly formed yarn is wound up onto the bobbin. To avoid the newly formed yarn being wound onto just one spot of the bobbin, the ring rail oscillates upwards and downwards during spinning to build up the yarn package along the bobbin length.

Figure 1.1 Diagram of a ring spinning system (Mathews & Hardingham 1994, p.9)

The three basic steps of ring spinning, i.e. drafting, twisting, and winding-on, are discussed below.

Drafting
The roving is drafted by a roller drafting unit on the ring frame. Figure 1.2a shows the typical drafting arrangement. They comprise three fluted bottom rollers (a), against which are pressed three top rollers (b) that carry the pivoted weighting arm (c). The top rollers are driven via frictional contacts by the bottom rollers, to which the drive is applied. The three pairs of rollers form two drafting zones. The **break draft** zone formed between the back and middle pairs of rollers has a small draft only, and there is little fibre control in this zone. The **main draft** zone is formed between the middle and front pairs of rollers. Fibre control is achieved by the revolving double aprons (e) in this zone.

(a) The drafting arrangement

(b) Cross-section through the drafting arrangement

Figure 1.2 The roller drafting arrangement (Klein1987, p.5)

You may recall the concept of perfect roller drafting. It requires fibres in the drafting zone travel at the speed of back rollers until the fibre leading ends reach the front roller nip, where they get accelerated instantly to front roller speed. Because of this requirement, the apron speed is close to the back roller speed (break draft is small), and the aprons have a 'nose' which is very close to the front roller nip (see figure 1.2b). The distance between the apron nose and the front roller nip should be as small as practically possible to ensure the best fibre control during drafting. Figure 1.2b also shows that the front top roller has a slight **'overhang'** (a) relative to the front bottom roller, while the middle top roller is set a short distance (b) behind the middle bottom roller. Such position is found to give smooth running of the top rollers. In addition, the 'overhang' of the front top roller shortens the spinning triangle (figure 1.3b), which tends to reduce the rate of yarn breakage (ends-down) in spinning. More on spinning triangle is discussed in the following section on twisting.
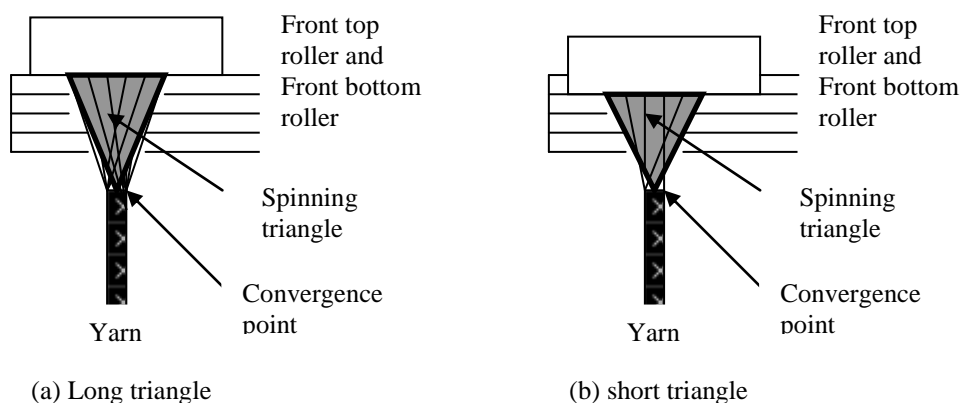

(a) Long triangle   (b) short triangle

Figure 1.3 Front top roller without overhang (a) and with overhang (b)

Twisting
The essence of staple spinning is about twist insertion. In ring spinning, twist is inserted into the thin strand of fibres emerging from the front roller nip to form the yarn. During ring spinning, the spindle is positively driven by a belt or tape at a constant speed. The traveller is dragged around the ring by the yarn being wound onto the bobbin. The rotation of the traveller allows the yarn between the traveller and the pigtail guide to rotate at the same speed. The persistence of vision will give us the impression of a **yarn balloon** as the yarn rotates at a high speed. It is the rotating balloon that inserts the actual twist into the yarn.

As twist is generated in the yarn balloon, it travels past the yarn guide towards the front roller nip. But the twist can not quite reach the nip line of the front rollers, because the fibres emerging from the nip have to be diverted inwards to be twisted around each other. So a small triangle of fibres, without any twist, is formed between the front roller nip and the fibre convergence point as shown in figure 1.3. This triangle is called the **spinning triangle** or **twist triangle**. It is also known as the yarn formation zone. Because there is no twist in this zone, it is a weak point and ends-down most often occurs in this region. For this reason, a large triangle is not desirable. The height of the spinning triangle is affected by the spinning geometry and the twist level in the yarn. Overhang of front top roller and high twist will reduce the height, hence the level of ends-down in spinning.

Because of air drag on the yarn balloon and friction between the traveller and ring, the yarn balloon and the traveller rotate at a slower speed than the spindle. As we will see shortly, the balloon speed keeps changing as spinning continues. Theoretically, we should use the balloon speed to work out the twist level in the yarn. But this is obviously difficult because of the changing speed of the balloon. In practice, the nominal twist level in the yarn is calculated using the constant spindle rotational speed rather than the balloon speed. The discrepancy arising from this approximation is quite small.

$$Twist\,(turns\,per\,metre) = \frac{Spindle\,rpm\,(revs\,per\,\min.)}{Yarn\,delivery\,speed\,(metres\,per\,\min.)} \qquad (1.1)$$

The yarn delivery speed is surface speed of the front rollers. It is also referred to as the yarn production speed (rate).

Winding-on
As mentioned earlier, the yarn balloon rotates at a slower speed than the spindle due to air drag (resistance) on yarn and the friction between traveller and ring. It is this difference in rotational speeds of the balloon and the spindle (bobbin) that allows the yarn to be wound up onto the bobbin. Without this difference in rotational speed or if the traveller and spindle rotate in sync, there will be no winding of yarn onto the bobbin. In addition, the linear winding-on

speed needs to match the delivery (surface) speed of the front rollers, otherwise the yarn will be too taut or too slack during spinning.
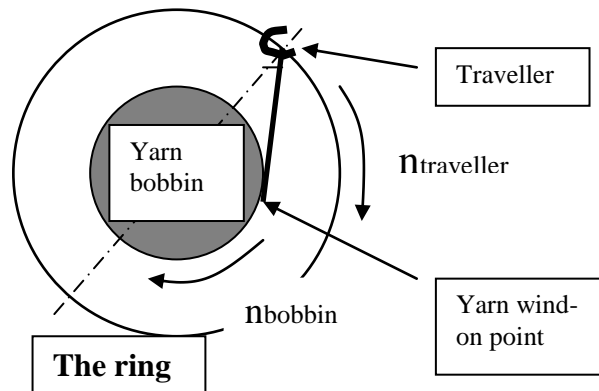

Figure 1.4 The cross-section of the bobbin/ring/traveller assembly

Figure 1.4 shows a cross-sectional view of the bobbin/ring/traveller assembly, with a yarn being wound onto the bobbin via the traveller. If the diameter of the bobbin at the yarn wind-on point is $d_{wind-on}$, the linear winding-on speed ($V_{wind-on}$) should equal the circumference of yarn package ($\pi\, d_{wind-on}$) multiplied by the difference in traveller and bobbin rotational speeds (n_{bobbin} - $n_{traveller}$), i.e.

$$V_{wind-on} = \pi\, d_{wind-on} \times (n_{bobbin} - n_{traveller})$$

This wind-on speed should match the speed at which the fibre strand is delivered by the front rollers. But as the yarn package builds up, its circumference changes. With a constant bobbin rotation speed (n_{bobbin}), the traveller needs to change its rotation speed ($n_{traveller}$) so that the winding speed ($V_{wind-on}$) remains constant and matches the front roller delivery speed. The beauty of ring spinning is that the traveller can self-adjust its rotational speed during spinning. It's all done automatically by the traveller itself.

Characteristics of ring spun yarns
Ring spun yarns are characterised by their good strength and smoothness, and their relatively high hairiness.

Ring spun yarns feature near-helical fibre configuration in the yarn structure. This is a result of twisting a strand of well-aligned and parallel fibres. In the whole processing stages from carding right up to ring spinning, fibre alignment has been an essential aim. By having well-aligned fibres within the yarn structure, the fibres are able to share the stress in the yarn when a force is applied to stretch the yarn. This is why ring spun yarns have excellent strength. The good fibre alignment and the near-helical configuration of surface fibres also impart the yarn with a smooth and neat surface.

During ring spinning, the fibres on the two edges of the spinning triangle must be strongly deflected to get bound into the yarn at the convergence point. The

deflection is higher with a smaller triangle (figure 1.3b). Not all fibres will be bound into the yarn, particularly those fibres with a high rigidity and low cohesion with neighbouring fibres. As a consequence, some of these fibres escape the twisting action and are lost as **fly**, others may only get partially bound in with their remaining parts projecting outside the yarn surface as **hair fibres**. This is why ring spinning produces relatively hairy yarns, especially when spinning short and coarse fibres. The majority of these hair fibres have their **tail ends** sticking out of the yarn surface. This is because as the tail ends emerge from the front roll nip, they are no longer under any positive control and the centrifugal force from the yarn rotation tends to throw these uncontrolled tail ends out away from the yarn body, making them protruding hair fibres. Figure 1.5 shows a photo of the spinning triangle and the hair fibres (trailing ends) on the newly formed yarn.

Figure 1.5 Formation of trailing hairs in the spinning triangle (Wang et al 1999)

The hairiness is a desirable feature of staple spun yarns. But too much of it can be a costly nuisance. The latest **compact spinning** technology, released at the 1999 international textile machinery exhibition in Paris, eliminates the spinning triangle all together by using a modified drafting arrangement to compact the fibres before twist is inserted. The compact spun yarns are very smooth with few protruding fibre ends.

Twist variation within yarn package
We mentioned in the previous section that as the yarn package builds up, the traveller adjusts its rotational speed automatically. This would suggest that within a yarn package, the twist level would be different. This is true. But the difference is only marginal as the following examples demonstrates.

Assume: (1) Cop dimensions as in the diagram below
(2) Front roll delivery speed is 15 m/min
(3) Spindle speed is 10,000 rpm
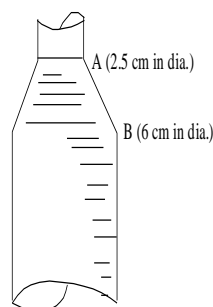
Since the linear wind-on speed = winding rpm x circumference of the wind-on point = front roll delivery speed, we have:

$$Winding\ rpm\ at\ A = \frac{15}{\pi\ x\ 2.5\ x\ 10^{-2}} = 191\ revs$$

$$Winding\ rpm\ at\ B = \frac{15}{\pi\ x\ 6\ x\ 10^{-2}} = 80\ revs$$

Ignoring the effect of up and down movement of ring rail, we have:
Traveller speed at A = 10,000 - 191 = 9,809 rpm
Traveller speed at B = 10,000 - 80 = 9,920 rpm

Therefore,

$$Twist\ at\ A = \frac{9809}{15} = 654\ twists/m,$$

$$Twist\ at\ B = \frac{9920}{15} = 662\ twists/m$$

The difference in twist is about 1% only. If the effect of added potential twist due to unwinding the yarn axially (at the next process) is taken into account, then at the minimum diameter A, more twists will be added and at the maximum diameter B less twists will be added thus bringing the twist levels more or less equal at both points. Therefore, the effect of traveller speed change (and cop build-up) on yarn twist is very small.

Physics of ring spinning

The physics of ring spinning considers the various forces acting on the yarn in the balloon, as well as the forces acting on the traveller. This consideration is necessary in order to gain an insight into the nature of ring spinning, and how different parameters/settings affect the spinning performance.

Balloon theory
Consider the section of yarn between the pigtail and the traveller as shown in figure 1.6. The centrifugal forces associated with the rotation of the yarn makes this section of the yarn balloon out to form a yarn balloon. Now consider a small element, of length ds, in the balloon. Ignoring the air drag and other small forces, the only forces acting on this small element would be the tensions T and T+dT at the two ends of the element, plus the centrifugal force (m ds ω^2 y) acting on the element.
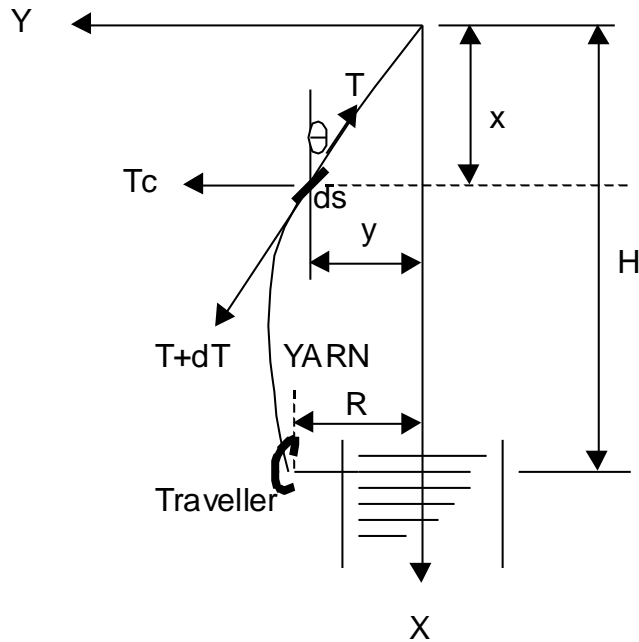
ω: angular velocity of balloon; m: yarn mass/unit length
Tc: centrifugal force = m ds ω^2 y; H: balloon height
R: ring radius; T: yarn tension

Figure 1.6 Forces acting on the balloon

In equilibrium, the forces acting on each element in the balloon should be balanced in both X and Y directions. So we have

$$T \cos\theta - (T + dT) \cos(\theta + d\theta) = 0$$

$$T \sin\theta - Tc - (T + dT) \sin(\theta + d\theta) = 0$$

or

$$\begin{cases} d(T\cos\theta) = 0 \\ d(T\sin\theta) = -m\,ds\,\omega^2\,y \end{cases}$$

If we assume the balloon is slim, i.e. $(\dfrac{dy}{dx})^2 = \tan^2\theta = 0$, and yarn tension (T) is constant and equals To (the tension at the pigtail guide), we get the following balloon equation.

$$y = \frac{R}{\sin(\sqrt{\dfrac{m\omega^2}{T_o}}H)}\sin(\sqrt{\dfrac{m\omega^2}{T_o}}x) \tag{1.2}$$

It should be stressed that this is the simplified balloon equation. The detailed derivation need not concern us here. What we are interested in is the practical implications of this so called balloon theory.
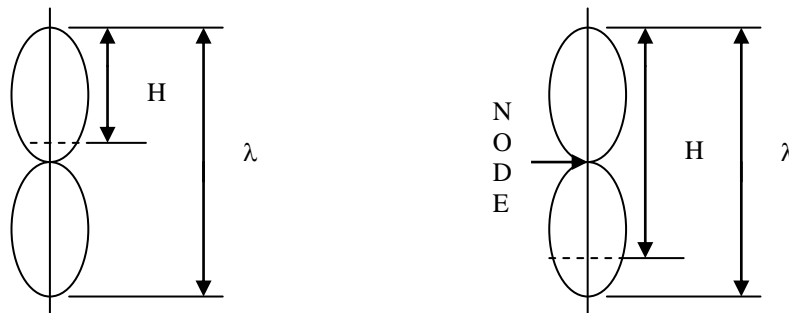
The shape of the balloon is sinusoidal, and its amplitude (A) and wavelength (λ) are:

$$A = \frac{R}{\sin\left(\sqrt{\dfrac{m\,\omega^2}{T_O}}\,H\right)} \qquad\qquad (1.3)$$

$$\lambda = \frac{2\,\pi}{\sqrt{\dfrac{m\,\omega^2}{T_O}}} = \frac{2\,\pi}{\omega}\sqrt{\frac{T_O}{m}} \qquad\qquad (1.4)$$

A sine curve can contain one or more points where the curve crosses the axis, and these crossing points are called nodes as shown in figure 1.7.

Figure 1.7 Formation of node in yarn balloons

For normal spinning, it is obvious from figure 1.7 (left diagram) that the balloon height (H) should be less than half the wavelength (λ/2). If the balloon height is more than half the wavelength (i.e. H > λ/2), a node appears in the balloon as indicated in figure 1.7 (right diagram). What this means is that during spinning, the yarn at the node would always want to be in the space occupied by the yarn package, so that the yarn at the node strikes the rotating package during spinning, resulting in an end-break. Therefore, this node should be avoided for normal spinning.

We now know that it is impossible to operate a ring spinning machine with a multiple-node balloon (H > λ/2). However, $H < \dfrac{\lambda}{2}$ means that the yarn package height or size is limited. Since, to spin yarn onto a large package, H should be large, this requires a large λ to avoid a node. A large λ is achievable (according to the equation 1.4) through:

either a large yarn tension T_O which may lead to yarn breakage;

or a low spindle speed ω, which usually means low production rate.

In practice, a **BALLOON CONTROL RING** is normally used to restrict balloon expansion, so that large yarn package may be used without having to reduce the production or increase the yarn tension.

Figure 1.8 shows a sketch of the ring spinning process with a balloon control ring restricting the balloon size. It should be pointed out though that the balloon control (restriction) ring tends to hinder **doffing** (removal of full package from spindle). For this reason, balloon control rings are not universally popular on modern ring frames fitted with automatic doffing systems. Instead, these ring frames use very small package sizes to reduce balloon size and yarn tension.
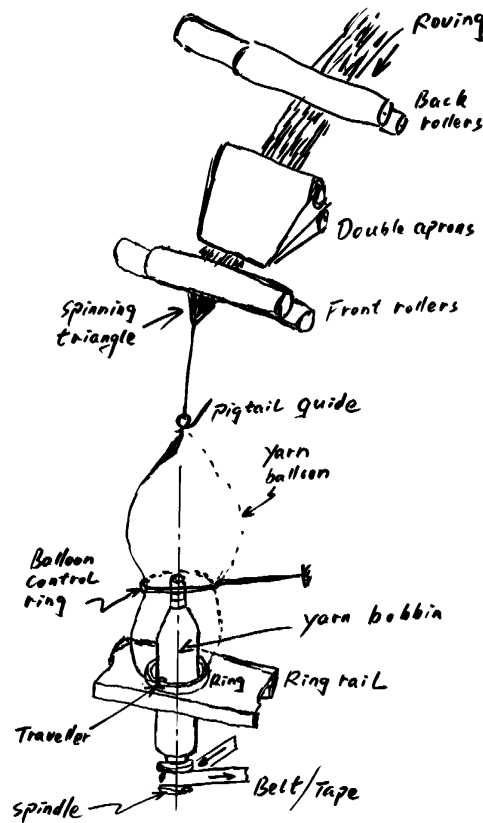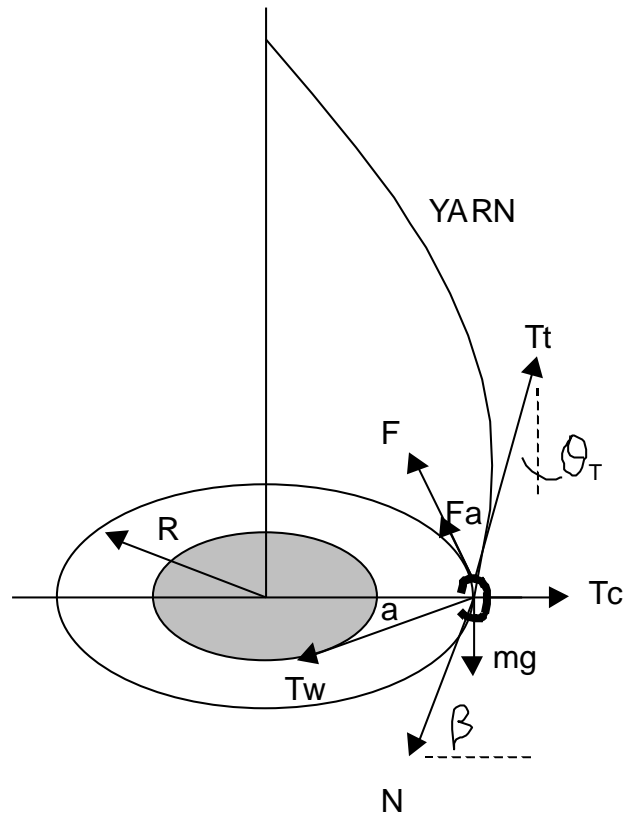

Figure 1.8 Sketch of ring spinning with a balloon control ring

Forces acting on the traveller

Figure 1.9 shows the different forces acting on a traveller during spinning.

YARN

T_t

θ_T

F

F_a

R

T_c

a

mg

T_w

β

N

Tt = yarn tension at traveller; Tw = yarn wind-on tension
N = normal force between ring and traveller; Fa = air drag on traveller
F = frictional drag between ring and traveller (= N μ_{RT}); mg = traveller weight

Tc = centripetal forces on traveller = m R ω
        (where m = traveller mass; R = ring radius; ω = spindle speed)

Figure 1.9 Forces acting on a traveller during spinning

All these forces must be balanced during spinning. It is possible to derive equations for this force balance to show the effect of variables such as traveller weight, balloon size, spindle speed, yarn count etc on the spinning tension.

In equilibrium:

$$\Sigma \, tangential \, forces = 0; \quad \Sigma \, radial \, forces = 0; \quad \Sigma \, vertical \, forces = 0$$

Ignoring Fa and mg, this gives the yarn wind-on tension,

$$Tw = \frac{m \, \omega^2 \, R}{\cos\alpha + \dfrac{\sin\alpha}{\mu_{RT}} (\cos\beta - \sin\beta \tan\theta)} \qquad (1.5)$$

Again, the detailed derivation need not concern us here, and we should focus on the following implications of this equation.

(1)   Wind-on tension increases with the square of the spindle speed (ω). Since wind-on tension is directly related to spinning tension in the yarn above the pigtail guide, increasing the spindle rotational speed will drastically increase the yarn tension, which may lead to increased ends-down. This limits the maximum spindle speed in ring spinning. If spindle speed is reduced to reduce yarn tension, the production rates will drop.

(2)   Winding tension increases as package diameter decreases. This puts a limit on the minimum diameter of the empty bobbin.

This is not obvious from equation 1.5. But if we look at figure 1.9a, we will see that as the yarn package diameter decreases, the winding angle or **angle of lead** (θ) decreases. As the angle of lead decreases, the tangential component (T') of the winding tension (Tw) reduces, since T' = Tw sinθ. But T' needs to be sufficient to be able to move the traveller around the ring during spinning. Therefore, as the package diameter reduces, the winding tension (Tw) will have to increase to maintain the T' required to move the traveller.
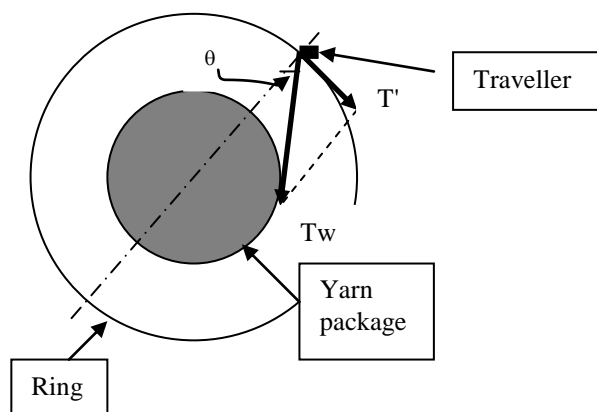

Figure 1.9a Winding tension and winding angle as indicated in figure 1.9

(3)   Since larger balloon means higher yarn tension, the winding tension increases as the balloon gets longer. This limits the length of the bobbin.

Points (2) & (3) suggest that a yarn is most likely to break when spinning at the bottom of an empty bobbin when the winding angle (θ) is the smallest. This has been confirmed in practice. For this reason, some machines operate at a lower speed at the start (since spinning tension increases with the square of spindle speed) to avoid the ends-down during start-up.

This also explains the general rule used in practice that the angle of lead (θ) should not be less than 28°. This minimum angle of lead is equivalent to a minimum ratio of **(empty bobbin or tube diameter)/(ring diameter) = 0.47**.

(4)   Winding tension increases as ring radius (R) increases. This limits the size of the full package that must fit inside the ring.

Points (2), (3) & (4) mean that there is a limit to how much yarn can fit onto the yarn package enclosed by the ring.

The package capacity is approximately proportional to (ring diameter)^2, so a large ring diameter is desirable for increased package capacity. But in practice, the ring diameter is restricted by considerations of the yarn tension, the minimum angle of lead previously discussed, as well as other factors such as power consumption, spindle rpm, and traveller speed limitations (see relationships below).

$$Max.\,spindle\,speed \propto \frac{1}{\sqrt{Ring\,diameter}}$$

$$Max.\,linear\,traveller\,speed \propto \sqrt{Ring\,diameter}$$

This is why we do not see ring spinning machines with very large rings and very small bobbins (tubes). For coarser and stronger yarns, large ring radius and yarn packages are used to allow for more yarns on the package. For finer yarns, both ring radius and the package size are smaller. Most worsted yarns are spun using rings between 45 and 75 mm in diameter at spindle rotational speeds between 7,000 and 12,000 rpm. Short staple yarns are spun with smaller rings, but at about twice the spindle speeds used for worsted yarns.

(5)   Winding tension increases with traveller mass. Heavier yarns require a greater centripetal force to keep them rotating. Traveller mass is used as a variable to increase the tension and generate the higher centripetal force for heavier yarns. The traveller mass is usually chosen according to the linear density of the yarn being spun.

(6)   Winding tension increases with an increase in the frictional coefficient between the ring and the traveller (μ_{RT}).

While we talk about the winding tension here, we should note that the spinning tension in the yarn is directly related to winding tension, so any factor that contributes to an increase in winding tension will also increase the tension in the yarn during ring spinning. In fact all the implications for winding tension apply to tension in the yarn or spinning tension.

Developments and limitations of ring spinning

As indicated in the beginning of this module, ring spinning is the most versatile spinning process. It can spin yarns of a wide range of counts (from very fine to coarse) from different types of fibres (short as well as long staple fibres). The quality of ring spun yarns has been a benchmark against which the quality of yarns produced on other spinning systems is judged.

The basic principle of ring spinning has not changed much since its invention by Thorpe in 1828. But there have been numerous developments of the ring spinning system, particularly in the short staple sector. These developments include:

- Automatic doffing of full cops (bobbins)
- Linkage to roving frame
- Linkage to automatic winding machine

Developments of worsted ring frames are relatively slow, because the market of worsted spinning is much smaller than short staple spinning. Therefore the incentive for manufacturers of worsted ring frame is not very high.

Over the years, the ring spinning system has also been modified to improve the properties of ring spun yarns. Examples of such modifications include:

- Sirospun (see the reading "Sirospun - A yarn with character" by Waldauser)
- Compact spinning (see the reading "The Suessen Elite Spinning system for long and short staple fibres", courtesy of Suessen, Germany)

Ring spinning also has several major limitations. These limitations include:

- High power consumption
- Small package size
- Low production rate

Staple spinning is basically about twist insertion. In ring spinning, twist insertion requires the rotation of the whole yarn package on the spindle. About 95% of the power used in ring spinning is consumed by rotating the yarn package to insert twist. This leads to the relatively high power consumption for the ring spinning systems.

The package size is limited in ring spinning due to the need to reduce the balloon height and yarn tension, as discussed in the section on the physics of ring spinning.

Perhaps the most serious limitation of ring spinning is its low production rate. We already know the relationship between yarn twist level, spindle speed, and

yarn production or delivery speed (equation 1.1). According to its end-use, a ring spun yarn needs to have a certain level of twist, which is determined before spinning is started. From equation 1.1, we know that the only way of speeding up the yarn delivery speed or production rate is to increase the spindle rotation speed. We already know that any increase in spindle speed will lead to significant increase in yarn tension, hence the possibility of ends-down. In addition, with the increase in spindle speed, the traveller speed increases. This increases the friction between the traveller and the ring. Considerable heat is generated because of this friction, which may result in traveller burning during spinning. Because of these, spindle speed can not be increased at will, and yarn production is limited as a consequence. Currently, the maximum spindle speed for short staple ring spinning is about 25,000 rpm, and that for long staple ring spinning is about 15,000 rpm.

The following example further illustrates this point.

> Suppose a spinning mill produces a standard 49 tex yarn, with a twist factor of 3500 tpm $\sqrt{tex}$, on 1,000 spindles operating at 15,000 revolutions per minute and 90% efficiency. If the mill works 120 hours per week, calculate the weight of yarn produced per week.

> Note that:

> $$Machine\,production = Spindle\,production\,x\,No.\,of\,\,spindles\,x\,Machine\,efficiency$$

> So we need to know the production per spindle first. This requires the yarn twist level.

> We know from the first module of this unit that:

> $$Twist\,(tpm) = \frac{Twist\,\,factor}{\sqrt{Tex}}$$

> In this example, we know the twist factor and yarn count. So the twist level in the yarn is:

> $$Yarn\,twist = \frac{3500}{\sqrt{49}} = 500\,\,(tpm)$$

> Using equation 1.1 we have:

> $$Yarn\,delivery\,speed\,(m/\min) = \frac{Spindle\,rpm}{twist} = \frac{15000}{500} = 30\,(m/\min)$$

> This is the production rate per spindle running at 100% efficiency. Since there are 1,000 spindles running at 90% efficiency, the total production of the ring frame will be:

Machine production = 30 m/min x 1,000 x 90% = 27,000 m/min.

Now the machine operates 120 hours a week, so the weekly machine production will be:

Weekly machine production = 27,000 m/min x (120 x 60 min) = 194,400,000 m = 194,400 km.

For a 49 tex yarn, each kilo meter of yarn weighs 49 grams. So a total of 194,400 km of yarn would weigh about 9525600 grams or 9525.6 kg. In other words, the average production per spindle is about 9.5 kg per 120 hour week.

If finer yarns are produced, the weight will be even less. This gives you an idea of the production rate of ring frames.

Winding and folding after spinning

It is convenient here to discuss some of the key processes immediately after ring spinning - winding and folding.

Winding
We already know that ring spun yarns are wound onto small bobbins or cops during spinning. Each bobbin contains only a few grams of yarn. For transport, storage and further processing, the small cops of yarn must be rewound onto large yarn packages of the right density and structure. If the yarns are to be dyed, then regular yarn packages of a low density are necessary for even and good penetration of the dye liquor. For weaving and knitting, fault free yarns should be prepared on a large package of high density. So the first process after ring spinning is yarn winding (or rewinding). Today automatic winding machines perform a number of important functions. These include automatic change of the small yarn cops, automatic yarn piecing, and yarn **clearing**. During yarn clearing, yarn faults such as very thick and very thin places are removed. Otherwise these faults may cause problems in weaving or show up in the final fabrics as defects.

The two basic winding mechanisms are: (a) a package rotation mechanism to form coils of yarn on the package; and (b) a yarn traverse mechanism to vary the position of wind. Two important parameters about winding are the **wind ratio** and **wind angle** (or angle of wind). The wind ratio is defined as the number of yarn coils wound on a package while the traverse mechanism completes a full stroke in one direction. In other words, the wind ratio is the number of revolutions of yarn package per traverse stroke. The wind angle is defined as the angle contained between a coil of yarn on the surface of a package and the diametrical plane of the package as indicated in figure 1.10. Increasing the wind angle will increase package stability but reduce the package density.
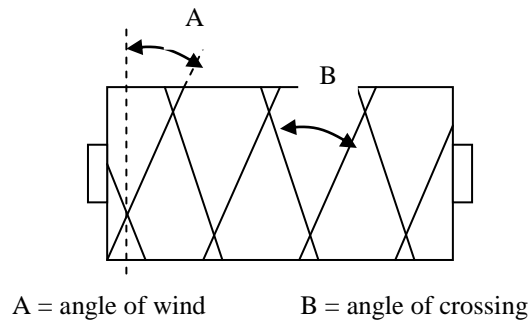
A = angle of wind   B = angle of crossing

Figure 1.10 Angle of wind and angle of crossing

Figure 1.11 shows the principle of **random cross winding** or **drum winding**. A grooved drum is used as both package rotation mechanism and yarn traverse mechanism. During winding, the yarn package rotates via frictional contact with the surface of the grooved drum, which is driven at a constant speed. Because the grooved drum rotates at a constant speed, the linear speed at which the yarn is wound onto the package is also constant. As winding continues, the package diameter grows, and the rotational speed (rpm) of the package decreases to maintain a constant yarn linear speed (linear speed = package rpm x package circumference). As a result, the wind ratio changes as the package builds up, but the angle of wind remains constant (i.e. package density is constant). When the wind ratio becomes an integer or half integer, each succeeding wrap of yarn is laid exactly on top of the preceding wrap, and a ribbon forms until the wind ratio assumes a value that is sufficiently different from the integer or half integer. This is the so called **ribboning effect** in random cross winding. Figure 1.12 shows a cone package with ribbons. Ribbons are a serious problem because they interfere with smooth unwinding of the package, cause localised abrasion of yarns in the ribbon, and change the density of the package (ribbons are much denser than the rest of the package). For this reason, many random cross winders are fitted with ribbon breaking devices to prevent ribbon formation. These devices may oscillate the yarn package or the grooved drum sideways in a random manner, or introduce rational speed variations to the yarn package.

Figure 1.11 Random cross winding (Lord 1981, p.557)

Figure 1.12 A cross wound cone package with ribbons

Another form of winding is **precision cross winding,** in which the wind ratio is constant but the angle of wind decreases as the package builds up. The mechanisms of precision winding are shown in figure 1.13. Instead of using a groove drum to drive the package via frictional contact, the package mandrel is driven positively by a motor, and a reciprocating yarn guide is used as the traversing mechanism. Ribbon formation is avoided by setting the package rpm so that the wind ratio is not an integer or half integer. As the package builds up, the angle of wind decreases so the package density increases. Precision winding can be used to build a very dense package.

Figure 1.13 Precision cross winding (Lord 1981, p.557)

Assembly winding is the winding of two or more yarns on to a single package side by side, without adding any twist. This is usually done in preparation for the subsequent folding or twisting operation.

Folding or twisting
Folding is a process of combining two or more single yarns by twisting. It is also known as **twisting**, **plying** and **doubling**. The resultant yarn is a folded yarn, also known as plied yarn or doubled yarn. Two-folding is a typical process in the worsted industry.

You may wonder why it is necessary to twist together two single yarns to make a two-fold yarn. This is because a two-fold yarn has a number of distinct advantages over its single components, including:

(1) A balanced yarn can be produced
Single yarns are twist lively. In other words, they always untwist when there is an opportunity. The twist liveliness may lead to snarling when the tension in the yarn is insufficient. Twist liveliness may also need to distortion of the resultant fabrics, knitted fabrics in particular. However, if two single yarns are combined and twisted together in reverse direction, a balanced folded yarn can be obtained.

(2) Improved abrasion resistance
As we have discussed already, ring spun yarns are relatively hairy. The hair fibres often cause problems in subsequent processes such as weaving. Also in weaving, warp yarns are subject to repeated abrasion and fibres may be gradually rubbed away, leading to yarn breakage. When two single yarns are twisted together, their surface fibres are trapped between the two single yarns. This improves the abrasion resistance.

(3) Increased strength
The two fold yarn is stronger than its single components.

(4) Reduced irregularity

The doubling reduces the irregularity according to the law of doubling discussed in the module on yarn evenness.

Two-for-one twisting has been the common method of producing a folded yarn. Figure 1.14 shows a schematic of the two-for-one twisting process. An **assembly wound package** (i.e. two yarns assembled onto one package without any twist) is usually used as the stationary supply package. The supply yarn is threaded through a guide mounted on a freely rotating flyer and then passes through the hollow rotating spindle. At the base of the spindle, the yarn comes out forming a balloon, and then goes onto the winding head via the yarn guide. Each rotation of the spindle will insert one turn of twist in the length of yarn within the spindle, plus another turn of twist in the yarn balloon. As a result, two turns of twist are inserted into the yarn for each rotation of the spindle, hence the name two-for-one twisting.

Figure 1.14 Two-for-one twisting (Grosberg and Iype 1999, p.20)

Review questions

1. Based on the discussion in this topic, sketch the appearance of a typical ring spun yarn.
2. Rovings of 500 tex are used to feed a ring frame with 1000 spindles running at 20,000 rpm and 90% efficiency. A spinning draft of 20 is used to produce the ring spun yarn. If 54 kilograms of yarn are produced each hour on the machine, calculate the twist level in the yarn (t.p.m) and its twist factor (t.p.m. $\sqrt{tex}$). Include details of your calculation.
3. One of the limitations of ring spinning is the relatively small amount of yarn on a full bobbin. Explain why we can not simply increase the ring radius and use a small empty bobbin to allow for a large quantity of yarn to be wound onto the bobbin before the full bobbin is doffed.
4. Explain, with the help of sketch, the principle of Sirospun and 2-for-1 twisting.

Topic 2

Rotor spinning

Introduction

Rotor spinning belongs to the family of open-end (OE) spinning. Open-end spinning systems are designed to overcome some of the problems associated with ring spinning. As discussed in the previous topic, twist insertion in ring spinning requires the rotation of the whole yarn package. In open-end spinning, only an end of the yarn is rotated to insert twist, which consumes much less energy than rotating a yarn package. The most successful examples of the open-end spinning concept are the rotor spinning and friction spinning systems. This topic discusses rotor spinning. Friction spinning will be discussed in the next topic.

Objectives

At the end of this topic you should be able to:

- Understand the basic concept of open-end (OE) spinning
- Know the principle of rotor spinning
- Understand the differences between ring spinning and rotor spinning

General concept of open-end spinning

Open-end spinning is a relatively new concept of spinning. The basic principle of open-end spinning is illustrated in figure 2.1 (Lord 1981, p.96).

Figure 2.1 The principle of open-end spinning (Lord 1981, p.96)

Like ring spinning, open-end spinning involves the three basic steps of drafting, twisting and winding-on.

Drafting
Very high draft is used to attenuate the feed sliver (not roving) into individual fibres. Such a high draft is usually by means of pinned drafting (with toothed rollers) rather than by roller drafting.

Because of the direct sliver feed, there is no need to convert the sliver into roving first before spinning, which is necessary in conventional ring spinning.

Twisting

The individual fibres are collected at the yarn open-end and twist is then inserted at the yarn open-end.

Since only the yarn opne-end is rotated to insert twist, open-end spinning is much more energy efficient than ring spinning, which requires the rotation of a massive yarn package to insert twist. In addition, the twist insertion rate in open-end spinning can be very fast. For a given yarn twist level, this translates into fast yarn delivery speed or high production rate.

Winding-on
In open-end spinning, twisting and winding are separate operations so that yarns can be wound onto a large yarn package.

In ring spinning, the package size is restricted and the yarns from the many small packages need to be joined up to make up a large package.

In summary, open-end spinning has the following major advantages compared to ring spinning:

- elimination of roving stage

- high productivity and low energy consumption

- large package size

Now that we know the basic principle of open-end spinning and its advantages, we can proceed to discuss the details of rotor spinning. As mentioned in the introduction, rotor spinning is a successful example of the open-end spinning concept.

We start with a brief account of the history of rotor spinning.

Historical perspectives of rotor spinning

Compared with ring spinning, rotor spinning is a relatively new spinning technology that has not yet reached its maturity. A brief chronology of rotor spinning developments is listed below:

1937   The first idea and basic rotor patented by Berthelsen (Denmark).

1951   Meimberg (Germany) developed the invention further and built the first spinning models.

1965   Rohlena and his group (Czechoslovakia) found the correct combination of spinning elements and showed the first commercially functional units in Brunn.

1967 The Czech firm ELITEX exhibited its rotor spinning machine (BD200) near the international textile machinery exhibition (ITMA) in Basel, Switzerland. The machine had a rotor diameter of 75 mm, a rotating speed of 25,000 rpm, and a high twist multiplier (TM=6, or a twist factor of about 5740 tpm. $\sqrt{tex}$).

1970 First sale of BD200 in the West

1971 Invention of the twin disk rotor drive allowing higher rotor speed (Suessen). With smaller rotors (60 mm), the rotor speed increased to 35,000 rpm.

1978 Introduction of 40-50 mm diameter rotors, improved spinbox geometries, lower yarn twist possible, first automatic yarn piecer and package doffer fitted on the rotor spinner.

1989 Smaller rotors with speeds of 100,000 rpm.

1992 Quality yarns as fine as 13-15 tex produced commercially at rotor speeds up to 120,000 rpm.

1999 Rotor speeds up to 150,000 rpm possible.

The development of rotor spinning technology continues today. The ultimate aim is to produce rotor spun yarns that match the quality of comparable ring spun yarns, but at a fraction of the cost of ring spinning.

Rotor spinning principle

Figure 2.2 shows the key elements inside the 'spin-box' of a rotor spinning system. Like any other staple spinning system, the principle of rotor spinning entails three basic steps of drafting, twisting and winding-on.

Drafting
When the feed sliver enters the 'spin-box', it is presented to a toothed combing roll (or comber roll) by a feed roller and feed plate assembly. The teeth on the comber roll comb the fibres in the sliver and because the surface speed of the comber roll is much higher than the feed roller, the density of fibres on the surface of the comber roll is much less than the density of the sliver. In other words, drafting is performed by the comber roll on the incoming sliver. The amount of draft exercised by the comber roll is very high, and can be calculated using the equation below:

$$Draft\ of\ comber\ roll = \frac{Surface\ speed\ of\ comber\ roll\ (m/\min)}{Sliver\ feed\ speed\ (m/\min)}$$
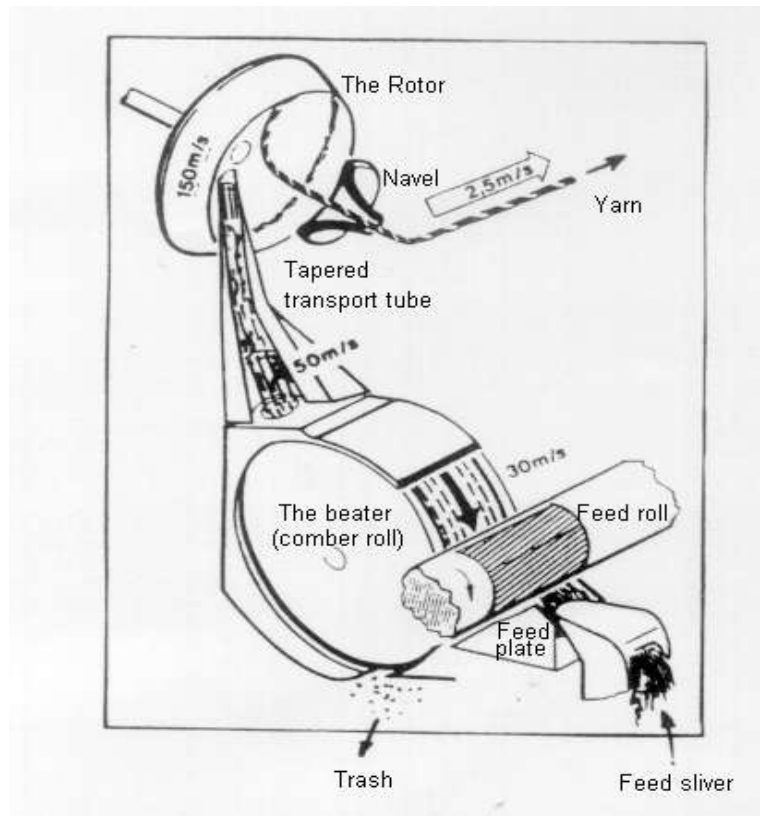
Figure 2.2 Key elements inside the 'spin-box' of a rotor spinner (Wulfhorst 1990, p.5)

The housing of the comber roll has an opening. Because trash and other impurities have a higher density than fibres, they are ejected through the opening by centrifugal forces, while the flexible fibres can bend their way around the comber roll until they are sucked into the rotor via a transport tube. The transport tube is tapered to allow acceleration of fibre flow through it. This acceleration helps with fibre straightening. This acceleration also means some fibre drafting is performed by the transport tube. This draft is usually quite small.

For a uniform flow of individual fibres into the rotor, the feed sliver should have good uniformity in linear density (e.g. a Uster CV% between 2.5 and 3.5), and the comber roll should be in good condition.

Twisting
Once inside the gyrating rotor, the individual fibres are thrown against the inner wall of the rotor by the centrifugal force. The fibres slide down the wall into the vee-shaped rotor groove as shown in figure 2.3. As the rotor rotates, many layers of fibre are collected around the rotor groove to make up sufficient linear density for the final yarn. This is the important **doubling** effect in rotor spinning. The doubling or layering of fibres tends to even out any short term irregularities in the yarn, which makes the rotor spun yarn surprisingly even. In contrast,

there is no doubling in ring spinning, the roving is attenuated to yarn linear density during ring spinning.

Once a sufficient number of fibres is collected in the rotor groove, the fibres need to be taken out continuously otherwise they will soon clog the rotor groove. To do this, a 'seed yarn' is first introduced into the rotor through the navel (figure 2.3). Again, the centrifugal force throws the seed yarn into the rotor groove. As the rotor is rotating rapidly, the seed yarn rotates with it. This rotation traps the loose fibres at the end of the seed yarn. At this point, the seed yarn is pulled out, the fibres trapped to the yarn end are peeled off the rotor groove by the outgoing yarn. Since the **peel-off point** is rotating with the rotor, twist is inserted into the out-going fibres. Furthermore, the twist at the peeling point extends a distance inside the groove to form the binding zone or twist zone as shown in figure 2.4. Within this zone, new yarn is formed. The stability of rotor spinning is affected by the length of this twist zone, which is in turn a function of the amount of twist at a given rotor speed and the additional **false twist** induced by the **navel**. Before we talk about the false twist, let us see how the actual (real) twist in a rotor spun yarn is calculated.
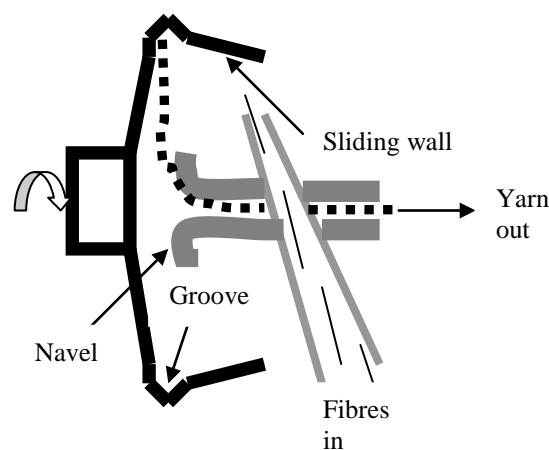

Figure 2.3 A look inside the rotor

Figure 2.4 Formation of a twist zone inside the rotor groove (Deussen1993, p.24)

We now know that the rotation of the peeling-off point inside the rotor groove inserts twist into the fibres to form a rotor spun yarn. The peeling-off point rotates with the rotor at a very high rotational speed (i.e. over 100,000 rpm). In addition, by continuously withdrawing the newly formed yarn from the rotor at the yarn delivery speed, the peeling-off point also moves relative to and in the same direction as the rotor, at the same speed as the yarn withdrawal or delivery speed. In other words, the real speed of the peeling-off point is actually

slightly faster than the rotor speed, by an amount equal to the yarn delivery speed. But the additional twist from this will be very small compared with the twist from the rotor rotation. The following example will demonstrate this point.

Suppose a rotor yarn is produced at 150 m/min by a rotor at 120,000 rpm, and the diameter of inner groove of the rotor is 30 mm. We wish to find out the actual twist put into the yarn by the peeling-off point inside the rotor groove.

Relative to the rotor, the peeling-off point travels at the yarn delivery speed of 150 m/min. The circumference of the rotor groove is 30 x π = 94.2 mm (or 0.0942 m). Therefore, the rotational speed of the peeling-off point (POP) relative to the rotor is:

$$rpm\,of\,POP\,(relative\,to\,rotor) = \frac{Linear\,speed\,of\,POP}{Circumference\,of\,rotor\,groove} = \frac{150}{0.0942} = 1592\,(rpm)$$

This rpm is about 1.3% of the rotor RPM, and the twist put into the yarn from this additional source will be about 1.3% of the twist due to rotor rotation.

This example shows that for practical purpose, the twist in a rotor spun yarn can be calculated from the rotor rpm and yarn delivery speed, using the equation below.

$$Yarn\,twist\,(tpm) = \frac{Rotor\,rpm}{Yarn\,delivery\,speed\,(m/\min)}$$

This will be the real theoretical twist in the rotor spun yarn. What about the false twist we mentioned a little earlier? This is briefly discussed in the following paragraph.

The trumpet shaped navel is usually made of wear-resistant ceramic material. The newly formed rotor yarn is withdrawn through the stationary navel to the winding mechanism. As indicated in figure 2.3, the yarn path is deflected 90° at the navel. The tension in the yarn pushes the yarn against the navel inner surface. Because of the friction between the rotating yarn and the navel inner surface, the yarn rolls on the navel surface. This rolling action produces a false twist in the section of the yarn inside the rotor and this false twist is in addition to the real twist from the rotor rotation. Because of this additional twist, the length of the binding zone or twist zone (figure 2.4) is increased, which increases the stability of spinning. The yarn (inside the rotor) is also stronger due to the additional twist, which reduces the ends-down. Therefore, the navel induced false twist plays an important role in rotor spinning. It should be noted that the false twist does not show up in the final yarn, which has real twist only. Also, rolling of the yarn against the navel surface tends to increase yarn hairiness.

Winding
The yarn withdrawn from the rotor is wound onto a large yarn package, ready for use. Unlike in ring spinning, twisting and winding functions are divorced and this permits the use of large package size. Figure 2.5 shows the key elements of the winding mechanism. The yarn package sits on a winding drum. The winding drum is positively driven and friction contact between the yarn package and the winding drum drives the yarn package. A reciprocation yarn guide ensures that the yarn is laid across the package traverse.

Figure 2.5 Yarn winding mechanism (Deussen 1993, p.12)

Figure 2.6 shows the whole process of rotor spinning from sliver feed to yarn package.

Figure 2.6 Rotor spinning process (Deussen 1993, p. 6)

Characteristics of rotor yarn
Ideally, fibres should be incorporated by twist into the yarn in a helical configuration. In rotor spinning, this is only possible if the fibres are laid parallel inside the rotor groove away from the twist zone and the peeling-off point (figure 2.4). However, during the course of spinning, it is unavoidable that some fibres actually land in the twist zone or on the yarn catenary between the peeling-off point and the navel. When this happens, the fibres get wrapped tightly around the already formed yarn and become the characteristic **wrapper fibres** on the yarn surface. The formation of a wrapper from a fibre landing in the twist zone is depicted in figure 2.7.

Figure 2.7 Formation of wrapper fibres in rotor spinning (Deussen 1993, p.24)

While a longer twist zone makes spinning more stable, it also increases the chance of wrapper formation. The percentage of wrapper formation can be approximated by the formula below.

$$Percentage\,of\,wrappers = \frac{Mean\,fibre\,length\,(mm)}{\pi \times rotor\,diameter\,(mm)} \times 100$$

From this formula, it is clear that long fibres and small rotors will increase the chance of wrapper formation. For this reason, rotor spinning has been primarily used for short staple fibres such as cotton and cotton blends. With long staple fibres, a large rotor is necessary to reduce the wrapper fibres and a slow rotor rpm has to be used, this makes spinning uneconomical. This is one of the reasons why rotor spinning has not been successful in the long staple spinning

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sector. In recent years, rotor technology has been used to spin fine and short wool fibres.

Increasing the twist will also increase the number of wrapper fibres. This is because an increase in yarn twist will increase the length of twist zone inside the rotor groove, causing the newly arrived fibres to be held on the otherside of the already twisted section and thereby increasing the number of wrapper fibres.

Because the wrapper fibres simply wrap around the yarn surface, they contribute little to yarn strength. However, wrapper fibres tend to increase the abrasion resistance and reduce the hairiness of rotor spun yarns.

Figure 2.8 Formation of a wrapper with two ends twisted in opposite direction (Nield 1975, p.34)

Sometimes, the middle section of a fibre gets caught by the rotating yarn arm inside the rotor, as indicated in figure 2.8. When this fibre gets wrapped around the yarn, its two ends are twisted in opposite directions. So it is possible to have both S-twist and Z-twist in the wrapper fibres, even though rotor spun yarn is usually spun with Z-twist only. Because of the presence of both S-twist and Z-twist, it is difficult to completely untwist a rotor spun yarn. The wrapper fibres, and difficulty to completely untwist the yarn have been used to differentiate between ring and rotor spun yarns. The presence of S and Z twists in wrappers also explains the fact that the measured twist of rotor spun yarns is lower than the nominal machine twist calculated from the rotor rpm and yarn delivery speed. The so-called the $\Delta T\%$ value has been used to reflect the degree of this difference, as indicated below.

$$\Delta T\% = \frac{Measured\ twist - machine\ twist}{Machine\ twist} \times 100\%$$

The lower the $\Delta T\%$ value, the more orderly and ring-yarn-like the fibre orientation is in the rotor yarn. High $\Delta T\%$ values indicate a more disorderly rotor yarn structure and the presence of wrapper fibres. Rotor yarns of 100% cotton exhibit $\Delta T\%$ values between near 0 and -20%, while polyester/cotton blends measure between -10 and -45% (Deussen 1993, p.27).

In ring spinning, fibre alignment is carried out right up to the point of twist insertion, and fibres are straight and parallel to each other when twist is inserted. In rotor spinning, fibre alignment is achieved to a less extent than in ring spinning. Poor fibre alignment may occur as fibres impinge on the sliding wale of the rotor, as they lie in the rotor groove (unlike in ring spinning, fibres are not under tension in the twist zone in the rotor groove). This, together with the formation of wrapper fibres, means that rotor spun yarns are usually weaker than comparable ring spun yarns, and a higher twist plus more fibres in yarn cross section is necessary to increase the strength of rotor spun yarns. A minimum of 90 fibres is necessary in rotor spun yarns, compared with a

minimum of 40 for ring yarns. So in the fine yarn market, rotor spinning can not compete with ring spinning.

Another important feature of rotor spun yarns is their good evenness. As mentioned before, fibres are deposited in the rotor groove in layers. The number of doublings is quite large, which tends to even out the short-term irregularities and improve the evenness of the resultant yarn. The number of doublings can be calculated using the equation below:

$$No.\,of\,doublings\,(in\,rotor\,groove) = \frac{Yarn\,twist\,(tpm) \times rotor\,circumference\,(mm)}{1000}$$

Table 2.1 summaries the characteristics of rotor spun yarns in comparison with ring spun yarns.

Table 2.1 A comparison of rotor and ring yarns

Rotor Yarn	Compared to Ring Yarn	Reason
Production rate	much higher	Higher twist rate
Package size	20 times greater	No ring
Twist level	10-15% higher	Structure
Strength	15-20% weaker	Fibre orientation
Extensibility	10% higher	Fibre orientation
Regularity	10-20% better	Doubling in rotor
Handle	harsher	Wrapper fibres, Higher twist
Abrasion	20-30% better	Wrapper fibres
Yarn count	coarser	Weaker
Fibre type	short staple mainly	Wrapper fibres
Hairiness	Lower	Higher twist, Wrapper fibres

This comparison highlights differences made by the presence of wrapper fibres. The fewer the number of wrapper fibres in a rotor spun yarn, the more closely the rotor spun yarn resembles the structure of ring spun yarns. This has been the aim that drives further developments in rotor spinning technology.

Selection or spinning components and parameters
The key components for rotor spinning are the combing roll, the rotor, and the navel. The combing roll (or comber roll) opens the feed sliver and individualises the fibres. The rotor is the twist insertion element, while the navel adds additional twist inside the rotor and changes the surface texture of the resultant yarn.

Figure 2.9 shows the tooth profiles of combing rolls used for different fibre materials, and the corresponding speed range.

Figure 2.10 shows the yarn count ranges in relation to rotor diameters and speeds. Small rotors of 30 mm diameter (K-230) and 31 mm diameter (G-231) are used primarily for finer yarns and higher rotor speed than large rotors.

In figure 2.11, the typical twist multipliers (TM) used for knitting and weaving yarns of different fibre compositions are given (note that twist factor = 956.7 x TM).

Finally, an explanation of different navels and their applications is given in figure 2.12.

Figure 2.9 Tooth profiles and speed ranges of combing rolls (Deussen 1993, p.55)

Figure 2.10 Yarn count ranges for rotor diameters and speeds (Deussen 1993, p.57)

Figure 2.11 Twist multipliers (TM) for weaving and knitting rotor yarns (Deussen 1993, p.60)

Figure 2.12 Different navels and their applications (Deussen 1993, p.62)

Review questions

1. Based on the discussion of the characteristics of rotor spun yarns, draw a sketch depicting the key features of a typical rotor spun yarn.

2. This question relates to a yarn being spun on a rotor spinner under the following conditions:

input sliver	5.0 kTex
output yarn	50 tex
diameter of combing roll	70 mm
speed of combing roll	7,000 r.p.m.
rotor diameter	45 mm
rotor speed	100,000 r.p.m
yarn delivery rate	200 m/min.

    (a) Calculate the yarn twist level (t.p.m) and the twist factor of the rotor yarn, ignoring the small additional twist due to rotation of the yarn "peeling-off-point".

    (b) If the above yarn is made from fibres all of the same length of 25 mm, what proportion of fibres will end up with some portion of their length in a wrapper configuration?

(c)   In order to reduce the number of wrapper fibres, would it be more effective to use fibres which are 5 mm shorter, or use a rotor of 5 mm greater in diameter? Show your reasoning.

(d)   Sliver for the above yarn received 2 drawframe passages between carding and spinning, with 6 doublings at each passage. Calculate the number of doublings provided during spinning and the total doublings the fibre assembly has received since carding.

(e)   The fibre transport chute (between beater and rotor) has been designed so that fibres enter the chute at the speed of the beater surface, and are accelerated by air so that they leave the chute travelling 50% faster. Calculate the average number of fibres lying across the chute inlet at any one time and the corresponding value at chute outlet. (Take the linear density of the fibres to be 0.25 tex.)

(f)   What are the finest yarns (expressed in Tex and English cotton count) that could be economically spun from fibres of linear density 0.25 tex on the rotor spinner. (Hint: consider the minimum nunber of fibres required for a rotor spun yarn).

5.   In about 1,000 words, compare and contrast the technology of ring spinning and rotor spinning, with reference to the economics and yarn quality of each spinning system.

Friction spinning

Introduction

Friction spinning belongs to the family of open-end spinning. Most patents related to friction spinning were filed in the 1970s and 1980s, many of which were from Dr Ernst Fehrer in Austria. Today friction spinning is almost synonymous with the term DREF(Dr Ernst Fehrer). It has been used to produce yarns usually much coarser than ring and rotor spun yarns at much higher production rate, and the yarns have been largely used for domestic and industrial applications.

This topic discusses the principle of friction spinning in general, followed by a discussion of the DREF 2 and DREF 3 friction spinning systems.

Objectives

At the end of this topic you should be able to:

- Explain the principle of friction spinning
- Understand the features of friction spun yarns
- Know the differences between DREF 2 and DREF 3 friction spinning systems

Principle of friction spinning

Friction spinning uses two friction surfaces to roll up fibres into a yarn. A simplified sketch of friction spinning is shown in figure 3.1. The fibres flow freely to two rotating friction drums (spinning drums, friction rollers, torque rollers). The surfaces at the nip of the two drums move in opposite direction to twist the fibres collected in the nip. The yarn is formed from inside outwards, by the superimposition of twisting of individual fibres. The yarn is then withdrawn from the nip to take-up package.
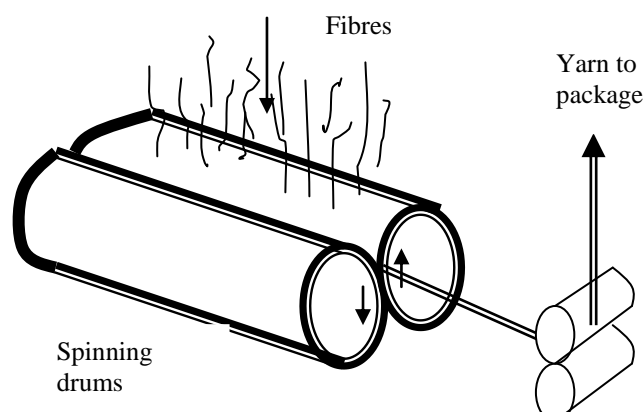

Fibres

Yarn to package

Spinning drums

Figure 3.1 A sketch of friction spinning

In friction spinning, the yarn end in the nip of the friction drums is tapered, just as the yarn tail inside the rotor groove is tapered in rotor spinning. Fibres are added continuously to the tapered yarn end as the newly formed yarn is withdrawn. This is illustrated in figure 3.2.
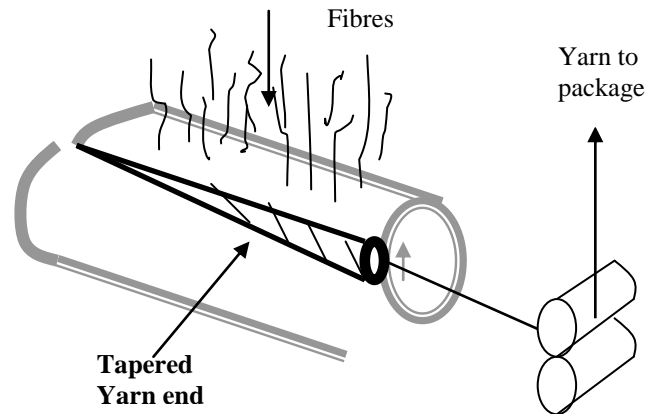

Figure 3.2 A tapered yarn end in the nip of the spinning drums

It can be envisaged that fibres deposited at the thin end of the taper will end up in the interior of the final yarn, while fibre deposited at the thin end will stay on the surface.

The twisting rate in friction spinning is related to the drum rpm, drum diameter and yarn diameter as indicated below.

$$Twist\ (tpm) = Drum\ rpm \times \frac{Drum\ diameter}{Yarn\ diameter} \times Twisting\ efficiency$$

Because of the very large ratio between the drum and yarn diameters, the rotational speed of the drums need not be high, provided adequate twist efficiency is achieved. The twist efficiency is reduced due to the slippage between the yarn in the nip and the drum surfaces. It is possible to have a twist efficiency as low as 40%. But even allowing for this, friction spinning is still the most efficient way of inserting twist to fibres, because twist is directly applied to yarn end.

Unlike ring spinning and rotor spinning, friction spinning imposes very little tension to the yarn. So the ends-down rate in friction spinning is very low and the yarn can be withdrawn from the nip of the drums at a very high speed, say 250 m/min. This makes friction spinning more productive than ring and rotor spinning.

Similar to rotor spinning, friction spinning uses sliver feed and tooth drafting. Fibres opened by a toothed roller are directed towards the nip of the friction drums, at a very high speed. The fibres should then impinge on the friction surface that is entering the nip or the rotating mass of fibres in the nip. Because the velocity of the entering fibres is much higher than the surface velocity of the drum surface and the rotating mass of fibres in the nip, fibres are decelerated as they impinge on the drum surface or the rotating fibres in the nip. This deceleration causes considerable fibre buckling just before the fibres are incorporated into the yarn structure. As a result, the fibre alignment in friction spun yarns is poor, leading to poor strength of friction spun yarns. Having long fibres does not help yarn strength much in friction spinning, because the long fibres buckle more readily than short ones, so their configurations within the yarn structure may not be as good as shorter fibres. The poor yarn strength also means that friction spinning can only produce relatively coarse yarns.

With friction spinning, a core component can be easily introduced in the nip to make a composite yarn of a sheath/core composition. Examples of this will be discussed in the following section on DREF friction spinning systems.

In this section, we have discussed the basic principle of friction spinning, and the key features of friction spun yarns. Next, we will discuss the DREF 2 and DREF 3 friction spinning systems developed by the Fehrer company located in Linz, Austria.

DREF 2 friction spinning system

The DREF 2 friction spinning system was introduced into the world market in 1977. It is designed for coarse yarn counts in the 100 tex to 4,000 tex range. The DREF 2 system is primarily used for the recycling of all types of textile waste fibres and mixtures with 10 -120 mm fibre lengths, and the spinning of technical and other yarns for specialised applications, such as blankets, cleaning rags and mops, yarns for secondary carpet backings etc.

A diagram of the DREF 2 friction spinning system is shown in figure 3.3.

Figure 3.3 DREF 2 friction spinning system (Fehrer AG)

As mentioned in the previous section, toothed drafting is used in friction spinning. With the DREF 2 system, the feed slivers are opened and drafted by the teeth of a carding drum. The individualised fibres are then stripped from the carding drum by centrifugal force, supported by an air flow. Gravity and air flow then carry the fibres into the nip of two perforated spinning drums. Assisted by air suction through the spinning drums, the fibres in the nip are twisted by friction on the two drum surfaces to form the yarn. The yarn is then withdrawn by the take-up rollers at delivery speeds of up to 250 m/min, and wound onto a large yarn package.

A filament core can be easily introduced into the nip of the spinning drums via the core feeding (figure 3.3), to make a composite yarn of a sheath/core structure. During spinning, the filament core gets false twisted by the spinning drums, while the staple fibres are deposited on the false twisted filament to make a sheath. The staple fibres are twisted as usual. But as the filament core emerges from the nip of the spinning drums, the false twist in it is removed automatically, and the sheath fibres receive a reserve twist in the process. The resultant composite yarn has the characteristics of a twistless filament core surrounded by a sheath of helical wound fibres of varying helix angles.

The core/sheath effect can also be achieved without the filament component. As indicated in the previous section, the yarn in the nip of the spinning drums has a tapered end, and fibres deposited in the thin end of the taper are likely to end up in the core position of the resultant yarn. For example, fibres in the left-most card sliver in figure 3.3 are likely to stay as core fibres in the yarn, surrounded by sheath fibres from the remaining two card slivers. This preferential fibre arrangement facilitates an economic use of a variety of raw materials. A 'core' sliver of waste fibres may be used with other 'sheath' slivers of high quality virgin fibres to make a quality yarn with reduced raw material cost.

It is worth mentioning that even if a filament core is not to be used as part of the final yarn, a filament is often used to help start the spinning process. Once started, the filament is then cut to allow the process to continue without it. This also applies to the DREF 3 friction spinning system that is discussed next.

DREF 3 friction spinning system

After the introduction of DREF 2 into the world market in 1977, Dr Ernst Fehrer began work on the development of the DREF 3 friction spinning system, which was first presented to the public at the 1979 international textile machinery exhibition (ITMA'79) in Hanover. In 1981, DREF 3 entered the global textile machinery market. DREF 3 is designed for the manufacture of multi-component yarns in the medium count range (25 - 667 tex). The yarns have been used in a wide range of industrial applications, including fire-resistant protective clothing, aircraft and contract carpeting, conveyor and transport belts, composites for aviation and automotive industries etc.

Figure 3.4 shows a diagram of the DREF 3 friction spinning system.

Figure 3.4 DREF 3 friction spinning system (Fehrer AG)

There are a number differences between DREF 2 and DREF 3. First of all, toothed drafted is achieved by two toothed drums in DREF 3 rather than just one carding drum in DREF 2. Second, another roller drafting unit (Drafting unit I in figure 3.4) is now added in DREF 3. This drafting unit will deliver parallel fibres that will form a **core of parallel fibres** in the final yarn, surrounded by the

sheath fibres from drafting unit II (figure 3.4). There is also the option for the introduction of a filament core as in DREF 2. Therefore, composite yarns of three different components can be engineered on the DREF 3 system. Figure 3.5 shows a side view of the DREF 3 system.
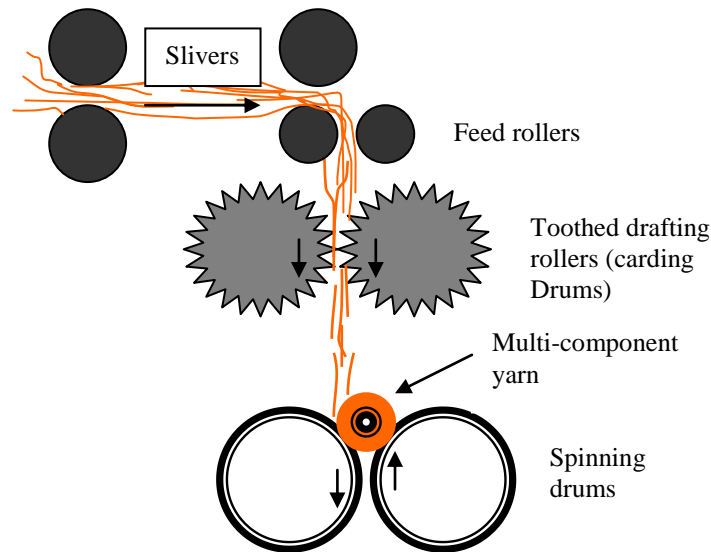

Figure 3.5 A side view showing the principle of DREF 3

For good doubling effect, fibres slivers are used as feed slivers. The overall density of the feed slivers is very high, which means they have to be fed to the toothed drafting rollers (carding drums) at a very slow speed. To minimise fibre damage, the distance between the clamping line of the last pair of feed rollers and the line of the narrowest clearance between the two toothed drafting rollers is set at about one fibre length. In addition, this distance is adjustable to cater for raw materials of different fibre length.

As with DREF 2, fibre buckling occurs as the individual fibres impinge upon the surface of the spinning drum and the mass of fibres already in the nip of the two spinning drums. This leads to poor fibre orientation in the yarn, which reduces yarn strength. But in DREF 3, the core fibres are of parallel configuration. So DREF 3 yarns should have higher tenacity than DREF 2 yarns under similar conditions.

The percentage of core/sheath components can be easily adjusted with the DREF friction spinning systems.

Review questions

1. Describe in your own words the principle of friction spinning.
2. Friction spun yarns do not have wrapper fibres on the yarn surface. Why are friction spun yarns weaker than comparable rotor spun yarns?
3. Compare and contrast the differences and similarities between DREF 2 and DREF 3 friction spinning systems.

Topic 4

Air jet spinning

Introduction

In the early 1960s, the DuPont company (USA) patented a method for producing what was called a **fasciated** yarn, which is composed of a core of more or less parallel fibres, wrapped around by a small proportion of surface fibres. A false twist air jet was used as the twister, hence the name air jet spinning or air vortex spinning. Because the speed of air vortex can be extremely high, the twisting rate is very high with air jet spinning, which then leads to high yarn delivery speed or high production rate. Today, air jet spinning is almost the most productive staple spinning technologies.

DuPont did not pursue its patented method to commercialisation. Instead, further research and development on air jet spinning were carried by other companies. Since the 1980s, the name most widely associated with air jet spinning has been Murata, Japan.

This topic discusses DuPont's basic idea of air jet spinning to make fasciated yarns. This is followed by a discussion of Murata Jet Spinning (MJS) and the associated developments.

Objectives

At the end of this topic you should be able to:

- Understand the basic principle of the Murata Jet Spinning system
- Appreciate the characteristics of air jet spun yarns
- Know the developments in air jet spinning

Principle of air jet spinning

As mentioned in the introduction, air jet spinning makes a fasciated yarn with a parallel core wrapped around by some surface fibres. The original DuPont process uses one air jet only. Figure 4.1 shows the principle of the DuPont method, together with a comparison of fasciated yarn versus conventional ring spun yarn.

Figure 4.1 Schematic diagram of the fasciated yarn spinning system (Hunter 1978, p.16).

The feed sliver is drafted by a roller drafting unit (now shown in full). The drafted fibres are presented as a flat bundle to the aspirator and then pass the air jet twister (torque jet). Because the fibre strand is nipped between the delivery rollers (on the right) and the front drafting rollers (on the left), only false twist is inserted into the fibre strand by the air jet twister. At the air jet twister, the main bundle of fibres are false twisted, but some fibres at the edges of the fibre ribbon will escape the twisting effect to some extent. As soon as the fibres emerge from the air jet, the main bundle of fibres will untwist to cancel out the false twist in the bundle. Because of the increased fibre contact with the main bundle, the edge fibres will also 'untwist' with the main bundle, and the amount of untwisting is greater than the initial false twist these edge fibres received from the air jet. As a result, the net result is that the edge fibres will be given a real twist in the opposite direction to that of the original false twist. This difference in twist direction is also depicted in figure 4.1.

An important feature of this process the high rate of twist, leading to much higher rate of yarn delivery than the ring and rotor spinning systems. Roving stage is also eliminated because the jet spinning systems can spin directly from slivers. Jet spun yarns are usually weaker than comparable ring spun yarns.

The jet spinning process relies heavily on the clever manipulation of the edge fibres which refuse to receive the full initial false twist. This aspect is further developed by Murata in its own jet spinning systems. The Murata Jet Spinning concept is discussed next.

Murata jet spinning (MJS)

The Murata jet spinning (MJS) system uses two air jets rather than one. The direction of air vortex of the two jets is opposite. The first jet is employed specifically to manipulate the edge fibres while the second jet (main jet) is used as the false twist jet. Figure 4.2 shows a schematic of the Murata jet spinning system.

Figure 4.2 Schematic of Murata jet spinning (MJS) process (Murata).

A drawframe sliver is fed from can (1) to a roller drafting unit (2). A high draft in the range 100-200 is used to attenuate the sliver to a thin strand of fibres. The fibre strand then proceeds to the two air jets (3 and 4). The direction of air vortex in these two jets is opposite to each other. The intensity of air vortex in these jet is also quite different, with the second jet (4) having an air vortex of much higher intensity. The angular velocity of the air vortex inside the 2nd jet (4) is more than 1 million rpm. Owing to the intensity of its air vortex, the 2nd jet (4) is the actual false twist jet and will affect the main bundle of fibres from the drafting unit. The first jet (3), on the other hand, will affect the small number of edge fibres. Because the air vortex inside the 1st jet (3) rotates in the opposite direction to that of the 2nd jet, the edge fibres are twisted by the 1st jet in the opposite direction to the main fibre bundle. As soon as the main fibre bundle

and the edge fibres emerge from the 2nd jet (4), the main bundle untwists to cancel out the false twist it received from the 2nd jet. In the same process, the edge fibres also 'untwist' with the main bundle. Because the direction of 'untwisting' is the same as the direction of the twist these edge fibres received from the 1st jet, the edge fibres actually receive a boost of real twist, allowing them to wrap tightly around the now parallel main fibre bundle. The distribution of twist in the fibre strand is depicted in figure 4.3.

Figure 4.3 Distribution of twist in the whole fibre strand (Klein 1993, p.14)

Since the installation of the 1st Murata jet spinner in USA, this technology has achieved considerable market penetration. Today, it is used to spin yarns in the count range Ne 10 to Ne 80 (7.5 to 59 tex), at a yarn delivery speed of about 200 m/min. Fibres used include 100% cotton, synthetics, and their blends (fibre length up to 2 inches).

Compared with ring spun yarns, the Murata air jet spun yarns are usually weaker, stiffer and harder, but they have a lower tendency to pilling and snarling.

Developments in air jet spinning

Two major developments in this field are from Murata - the Murata Twin Spinner (MTS) and the Roller Jet Spinner (RJS).

Murata Twin Spinner (MTS)
The Murata twin spinner produces an assembly wound air jet spun yarns directly on the spinning frame.

Figure 4.4 shows the process of Murata twin spinner. The principle of yarn formation is exactly the same the Murata jet spinning discussed in the previous section. Rather than making one air jet spun yarn, two single air jet spun yarns are produced from two feed slivers. Upon emerging from the air jets, these two single yarns are brought together, cleared if necessary by a yarn clearing device, and assembly wound onto a large package. The assembly wound package is usually twisted with a two-for-one twister to form a quality 2-folded yarn or doubled yarn.

Figure 4.4 Murata Twin Spinner (Murata)

Roller Jet Spinner (RJS)
This is a relatively new development. Again the basic principle is similar to Murata jet spinning. But only one jet is used, the 2nd false twist jet is replaced by a pair of twisting rollers, called the balloon rollers. The rotation of the balloon rollers not only inserts false twist to the main fibre bundle, they also drive

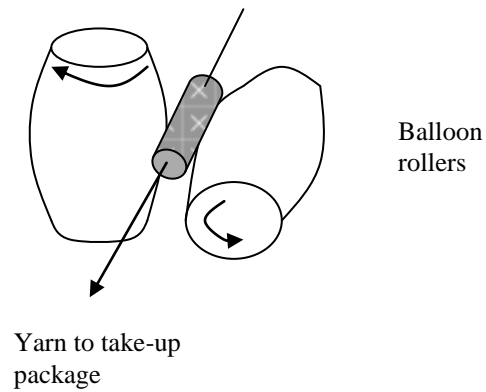forward the yarn at a predetermined delivery speed. A schematic diagram of the balloon rollers is shown in figure 4.5.

Balloon rollers

Yarn to take-up package

Figure 4.5 The balloon rollers used in RJS

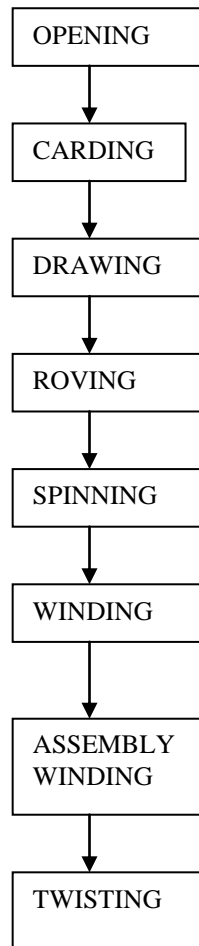The roller jet spinner (RJS) can achieve a yarn delivery speed of bout 400 m/min, making it the most productive staple spinning system in commercial production. A notable feature of the roller jet spun yarns is the very low yarn hairiness level. This is because of the rolling of surface fibres on the yarn by the surfaces of the balloon rollers.

The reading material "Murata: RJS Spinning for Coarse Counts" by Murata Machinery Ltd briefs explains the principle of roller jet spinning, and compares the relevant yarn and fabric performances.
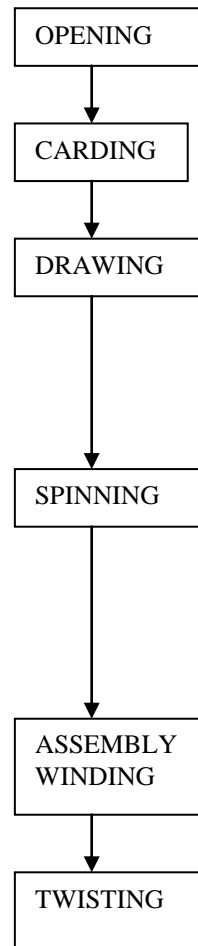
Review questions

1. Rotor spun yarns have wrapper fibres and Murata jet spun yarns also have wrapping fibres binding the yarn together. What is the main difference between the structures of yarns produced by these two spinning systems?

2. The following diagrams show the process flow-chart for making two-folded (two-plied) ring and rotor spun yarns from cotton fibres. Please sketch the processing flow-charts for making two-folded cotton yarns from Murata Jet

Ring Spinning	**Rotor Spinning**
OPENING	OPENING
↓	↓
CARDING	CARDING
↓	↓
DRAWING	DRAWING
↓	↓
ROVING	
↓	
SPINNING	SPINNING
↓	↓
WINDING	
↓	
ASSEMBLY WINDING	ASSEMBLY WINDING
↓	↓
TWISTING	TWISTING

Spinner (MJS) and Murata Twin Spinner (MTS).

3. There are a number of spinning systems that are not discussed in this module. These spinning systems, while not as commonly used as the ones discussed in this module, are nevertheless worth knowing. Please consult the relevant library resources at Deakin and class handouts, explain (with the help of sketches) the working principle of each of the following spinning systems:
(1) Wrap spinning
(2) Self-twist spinning
(3) Mule spinning
(4) Woollen ring spinning

Topic 5

Filament Yarn Texturing

Introduction

Manufactured fibres have been used increasingly, often at the expenses of a declining share of natural fibres. Manufactured fibres can be produced in various forms - tape, mono-filament, multi-filament, and tow. Figure 5.1 shows an overview of the production and subsequent processing of manufactured fibres.
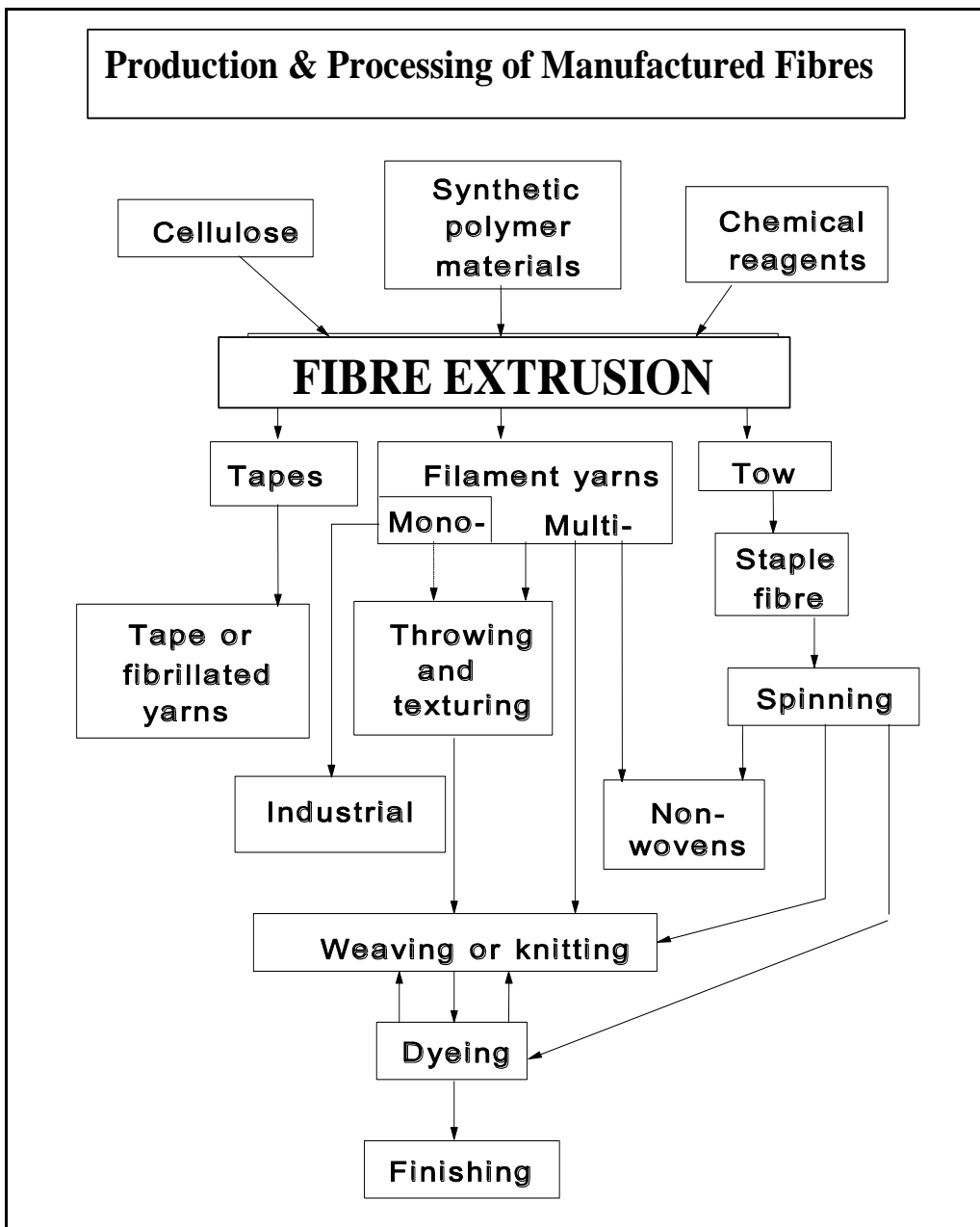

Figure 5.1: An overview of manufactured fibre production and processing

Different dies or spinnerets are used to extrude the various forms of manufactured fibres. For example, to make a tape yarn, the polymer material is extruded as a thin sheet first, which is then slit into flat and narrow tape yarns for applications such as carpet backing, sacks and packing bags. Manufactured fibres can also be extruded as a think bundle of continuous filaments known as a **tow**, which is subsequently cut or stretch broken into staple fibres for processing on their own or in blends with other fibres on conventional short staple or long staple processing systems. But most commonly, manufactured fibres are extruded as continuously multi-filament yarns. The majority of multi-filament yarns that we use today are polyester and nylon. In making these yarns, the polymer chip is melt by heat and extruded through a series of tiny holes in a spinneret. The filaments are then brought together and drawn to align the molecular chains in each filament to improve the strength of the resultant multi-filament yarn. Depending on the level of drawing, the resultant multi-filament can be a partially oriented yarn (**POY**) or a fully oriented yarn (**FOY**). Up to this stage, the yarn is often referred to as producer filament yarn, smooth filament yarn, and flat filament yarn. Such a yarn is generally unsuitable for apparel applications. Owing to the smooth surface of individual filaments, the filaments are closely packed together, with little bulk and extension. Fabrics made from these yarns are slippery, have poor breathability and handle. To overcome these drawbacks, the filaments are either converted into staple fibres first for processing on conventional wool or cotton processing machinery, or are textured through a filament yarn texturing process.

For information on converting continuous filaments to staple fibres, please raed the reading "Tow-to-sliver conversion and bulked acrylic yarn production" by Oxtoby (1987, p.232). Please note that "tow-to-sliver" conversion is also known as "tow-to-top" conversion. Furthermore, a similar technique to bulked acrylic yarn production has also been used to produce bulky yarns from wool fibres.

This topic focuses on the texturing of continuous filament yarns.

Textured yarns in comparison with the original smooth filament yarn show increased bulkiness, porosity, softness, and some of them also possess high elasticity. Garments made from textured yarns are comfortable to wear. They are noted for good draping qualities. They have good air permeability and thermal insulation properties. They are more absorbent and allow less static build-up than the original smooth filament yarn. Textured yarns may be in different forms, depending on the texturing process used.

The basic principle of texturing is to introduce arcs, crimps, or loops into the smooth structure of continuous filament yarns. Different processes have been developed for this purpose. The two commonly used processes are false-twist texturing and air-jet texturing.

Objectives

At the end of this topic you should be able to:

- Understand the process of 'tow-to-top' conversion and the production of bulked acrylic yarns
- Understand the objectives of filament yarn texturing
- Know the principle and process false twist texturing
- Know the principle and process of air jet texturing

False-twist Texturing

Principle and process

Filament yarns like polyester and nylon and thermoplastic. They soften and can be easily deformed with the application of heat; and upon cooling, the filaments remain in their deformed state (i.e. the filaments become heat-set). Normally if filaments are twisted, torsional stress develops in the filaments and the filaments will want to untwist to release the stress. However, if such filaments are twisted and heat-set (i.e. heated above their glass transition temperature and then cooled below their glass transition temperature), their torsional stress will be relaxed and the filaments will remain twisted even though the external force is removed. If these filaments are then untwisted, stress will develop again in the individual filaments. If these stressed filaments are allowed to relax, they will seek the **minimum-energy-state** (or least stressed state!) by forming adjacent helices and snarls. These helices and snarls prevent the individual filaments from staying as closely packed as before and the filaments will occupy a much greater volume than before. In other words, the filaments become bulky and textured. This process is illustrated in Figure 5.2
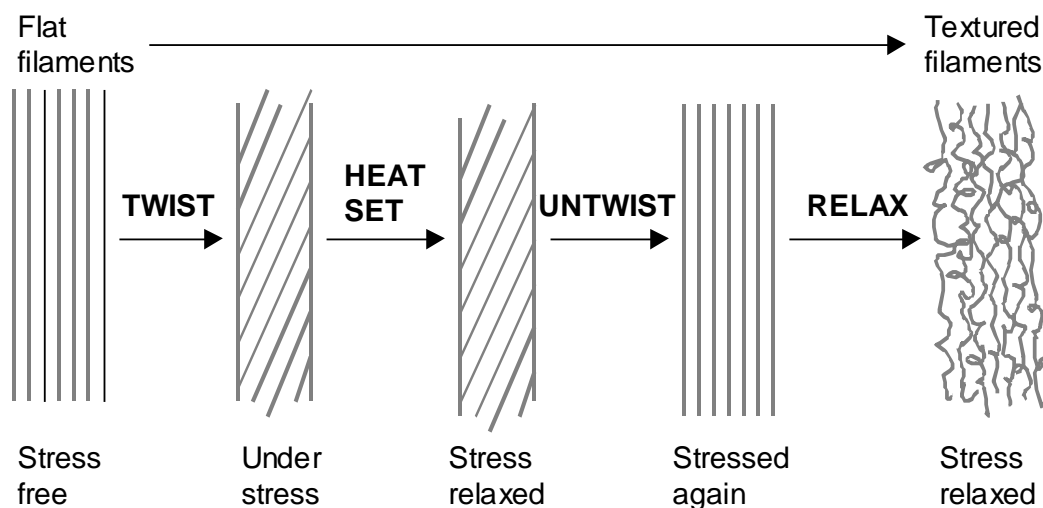

Fig. 5.2 Principle of filament texturing by twisting, heat-setting and untwisting

In the early days of filament yarn texturing, the three steps of twisting, heat-setting, and untwisting are carried out in separate stages as indicated in figure 5.3. This traditional process has now become obsolete. But the principle has been used in modern continuous false twist (FT) texturing processes.

1 - Redraw or downtwist to uptwister bobbin

2 - Uptwisting

3 - Heat-setting in steam autoclave

4 - Redraw to uptwister bobbin

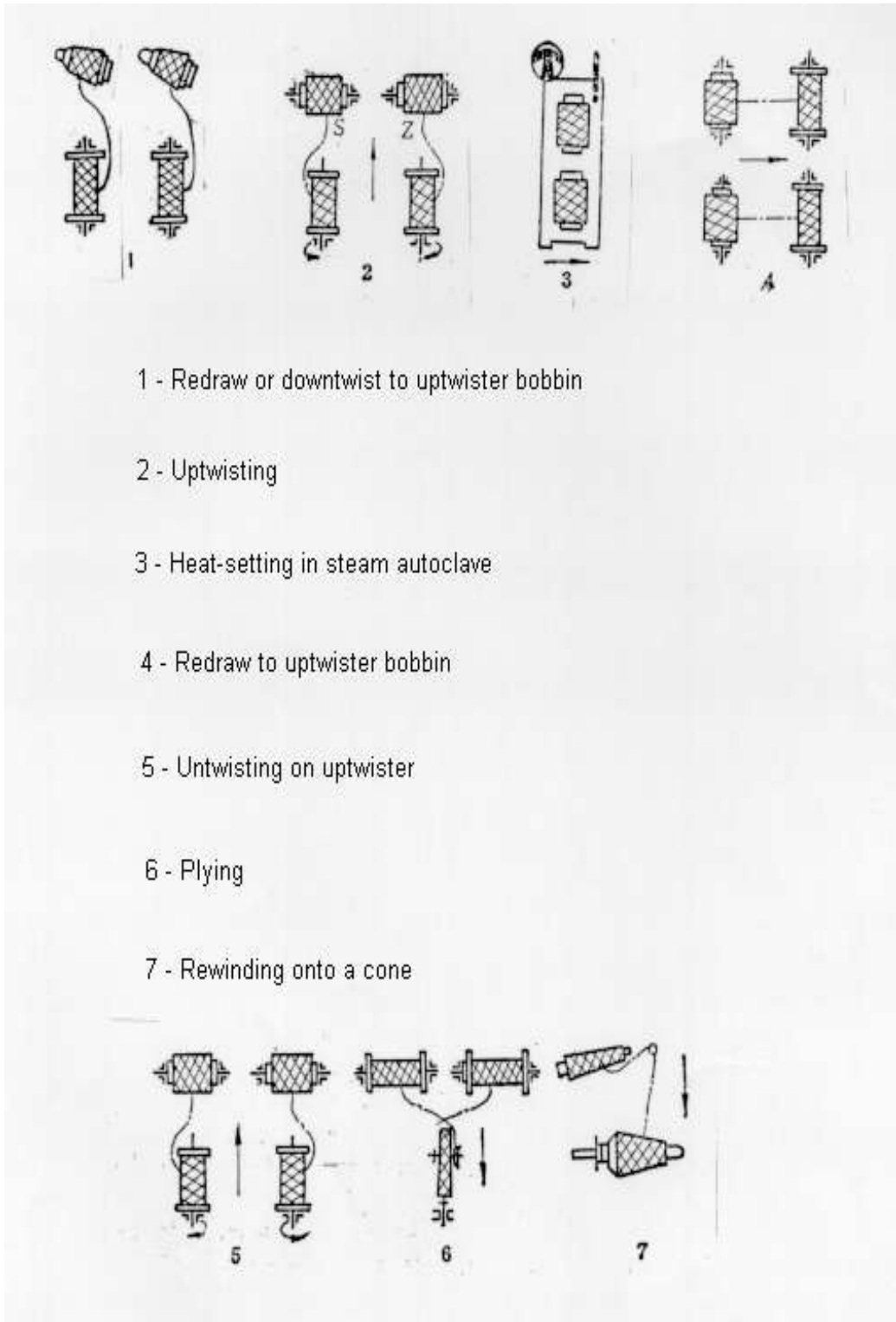5 - Untwisting on uptwister

6 - Plying

7 - Rewinding onto a cone

Figure 5.3: Traditional filament yarn texturing with separate twisting, heat-setting, and untwisting stages

In principle, continuous false-twist (FT) texturing is very similar to a dynamic false-twisting process, as indicated in figure 5.4. The main difference is that in FT texturing, heating setting is involved. This is also why FT texturing can only work on thermoplastic filaments. Non-thermoplastic filaments, such as glass filaments, can not be false-twist textured.
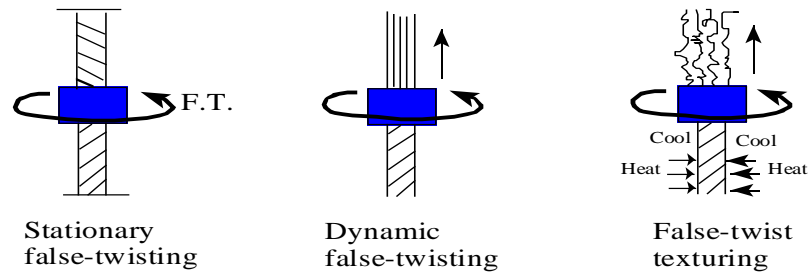

Fig. 5.4 Difference between stationary false twisting, dynamic false twisting, and false-twist texturing

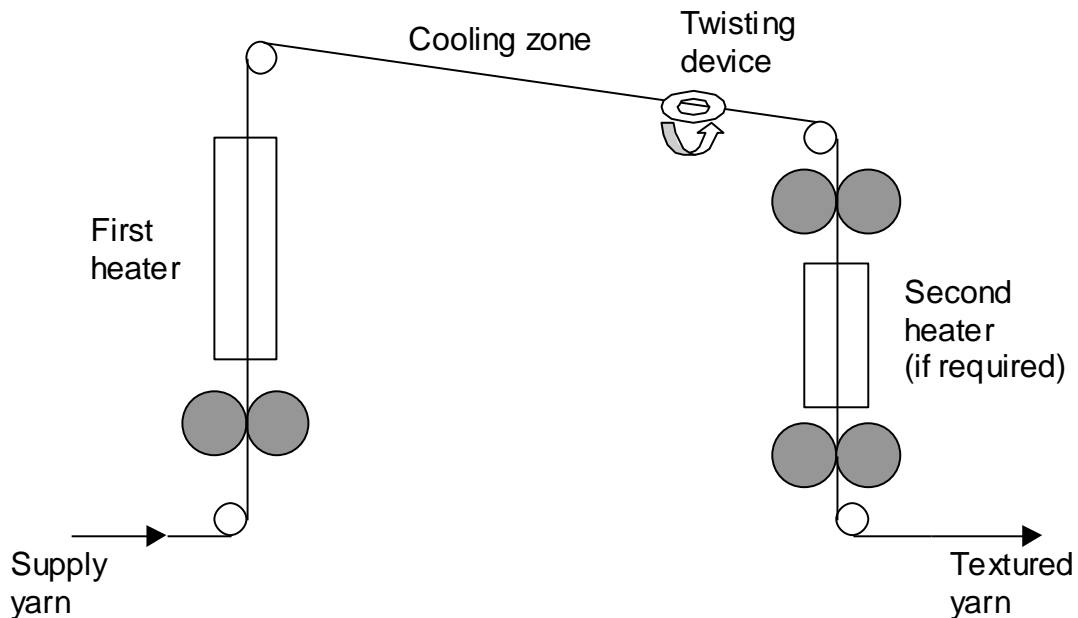A typical false-twist texturing process is shown in Figure 5.5.

Figure 5.5 A continuous FT texturing process

Without the second heating process, the textured yarn is called a stretch yarn, which is bulky and stretchy. The stretch yarn is suitable for hosiery and sportswear (track-suiting, stretch pants, and swimwear etc). If less stretch is required, the yarn can pass through a 2nd heater under controlled tension. This results in a modified stretch (or set) yarn, which retains certain bulk, but with much reduced extensibility, suitable for outwear applications.

Figure 5.6 shows the possible processing routes from filament extrusion (spinning) to textured yarn.

1 - spinning,   2 - drawing,   3 - texturing
Route A: 3-step process (Spin undrawn yarn conventionally + Draw + Texture)
Route B: Spin-Draw + Texture
Route C: Spin + Sequential Draw Texture
Route D: Spin + Simultaneous Draw Texture
Route E: Spin-Draw-Texture (under development)

Figure 5.6 Possible processing routes from extrusion (spinning) to textured yarn (Hes and Ursiny 1994, p.24)

False twist devices

A key element of a false-twist texturing system is the actual false-twister. The false twister should satisfy the following requirements:

- Grip yarn well to rotate it
- Allow yarn to travel through
- Insert twist at high speed, and
- Easy to thread up

(A) Pin-spindle false twister

This is a hollow spindle with a horizontal pin made of ceramic or sapphire. The filament is threaded across the pin. The hollow spindle is driven via frictional contact with large rolls at speeds up to 1,000,000 rpm, and each rotation of the spindle (and the pin) will insert one turn of twist into the filament. Figure 5.7 shows a pin false-twist spindle.

Figure 5.7: Pin spindle false twister (McIntyre and Daniels 1995, p. 247)

(B) Stacked disk type false twister

This is the most widely used false twister in filament yarn texturing. It consists of three sets of stacked disks mounted on three shafts (figure 5.8), through which the filament yarn runs. The rotation of the disks not only inserts twist into the filament, but also drives the filament through the disks. By setting the surface speed ratio between the disk and the yarn (the **D/Y ratio**) correctly, equal yarn tension can be achieved at both sides of the false twister. For easy threading of the filament, one disk shaft is movable while the other two are fixed.

Figure 5.8 Stacked disc type false twister (McIntyre and Daniels 1995, p. 144)

(C) Crossed-belts false twister

As shown in figure 5.9, this false twister has two belts crossed at a specific angle. The filament yarn is twisted and driven between two belt surfaces by the rotation of the belts. It is said to give a soft yarn texturing with little yarn damage. This type of false twister is difficult to work with fine denier filaments (eg. <78 dtex).

Fig. 5.9: A crossed-belts type false twister

(D) Ring false twister (disk-sandwich twister)

This false twister consists of two off-setting rings or disks rotating in opposite direction, with the filament yarn running between the rings. One of the rings is rigid while the other is flexible. At the yarn input end, a presser presses on the flexible ring so that the yarn can be twisted as the rings rotate. Similar to the crossed-belts, the rotation of the rings also provides a 'driving force' that drives the yarn through the rings. Figure 5.10 shows two diagrams of a ring false twister.

Figure 5.10: A ring false twister (Demir and Behery 1997, p.90)

(E) SZ simultaneous texturing twister

This is a new development, released by Muratec (Japan) at the 1995 international textile machinery exhibition (ITMA'95) held in Milan.

It works on two filaments simultaneously, inserting S twist in one filament and Z twist in the other. The two filaments are then combined and wound onto the same package. The resultant textured yarn is claimed to have high bulkiness, and is torque-free (balanced).

Figure 5.11 shows the SZ twister and the actual texturing process using this type of twister.

Figure 5.11 A SZ simultaneous twister (a) and the texturing process (b) (Courtesy of Muratec, Japan)

Air-jet Texturing

Principle and process

Air-jet texturing is a versatile process. It works with both thermo-plastic (eg. Polyester and nylon) and non-thermoplastic (e.g. rayon, glass filament) filaments. In air-jet texturing, yarn morphology is modified without disturbing the internal structure of individual filaments. This is achieved by creating loops and air pockets in the yarn by opening up the yarn structure, buckling the filaments, and locking up the structure again.

The principle of loop formation in air jet texturing can be described as:

- Overfeed the filament yarn into an air nozzle
- Open the feed yarn (or parent yarn) in a turbulent air stream
- The air stream displaces the filaments, and convert the excess length into loops
- interlace filaments to stabilise the loop structure

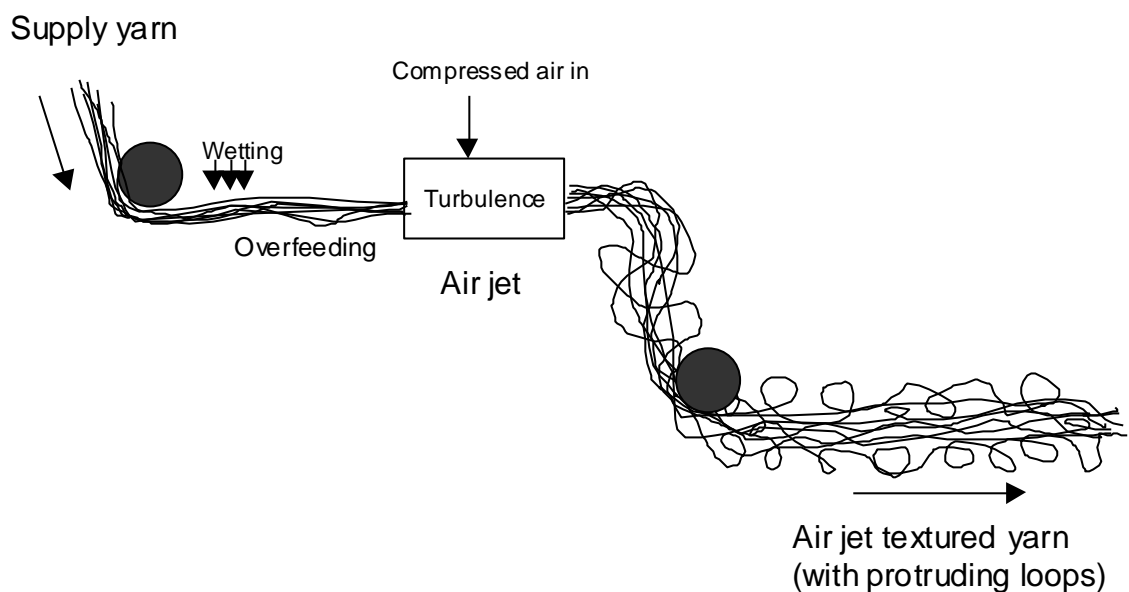Figure 5.12 depicts the principle of air-jet texturing.

Fig. 5.12: Sketch of an air jet texturing process

Wetting of the filaments before the air nozzle is used for the following reasons:

- to reduce between-filament friction
- to reduce friction between filaments and nozzle wall
- to improve separation of filaments

- to get better texturing effect with smaller and more even and frequent loops

A yarn with good textured effect is shown in figure 5.13 below.

Figure 5.13: An air jet textured yarn with good texturing effect

Figure 5.14 shows example photos of dry and wet textured yarns, while figure 5.15 shows a series of high-speed still photograph of yarn being textured under wet conditions.

Fig. 5.14: Photos of dry and wet textured yarns (Demir & Behery, 1997, p.276)

Figure 5.15: High-speed still photograph of yarn being textured under wet conditions (Demir & Behery, 1997, p.249)

As can be seen from figure 5.13, air jet textured yarn closely resembles a spun yarn, with the protruding loops mimicking surface hairs of a spun yarn. For this reason, air jet textured yarns have found applications in a wide range of products, such as jackets, shirts, blouses, suits, outwear, furnishing fabrics etc.

Air nozzles

Many different air jet texturing nozzles have been developed and the development is continuing.

The reading material "Air-jet texturing: Effect of jet type and some process parameters on properties of air-jet textured yarns" by Kothari and Timble (1991, p.29) gives a good account on the history of air-jet development, as well as on the test of air-jet textured yarns.

Other possibilities with air-jet texturing

Apart from being a versatile texturing process, air-jet texturing also offers considerable scope for engineering quite different yarns.

First of all, the linear density of air jet textured yarns can be easily changed by changing the level of overfeed into the air nozzle. A higher overfeed will lead to a heavier textured yarn.

Secondly, co-texturing is possible by feeding two or more filaments yarns together. By having different overfeeds for the different yarns, a core-and-effect yarn can be produced. The yarn with a lower overfeed will stay in the centre as the core while that with a higher overfeed will stay predominantly on the surface. Figure 5.16 shows the process of producing a core-effect yarn using three feed yarns.

Figure 5.16: Core-effect textured yarn production (Demir & Behery, 1997, p.214)

The loops of air-jet textured yarn can also be broken after textured with a loop breaker as shown in figure 5.17. In this process, the air textured yarn wraps around several rolls in succession so that protruding loops of the incoming yarn are rubbed by the outgoing yarn and thereby broken up. The resultant yarn is called a **Texspun** yarn, because the free fibre ends of this textured yarn give the yarn a very spun-like appearance.
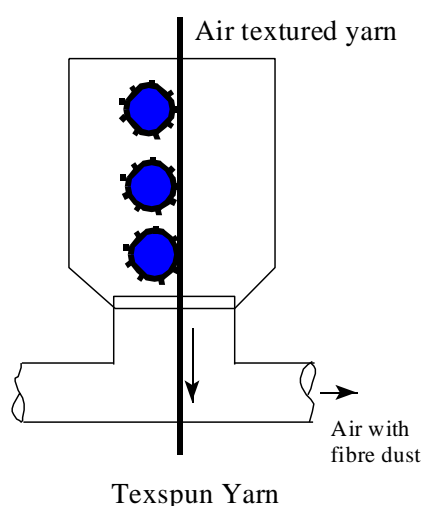

Figure 5.17: A Texspun process

Intermingling/Interlacing

In staple spun yarns, twist is used to hold the fibres together in the yarn. In multi-filament continuous yarns, there is very little cohesion between individual filaments in the yarn, and filaments separate easily. Even after texturing, the yarns still lack inter-filament cohesion. Consequently, the tendency for individual filaments to separate has caused problems in subsequent winding and weaving processes. While twist can be used to impart inter-filament cohesion, it is not a very efficient and is costly. The favoured approach in the synthetic fibre industry is the intermingling or interlacing process.

So what is the intermingling process then? Intermingling is a process of imparting inter-filament cohesion by entwining the filaments instead of or in addition to inserting twist. The entwining is usually achieved by passing the yarn under light tension through the turbulent zone of an intermingling or interlacing jet (nozzle).

A simple intermingling nozzle is shown in figure 5.18. It consists of a yarn channel, and an air inlet in the centre of the channel. The compressed air impinges on the traversing yarn vertically and entwining the yarn at regular intervals.
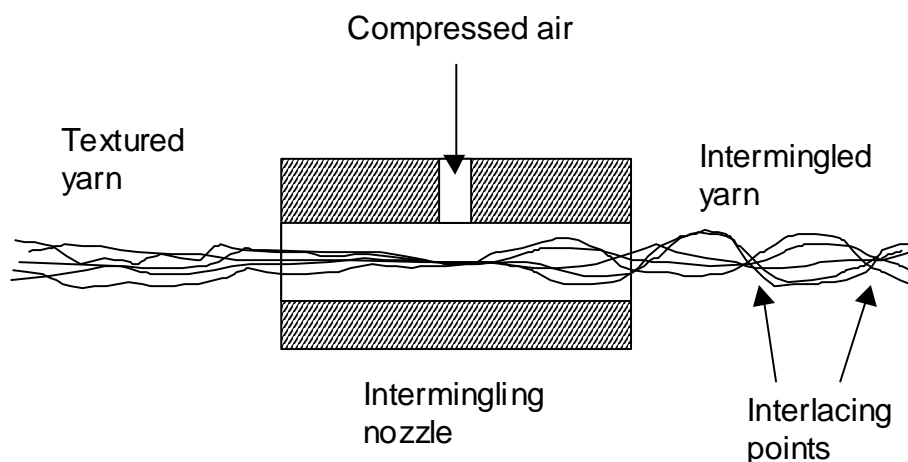

Figure 5.18: Simplified representation of the intermingling process

Intermingling has become a very efficient and low-cost way of imparting cohesion to multi-filaments. It has been used in many fields where inter-filament cohesion is required. Figure 5.11(b) shows the use of an interlacing nozzle in false-twist texturing. The use of intermingling in other processes is depicted in figure 5.19.

Figure 5.19: Applications of the intermingling process (Demir and Behery 1997, p.310)

REVIEW QUESTIONS

(1) Compare and contrast false twisting texturing with air-jet texturing. You should make reference to differences in filament input, the texturing process, and the resultant yarn. You can use sketches to help explain the points.
(2) Briefly describe the objective, principle, and process of filament intermingling.

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