7

Short-staple spinning

7.1 Ring spinning

7.1.1 Ring spinning and associated processes

A ring-spinning machine is an uncomplicated, flexible, low cost device that is well established with a wide range of applications. In the past, differences in fiber length between cotton and wool determined whether the system was regarded as being in the short- or long-staple category; that view persists even though there are now many more types of fiber and machines. However, in this book we shall persist with the original demarcation and, for the present purpose, we may define 'short staple' as covering the range of fiber lengths up to, say, 2 inches (≈ 50 mm). Short-staple spinning machines may process a variety of fibers, the most important of which are cotton, polyester, and blends thereof.

Although it was initially developed in the nineteenth century, ring spinning still is attractive for a wide range of services and is likely to endure for many more years. The systems described in this section include roving production, ring spinning, and winding. Roving is an intermediate product made from sliver and it is normally used as a precursor for yarn. A problem that requires attention is end-breakage in spinning, roughly half of which arise from faulty roving preparation. This is mentioned to underline the need to consider the whole production line; concentrating on individual machines is not sufficient. Since sliver production has already been discussed, we now continue with roving production.

Essential parts of a roving frame are:

1 A creel, which contains cans from which sliver is drawn to feed the drafting systems (see Section 6.2.1),
2 Drafting systems to reduce the linear density of each sliver to that of rovings (see Section 3.7),
3 Flyers to twist the emerging rovings.
4 Individual winders to take up the twisted rovings onto bobbins.

Items (3) and (4) are usually combined as will be seen in the next section.

7.1.2 Flyer twisting and winding of roving

The flyer (Fig. 7.1(a)) is ideal for twisting low strength strands such as roving, but it has a limitation in speed because of the sheer size needed and the associated mechanical stresses. However, the productivity is reasonable for roving because both the count and twist are low.

One revolution of the flyer inserts one turn of real twist in the roving emerging from the drafting system. One turn of the bottom feed roll delivers *D* inches of yarn, where *D* is the diameter of the roll in inches. If the flyer rotates $k\pi D$ times during a single rotation of the front drafting roll, the twist is *k* tpi. The factor *k* is controlled by a twist gear, which is part of the gear train connecting the bottom front roll and the flyer. Since the feed roll speed is fixed, it is also necessary to fix the flyer speed to maintain an unchanging twist level.

The roving is supported inside the flyer arm or in a slot, and this reduces the forces acting on it due to centrifugal force. Winding tension is, in part, controlled by wrapping the roving around the presser arm two or three times. The more wraps, the higher the tension and the more dense the roving package. In addition to real twist there is also false twist involved. The rubber grommet provides a surface on which the whirling yarn rolls to produce false twist between the grommet and the feed roll. This false twist strengthens the weak twist triangle and reduces end-breakages.

It is not enough to merely twist the strand; it has to be wound on the bobbin and this requires that the bobbin speed be different from the flyer speed. In some machines, the bobbin speed is greater than the flyer (one can tell by the direction of the foot) and sometimes vice versa. The one is referred to as a ‘bobbin-lead’ machine and the other as a ‘flyer-lead’ machine. In both cases, a so-called ‘warp wind’ is used, and this means that cylindrical layers of roving are laid onto the bobbins (Fig. 7.1(b)). This has certain consequences. After the first layer of roving has been laid on the bare surface of the cylindrical bobbin, it is necessary not only to change the direction of lay but also to adjust the bobbin speed, because the diameter has just become larger by two roving thicknesses. After each complete layer is wound onto the bobbin (i.e. after each lay), the direction of lay is changed and so is the bobbin speed.

This is usually accomplished by means of a pair of opposed cone pulleys and differential gearing. The cone pulleys are set parallel but in opposite directions so that a belt connecting them may be moved parallel to the cone axes without being stretched or going slack. Movement of the belt produces different speed ratios. The differential gearing is merely a mechanical means of combining two separate input speeds to give an output speed proportional to the difference of them. In a conventional roving frame, one input is calculated for the case when the flyer and bobbin speeds are equal; the other is arranged to give the appropriate wind-on speed. The ‘wind-on’ speed is changed at the end of each traverse by altering the position of the belt on the pair of cone pulleys just described. In some modern machines, the speed change is controlled electronically. If the speeds are improperly adjusted, the winding tension is changed after each layer of roving is placed on the bobbin. If the roving is larger in diameter than allowed for in the calculation, the bobbin becomes very compact and difficult to unwind at the next stage of processing. If the strand is wound too slackly, the package becomes unstable and prone to damage. (If the changes are too great, there is danger of causing a machine stop due to a broken end.) Thus, selection of the correct lay gear is important. The precise choice depends on the fiber being used, as well as the count and twist of the roving. A production unit usually has data, based on experience, for the best value to use. The drive train controlling this speed change

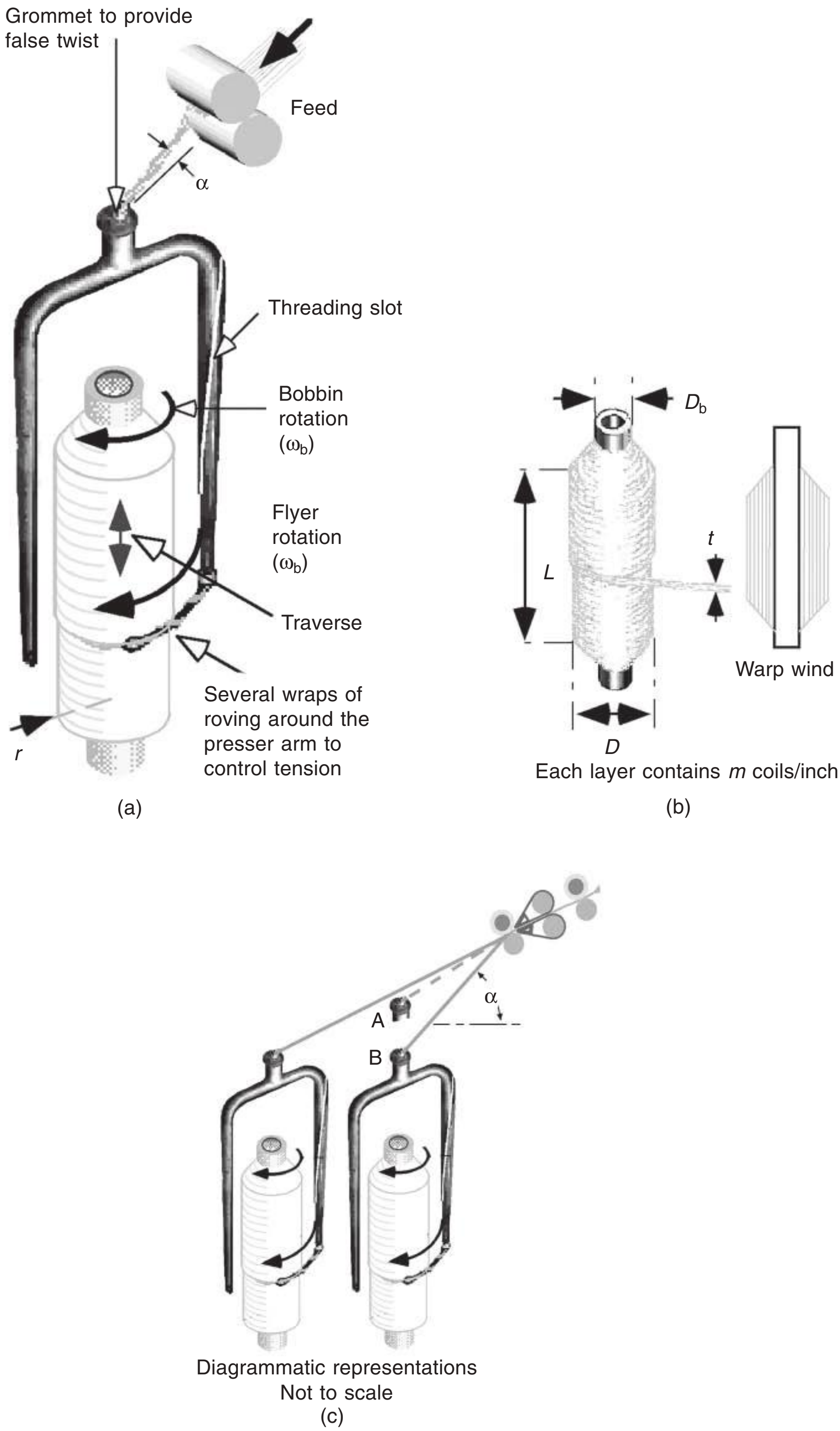

Fig. 7.1 Roving spindle and bobbin

contains the lay gear. If an end breaks and the machine is not stopped, these speed adjustments get out of kilter; further operation is not possible until the machine is reset.

To give good stability to the roving package, it is normal to progressively change the length of traverse of the flyer foot with respect to the bobbin. Each successive layer involves a progressively shorter traverse with the result that the completely filled bobbin has conical shoulders of about 80° to 100° inclusive angle (which reduces damage from handling). The setting of the traverse mechanism determines the slope of the shoulders of the package.

The strand is fed to the twister at a steady pace and therefore the flyer speed has to be maintained to keep the twist level constant. However, the winding-on speed has to be varied to match the feed of the roving. The ratio of bobbin and flyer speed[1] is:

$$U_b/U_f = 1 \pm 1/\tau_c \qquad [7.1]$$

The sign in the equation changes according to whether it is a flyer-lead or a bobbin-lead design.

The twist is adjusted by changing the twist gear (part of the gear train connecting the front and back rolls). There was discussion of twist and draft in Chapter 3.

7.1.3 The roving machine

Good descriptions of roving machines are given by Klein [1]. The machines comprise between 60 and 120 spindles, each containing a drafting system and a flyer twister. Rotation of the flyers twists the strands and, since the strand is supported within one of the flyer arms, centrifugal force does not cause it to be tensioned due to ballooning. It is not possible to rotate such a flyer at very high speeds because of mechanical design difficulties; speeds up to 1600 r/min are obtained in practice. Bearing in mind that the productivity of a spindle is a function of the linear density of the strand, it will be realized that a flyer frame finds its best use in processing relatively thick, weak rovings that vary between 0.2 and 1.2 ktex.

Input to a roving frame is 'drawn' sliver, taken from a can filled in the last drawing stage. Sliver is normally drafted by the roving frame to roughly 1 hank/lb and it is then twisted just sufficiently to permit handling before being wound onto a large bobbin. A roller drafting system is used as discussed in Chapter 3 and in Appendix 8. The top rolls are similar to those used in ring spinning (Fig. 7.2(b)). The spindles and flyers each share common drives and the bottom rolls of the drafting system are formed from long steel bars, which are articulated along the length of the machine. These arrangements enable the gearing to be concentrated in a headstock at one end of the machine; they also enable the gearing to be enclosed for safety and cleanliness. The top rolls are similar to those used in ring spinning. Note: 0.5 hank/lb ≈ 1.2 ktex, 1 hank/lb ≈ 0.6 ktex, 3 hank/lb ≈ 0.2 ktex.

The building motion is controlled by the steady upward and downward movements of the rail containing the bobbins and spindles. The bobbins and spindles are coaxial; the flyers all operate at the same speed and direction (by custom, Z twist). The bobbins rotate at a common speed. The best time to set the tension is when the build

1 Relative winding speed = material supply speed, thus $(U_f \pm U_b)\pi D = U_f\, \pi D/\tau_c$ which leads to Equation (7.1). τ_c is the twist/unit length, U_b is the bobbin speed, and U_f is the flyer speed. It might be noted that U_f and τ_c are virtually fixed by the machine design and product, respectively.

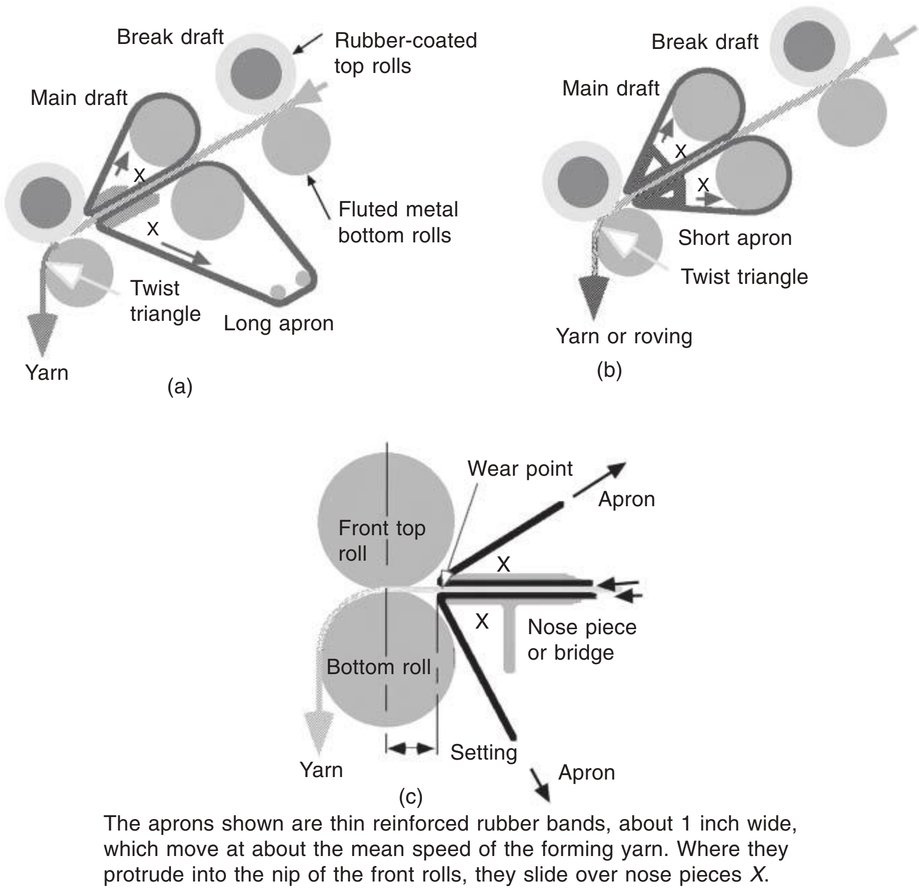

Fig. 7.2 Apron drafting

of the bobbin just begins because, if an end breaks and the machines are not stopped quickly, these speed adjustments get out of balance and further operation is not possible until the whole machine is reset. The twister has already been described. Because the roving packages are large they are usually arranged in two rows (Fig. 7.1(c)). In some machines there is a difference in the angle α made by the roving entering the grommet; this leads to differing false twist and tension between the front and back rows. The result shows up as differences in yarn coming from one roving bobbin and another; the differences can produce barré in fabrics. The solution is to use extensions, which raise some grommets from B to A to give equal amounts of false twist. Worn grommets can cause similar problems but they are occasional rather than prevalent.

7.1.4 The roving process

Roving usually has a count of about 1 or 2 hank/lb irrespective of whether it is in cotton or worsted processing. The count of roving is often quoted as 'hank roving'.[2]

2 See Appendices 1 and 2 for definitions and calculations relating to N_e or N_w.

Since this roving has then to be drafted to make yarn, and this drafting involves the sliding of fibers over each other, it is not practical to insert a high level of twist in the roving. Twist multiples (TM) of less than 1.0 are typical, but precise values depend on the staple length, fineness (or denier), and type of fiber. Data given by Klein [2] suggest that the TM for cotton is given by the regression TM = 1.785 – (0.46 × fiber length in inches). Cottons need a higher twist than synthetics; coarse fibers need more twist than finer ones. In addition, lightweight rovings need more twist than heavier ones. More roving twist and the use of lightweight rovings lead to less yarn hairiness, but too high a roving twist impairs the drafting operation in ring spinning. High roving twist is liable to cause defects in the yarn. There has to be a compromise between having a high enough twist in the roving to give it sufficient strength to withstand processing and having a low enough twist to permit proper drafting in ring spinning.

Imperfections in drafting at this stage are likely to lead to thick and thin spots in yarns produced in ring spinning. A thick spot (or 'slub') is more difficult to twist than a thin one, and when a strand containing thick and thin spots is twisted, the twist therefore concentrates in the thin spots. Irregular roving is weak at places and over-twisted at others; it is difficult to process. Such poor material can cause considerable problems at the ring frame because of the so-called hard ends or tight spots. It becomes more likely that an undrafted portion of the roving is drawn through the drafting system of the ring frame creating a thick spot followed by a thin spot in the yarn. The weak spots give so-called creel breaks. A rule of thumb is that the roving should be just strong enough to remove it from the bobbin, manually, in a direction parallel to the axis of the bobbin. Differences will be found in this attribute if the roving is stored for any considerable time. The twist becomes 'set' and the layers more firmly bedded, with the result that it is sometimes difficult to process such aged material in the ring frame. High humidity in the workplace can produce a similar effect.

A machine is incapable of shutting down immediately and there is always some discharge of fiber when an end breaks. In consequence, the whole frame is normally shut down automatically when an end does break. When an end breaks in roving, a free end of the weak roving lashes the adjacent structure creating a veritable snowstorm of fibers until the machine finally stops. In addition, there is always fly (airborne fiber) from other machines. Fortunately, this is not normally a frequent occurrence. Nevertheless, it still requires vigilance by the operator and the ability to shut down quickly. Uneven or faulty sliver should be avoided. It goes without question that the machine must be correctly set. The solution of increasing the roving twist to reduce end-breakages of the roving is rarely acceptable. There are a few machine designs emerging which break out the sliver supply when an end breaks.

Fly contains dirty fibers and aggregates into masses, which are often picked up by the sliver or roving to give an undesirable thick spot. These can cause flaws in the materials or end-breaks in subsequent processes. A snowstorm of fiber also causes considerable masses of unwanted fiber to be deposited on adjacent rovings and serious yarn faults can also result from this. To reduce this danger, it is now standard practice to install traveling cleaners, which patrol a series of machines to blow fibers from sensitive areas and pick up the material disturbed by the blower. The cleaners consist of long, vertical, pendant tubes with air nozzles protruding at appropriate heights and a suction nozzle, which sucks the displaced fibers from the floor. These systems of tubes are moved along elevated tracks that pass along the fronts of several machines. The fibers swept up are filtered from the air and might even be reworked. Substantial lint collection systems with adequate suction are also needed. The lint collection systems have to be maintained, which involves regularly cleaning (or replacing) the filters, and removing the reusable fiber. The air for blowing is usually supplied by a blower on the traveling cleaner itself.

7.1.5 Apron drafting in roving and ring spinning

Both roving and ring spinning usually have apron drafting. It is usual to angle the drafting systems with respect to the vertical (Fig. 7.2) to improve access and to help control the fibers in the twist triangle. The top rolls hinge upwards, out of the way, when the system needs rethreading, cleaning, or maintenance. Roving is removed from the drafting system at a fairly shallow angle to the horizontal and there is a little wrap around the front roll. Fully formed yarn is nearly always taken from the drafting system with a partial wrap of the fibers on the front roll, which causes moderate pressure to be applied to at least a part of the twist triangle. This gives a measure of control of the weak ribbon of fibers emerging from the front nip. Many end-breaks occur in this zone and control is important.

There is a choice between short and long aprons (Fig. 7.2(a) and (b)). Long aprons are less likely to choke and are easier to fit than short ones but the long ones have a larger initial cost. Short aprons have better fiber control. To some extent the choice is governed by the rate of fly production and the class of yarns being made. Correct aprons and settings are needed to control the unevenness of the yarn since the greatest added variance to the product is created at the ring frame. Setting assumes a different meaning from that applied to a drawframe, and an example of it is given in Fig. 7.2(c).

The extent of the variance is related to the high drafts used. Also, the use of correct hardness of the rubber cots on the top rolls is important. Referring to the whole drafting system, the back rolls have to control more fibers than the front ones. Consequently, heavier pressures have to be applied to control the fibers, and harder rubber is used there. Typical hardnesses of the rubber are 80° to 85° Shore at the back and 65° to 70° Shore at the front rolls. Rolls tend to harden in use and vigilance has to be maintained to spot any loss of fiber control due to the hardening of the rubber. The softer rubbers wear more rapidly than the harder ones and the hardest rubbers consistent with fiber control should be used. Also, soft rubber cots tend to lap more easily. When fibers first lap a roller, a surface is created that tends to collect more fibers, and very quickly a dense wrapping of fibrous material forms. This build-up can be so powerful that it forces the rolls of a drafting system apart and can even bend the shafts. The condition is created when the fibers are longer than a certain percentage of the roll circumference, or when the fibers or the surfaces are sticky. When rubber-coated rolls are used, a build up of static electricity can also start the undesirable process of roll lapping. Maintenance of correct rh in the vicinity of the rolls minimizes this problem. A discussion of the phenomenon of lapping is given in Section 8.2.1. Experience has to be used to make the final choice, depending on local conditions. Related to this, it might be seen that maintenance is important; a normal cycle includes buffing the rolls at intervals varying between 150 and 200 production days. This interval depends on the fibers being processed, roll weighting, draft, and rubber hardness.

In ring spinning, the possibility of a lap-up is increased when an end breaks and the fiber stream is diverted into the pneumafil waste suction system. (A pneumafil waste system collects fibers emerging from the front rolls of a ring frame at those times when an end is broken; it is uneconomic to stop the whole frame, or even a section of it, for a single break.) Schiffler [3] postulates that the wrap frequency varies inversely with time, logarithmically with respect to the number of fiber ends entering the waste suction, and inversely with the apron clearance. Schiffler calls a lap-up a ‘wrap’ and he goes on to say that the wrap frequency (the number of wraps/unit time), is normally a very small number. The apron clearance is defined as the distance apart of the aprons at the nose. The state of the rolls and the extent of ageing of the rolls affect the issue, as does any change in fiber, roll size, weightings, etc. Periodically, farmers suffer infestations of aphids and other insects, which eventually produce contaminants such as sugars on cotton; the fibers become sticky and difficult to handle in processing. Fiber lapping then becomes a problem. The effects of sugar reduce gradually as microbial action breaks down the substance, but insect excreta take longer to break down and sidelining the affected bales is then no longer a reasonable option. In man-made fiber production, the application of too high a fiber finish level can produce a similar result. Carelessness in tending the machines can sometimes result in deposits of oil or grease on the rolls; this too can produce these effects.

7.1.6 The ring spinning machine

The ring spinning machine took about two human generations to replace the mule but, by 1982, some 150 million spindles were installed throughout the world, of which 80% were used for short-staple spinning [4]. The ring frame consists of a large number of spindles. One traveler and spindle co-operate with a bobbin, to twist and wind the yarn from a drafting system as shown in Fig. 7.3(a). This sub-system is replicated several hundred-fold in a ring frame because of the low productivity of a spindle. As with the roving frame, the bottom rolls are sometimes long cylinders, extending over many spindles, articulated at intervals along the frame and connected to gearing in the headstock. There are now some very long frames of about 1000 spindles/machine, and articulation is necessary to prevent trouble from changes in floor height that might distort the whole frame and cause bearing problems. The spindles are driven by one or more tapes (thin flat belts), which engage the whorls (pulleys) that project from the bottom of the spindle. Slippage of the tapes can lead to twist losses, which vary from spindle to spindle and which, in turn, give barré and streaking problems when the yarn is assembled into finished fabric. Consequently, it is desirable to carry out periodic checks with a stroboscope to find spindles that are out of tolerance regarding synchronism. This is not a small task because the spinning area is very large and sometimes covers acres of floor space.

The ring frame is normally fed with roving from a large bobbin, and delivers yarn to a smaller one. Because of this, the roving bobbins in the creel have to be renewed less frequently than the yarn bobbins (ring tubes). When spinning a coarse count, the ring bobbins have to be doffed every few hours. This used to consume considerable amounts of labor. These days, the doffing is carried out automatically or semi-automatically and this process is referred to as autodoffing. At the time of writing, there is also some use of automatic or semi-automatic creeling in which the roving bobbins are transported to the ring frame by a rail system and the empty bobbins are automatically replaced by full ones as necessary. This further reduces the labor needed.

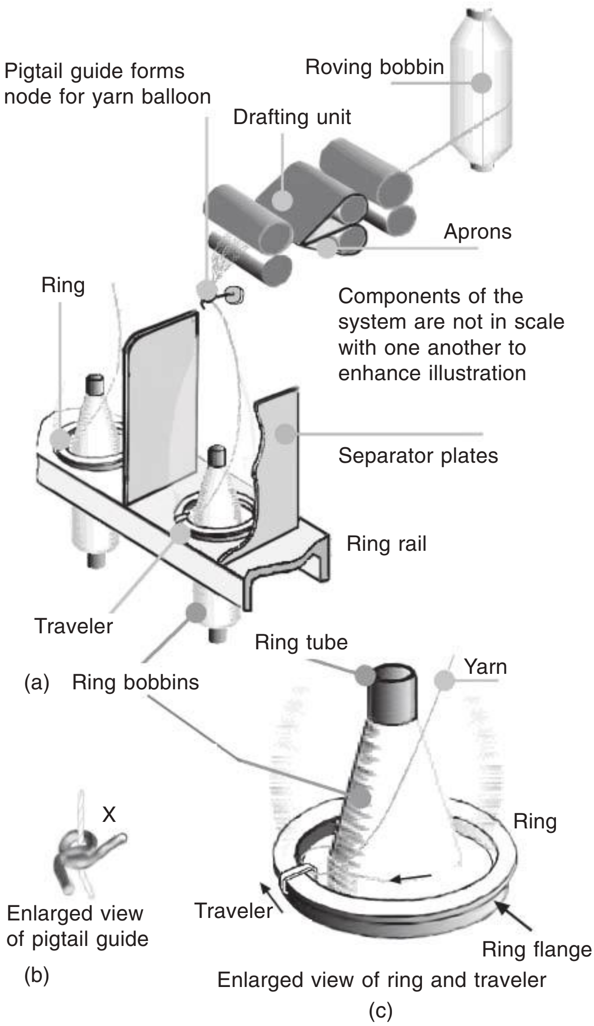

Fig. 7.3 A typical ring frame position

Typical spindle speeds for new machines in 1995 were in a range around 18 000 r/min, but new materials have been introduced, which inhibit ring and traveler wear and it now possible to raise the speeds to about 25 000 r/min. However, when spinning yarns with abrasive fibers or fibers with poorly formulated finishes, or fine yarns, speeds have to be reduced. Occasionally, two rovings are fed to each spindle ('double creeling') to even out errors by doubling, but the draft ratio is thereby increased, which also increases the errors generated by the drafting process. The result is a trade-off between improvement in long-term errors and deterioration in short-term errors. The practice is avoided by many, purely for economic reasons.

High levels of error are often obtained with high draft. However, with attention to design detail and proper settings, short- and medium-length errors can be reduced to very acceptable levels. Nevertheless, high draft also tends to increase long-term errors and to produce yarn hairiness, unless condensers are used in the main draft zone [5]. Unfortunately, the lengths of the long-term errors fall outside the ranges normally measured, and often these defects are not detected until the yarns are assembled into fabric.

Twist seeks the thin spots because of the low stiffness there; this phenomenon can give exaggerated defects in the fabric. With a good, even yarn there is little problem, but with an uneven one there may be complaints.

7.1.7 The twisting phase in ring spinning

In ring spinning, the energy to drive the twisting mechanism is derived from the bobbin, but the level of twist is controlled by the traveler. The traveler is a C-shaped piece, which slides around a flange on a ring that is set into a ring rail as shown in Fig. 7.3(a). The rotating yarn balloons out, and it is necessary to use separator plates to prevent the clash of yarns from neighboring spindles. (If the balloon gets large enough to impinge on the separator plates, the yarn becomes more hairy and the spinning efficiency is impaired.) The mass of the traveler has to be balanced against the yarn linear density, and the so-called 'traveler weight' is an important factor in determining the yarn tension. The yarn tension, in turn, is an important factor in determining balloon size as well as the end-breakage rate.

Each revolution of the traveler inserts one turn of twist into the yarn. There is a twist gradient across the pigtail guide (Fig. 7.3(b)), and some false twist caused by the yarn rolling on the internal surface of the pigtail guide. Consequently, the twist above the pigtail guide is a little less than might be expected. The bobbin rotates faster than the traveler and the trailing yarn drags the traveler behind it (Fig. 7.3(c)). The difference in speed causes the yarn to wind onto the constant speed bobbin. The yarn winds at different diameters during the build of the package and this causes slight variations in the twist insertion rate, but the differences even out over the length of the yarn.

Productivity of a ring spindle is very low. For example, a spindle producing a 4 TM, 36s yarn at 18 000 r/min and 95% efficiency delivers only 0.039 lb/hr. Consequently the machine has to contain many spindles to achieve economy of tending and workspace. These are reasons for the ring rails, which hold many rings and serve many spindles. As an aside, it might be mentioned that it is also a reason for the bottom rolls of the drafting system to cover many spindles. It is an economical arrangement that reduces the capital cost of spinning.

7.1.8 Package build

To build a yarn package, it is necessary to move the ring rail, which extends the length of the machine and carries the rings. This rail oscillates over about 2 inches (≈ 5 cm), in an asymmetrical pattern, during which the spindle rotates several hundred revolutions on, say, the upstroke and a much smaller number on the downstroke or vice versa according to the design of the machine. This short oscillation is called a chase; the term serves to distinguish it from the creeping build motion (Fig. 7.4(a)). The asymmetric building motion gives a wind structure that is stabilized by the longer yarn spirals generated on the downstroke. Each cycle of the chase creates an interlocked double conical layer of yarn on the top of the package (Fig. 7.4(b)) and this is called a weft wind. The actual number of rotations of the spindle can be set by changing the appropriate gearing. Superimposed on this motion is a slow lift, which changes the rail height sufficiently to accommodate the conical layer of yarn just

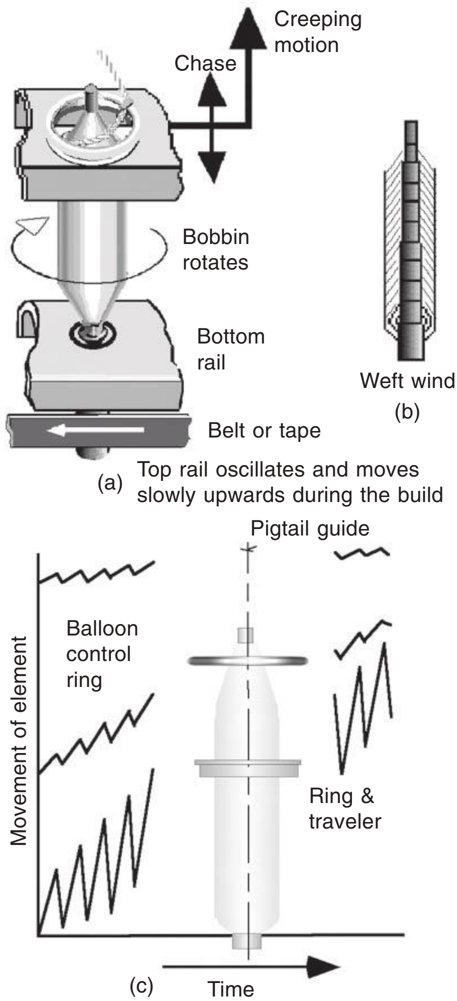

Fig. 7.4 Package building

laid. Many machines not only move the ring rail but also control the position of the balloon control ring and pigtail guide (Fig. 7.4(c)). This helps to keep the yarn tension variations within a closer band than otherwise would be the case. The tube height is about 5 ring diameters plus about 0.2 inch (5 mm) and the total lift of the ring rail is about 0.8 inch (≈ 20 mm) shorter than this. The balloon height is about 6 ring diameters and this is important because an excessively tall balloon induces a high spinning tension and increases the chance that the top of the tube will interfere with the yarn in the balloon. These circumstances are undesirable because of increased end-breakage in one case and variable yarn hairiness in the other. Some travelers create more yarn hairiness than others.

7.1.9 Ring and traveler

Travelers are shaped to accommodate the ring flanges and flowing yarn; they are normally made from small lengths of wire of a variety of cross-sections. There have been developments over the years in the profile and size of the ring flange, as well as in the corresponding traveler.[3] These developments have been aimed at increasing productivity or reducing end-breakage rates. Also, the traveler has been changed to lower the point of contact of the yarn to lessen the tilting action that leads to jamming. A sampling of typical flanges and traveler profiles is given in Fig. 7.5. Diagram (a) shows a typical shape and (b) shows a design of ring that has two flanges to permit reversal so as to provide a new wear surface when the first flange is worn; this extends the life of the ring. The SU ring shown in (c) has a conical flange that distributes the load from the traveler to lessen wear and give greater stability, but it has a tendency to be difficult to piece. Piecing refers to the repair of an end-break, which is discussed in Section 7.1.11. Special techniques have to be developed to deal with the piecing problem. All rings should be uniformly smooth and properly centered, otherwise once-per-revolution variations in yarn tension occur and the end-breakage rate is increased. Diagram (d) shows a selection of traveler wire cross-sections. Round cross-sections are used for wool and long-staple spinning, whereas flat and half-round cross-sections are used for short staple. Flat cross-sections are often used for cotton because such travelers help clean the yarn; they shave off projecting hairs, which help lubricate the ring, but produce fiber build-ups on the traveler. The half-round cross-sections are frequently used in elliptical travelers. Elliptical shapes give a lower center of gravity to the travelers, which reduce the tendency for them to tilt in operation. Some travelers are made from special wire, which more readily transfers heat from the sliding surfaces and permits high speed operation. Both rings and travelers should be run in at low speed for a period before they are used in high speed operation. In practice, it is rather onerous to run in travelers and many do not do it. Normally, no oils can be used for lubrication of the traveler, otherwise there is a risk of oil stains on the product. Crushed fiber debris is usually sufficient for lubrication; sometimes non-liquid anti-friction surfaces are used. When lubrication fails, short-lived micro-welds form, which disrupt the smooth movement of the traveler. The choice of traveler is conditioned by the type of ring flange used, as well as by the intended product and the production speed. If the machine elements are improperly

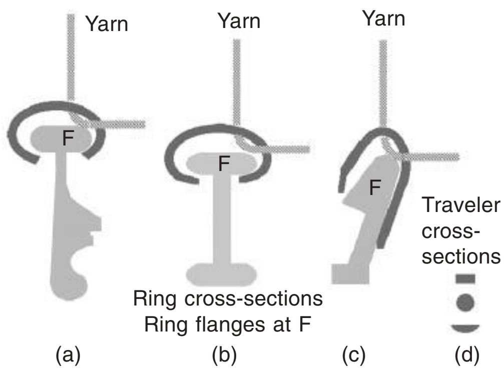

Fig. 7.5 Ring and traveler cross-sections

3 Rotating rings have been tried in attempts to overcome the sliding problem just discussed, but although productivity increases of up to 40% have been cited [6], the capital cost of the ring is increased, and the lack of simplicity has prevented the system gaining significant market penetration.

placed, or the sliding surface on the ring becomes damaged by rust or micro-welds, the defect is reflected in a periodic variation in yarn tension.

An eccentric spindle also produces variations. Since the probability of an end-break is greatest at the peaks of yarn tension, it is the maximum tensions that matter rather than the average. Thus, reductions in the deviations from the normal are important in minimizing the end-breakage rates. The efficient running of a mill depends, in part, on ensuring that the rings are well maintained and that the correct travelers are used.

The foregoing implies that the traveler must be changed when the yarn count is altered and sometimes when the fiber is changed. If the traveler is too heavy, or the spindle too fast, the load between the tiny traveler and the ring flange becomes sufficiently high to cause excessive wear or burns. Travelers wear and have to be changed frequently. Consequently, not only must the correct traveler be chosen for the job but also the traveler changes have to be scheduled on a regular basis. Burned and worn travelers can fly off and eye protection is advisable in the ring room. Attempts to run the traveler too fast not only cause the contact area of the traveler to burn, but also cause the yarn to be damaged.

Speed is limited by the traveler, which, in short-staple spinning, is rarely lubricated with oils. Even if the travelers are nickel plated or otherwise treated, they can only slide up to between 100 and 150 ft/sec (30–46 m/sec) during their short working lives. The precise speed depends on the ring diameter, smoothness of the ring surface, yarn tension, and the traveler weight and design. The ring surface must not be polished since a suitable micro-structure of the surface is needed. The life of a traveler is very short and is measured in days of running time. The combination of the various forces acting on a running traveler causes it to tilt and this affects performance. According to Klein [2], normal running pressure between the traveler and ring is 35 N/mm^2; consequently the ring has to have a hard, smooth (but not polished) surface and the traveler has to have a less hard running surface so that there is sacrificial wear on the cheaper traveler. As mentioned, it is good practice to ‘run in’ new rings to produce a viable surface. This entails running at reduced loads and speeds for some hours before resuming normal operational conditions.

It can be calculated that the speed of winding on the ring frame is only a very small percentage of the spindle speed, which is fortunate because the spindle speed is fixed and it is the traveler that controls the twist insertion rate.[4] Some calculations in this regard are given in Appendices 1 and 2. As the bobbin diameter changes, so a very small variation in twist occurs. When the bobbin diameter builds from (say) 1 inch (≈ 25 mm) to 1.75 inch (≈ 44 mm), the traveler speed might vary from 15 950 to 15 900 r/min, a difference of about 0.3%, which is negligibly small as far as twist is concerned.

The outside diameter of the yarn on the package must be less than the ring size. The diameter of the empty tube onto which the yarn will be wound has a minimum size of at least 45% of the ring size, otherwise excessive yarn tensions would be generated. The density of the yarn is approximately fixed. As mentioned earlier, the length of the package is limited to about 5 ring diameters. This limits the changes in yarn tension caused by increases in balloon height. Since practically the whole bobbin has to fit inside the balloon at some time or other, the length of the package has to be limited and therefore the mass of yarn that can be stored on a ring tube is often limited to just a few ounces (1 oz ≈ 28 g).

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4 It is not correct to say that the traveler puts in the twist; the energy derives from the spindle.

Forces acting on the yarn passing through the traveler, and forces acting on the traveler, have to be in equilibrium. There is an important balancing mechanism provided by the traveler. The forces acting can be classified as (a) those coming from the yarn, (b) centrifugal force acting on the traveler, (c) frictional force acting on the traveler, and (d) the reaction component between traveler and ring, acting normal to the ring. The resultant of force components (a), (b), and (c) is balanced by the reaction force (d). Part of the centrifugal force acting on the traveler is absorbed by the ring at the point of the sliding contact, and part applies tension to the yarn entering and leaving the traveler. The very important balance between these two parts is affected by the angles that the yarn and traveler adopt under the given running conditions. The balance changes with the ring rail position and so do the forces (and tensions) involved. The tension averaged over, say, one second, changes with the geometry of the system. There is a variation that more or less follows the movement of the ring rail. During the chase, however, the tension is not in exact synchronization with the rail position because the winding point on the bobbin lags behind the recent movement of the rail. In the main, the yarn tensions are at a maximum when the rail is near the top of its chase but near the beginning of the build. Some machines control the spindle speed according to the position of the ring rail, to restrain the yarn tension [7].

If the yarn tension is too high, the probability of an end-break increases. The practical way of adjusting the yarn tension in mill practice is to alter the traveler weight and type according to the yarn being spun. Changes in traveler weight and design affect yarn hairiness, but there is some dispute as to the extent [8]. The traveler weight also affects the yarn package density. Too light a traveler can produce an undesirably soft yarn package with poor yarn storage capability, but what is more important, it can shift the operational condition to a zone of instability when a bobbin is in the early stages of build. The balloon collapse associated with the instability leads to end-breaks. The complex subject of ballooning is considered in Appendix 9. The traveler weight is selected on the basis of the yarn count and traveler type. Travelers are described commercially by numbers in both the direct and indirect systems of counting; for example, they are often quoted in grains per 10 travelers but they might be quoted in the number of travelers per unit mass. However, it is helpful to use a traveler mass unit related to the linear density of the yarn instead. In that case, recommended traveler weights range from 2.6 mg/tex for high yarn counts to 3 mg/tex for counts in the range of 20 to 30 tex. The values given are subject to adjustment for the type of traveler in use and the spindle speed.

7.1.10 Spindle eccentricity

Lünenschloss *et al.* [9] showed that eccentric spindles can produce increases in hairiness of the yarn as well as influence its strength and elongation. This was especially true at high eccentricities. With a 20 tex, 65/35 polyester/cotton yarn, the hairiness changed from about 1000/m to 1700/m at a spindle eccentricity of 2.5 mm. With combed cotton, the change at the same eccentricity was from about 500/m to 700/m. Apart from its effect on the yarn, the life of an eccentric spindle is shorter than that of one that runs true; also, the noise level is worse. An eccentric spindle, or a displaced guide or ring, can increase the end-breakage markedly because of the once-per-revolution cycle of tensions produced; this has important economic repercussions. (Note: 407/yd ≈ 500/m, 640/yd ≈ 700/m, 914/yd ≈ 1000/m, 1550/yd ≈ 1700/m, 0.1 inch ≈ 2.5 mm, 20 tex ≈ 30 cotton hank/lb (N_e.)

7.1.11 Dealing with end-breaks

End-breaks cause a loss in production because the spindle produces no yarn after an end-break until it is repaired. An operator may serve up to several thousand spindles in modern plants and it is unavoidable that, on occasions, an end-break will cause a delay of perhaps twenty minutes or even longer before a repair is made. If an end-break were to occur every hour on every spindle, the production efficiency would be terrible; even if it occurred once a day, there would still be a significant production loss. An end-break has to be a rare event if reasonable production efficiencies are to be maintained.

When an end breaks, normally the textile fiber keeps flowing and is sucked away by a pneumafil or waste fiber suction system. To manually repair the breakage, the operator has to retrieve the end from the bobbin, thread it through the traveler, balloon control ring (if one is fitted), and the pigtail guide before inserting it into the nip of the front drafting roll. With an experienced operator, this takes only a second or so, but the time spent in patrolling to find the end-break is quite another matter. Machines, or attachments to the ring spinning machine, can simulate the action, but the capital cost is high.

It is also possible to interrupt the roving supply (known as a 'roving stop' system) to prevent wastage and choking. The complexity of the roving stop results in an initial cost that amounts to a significant sum because of the thousands of spindles involved, but it does reduce the fiber loss significantly and it improves yarn quality as a consequence. Because of the capital costs involved with the roving stop system, most users prefer the conventional method but it involves the expense of dealing with about a 2% fiber loss.

Waste fiber can be recycled, but only with care because it does not spin well. It has to be mixed and diluted with virgin fiber. In spinning, there is always some fiber loss from the twist triangle zone and suction is always required to remove the waste. When an end breaks, the amount of waste increases. Over all the spinning frames, there is a level of waste that is dependent on the mean end-breakage rate and beyond a certain level it becomes difficult to absorb the wastage without deterioration of the mill performance or the quality of the product.

7.1.12 Ring frame limitations

As already mentioned, the ring size is limited on the large side because of traveler burns at normal production speeds, but, on the other hand, the ring cannot be too small, otherwise the bobbins would hold so little yarn that the cost of changing bobbins would be prohibitive. One of the limitations of the ring frame is the traveler speed. With non-rotating steel rings and steel travelers, the linear speed is limited to about 100 ft/sec ($\approx$ 30 m/sec). The limit arises because the poorly lubricated traveler makes micro-welds with the surface of the ring, which are immediately broken as the traveler goes on its way. This creates incremental damage to the surface of the ring, which still endures over the life of many, many travelers. However, the roughening of the ring surface also progressively shortens the life of travelers. One solution is to use ceramic materials for the rings to minimize the damage.

For a frame to run at a higher speed, the ring diameter has to be smaller and clearly there is a limit to how small the ring can be. The volume of yarn on the package is less than $\rho(\pi/4)(D_1^2 - D_2^2)L$, where D_1 is the outside diameter of the package which must be less then D_r, the ring inside diameter, D_2 is the diameter of the bobbin, and

L is the length of the bobbin covered with yarn. D_1 must come as close to D_r as practicable and the corresponding mass needs to be as large as the limitations in ring geometry will permit. Currently the ring sizes for short-staple spinning vary from 1.4 to 2.1 inches (≈ 36 to 53 mm) inside diameter and they use several sizes of flange varying from 0.125 to 0.16 inches (≈ 3.2 to 4.1 mm). Smaller rings mean not only that the mass of yarn that can be stored is reduced but that the frames have to be doffed more frequently. With automatic doffing and good splicing this is of less importance than formerly. However, doffing still takes time from production and the smaller the ring, the lower the spinning efficiency (but only incrementally so). An offsetting factor can be that smaller rings mounted on a machine that is designed to take them, reduces the capital cost.

Another limit is reached when spinning medium to fine counts of highly twisted cotton and blend yarns, in which case the speed has to be reduced to suit the prevailing conditions. The heat dissipation at the traveler is approximately proportional to the third power of spindle speed and the traveler has to be able to dissipate the heat generated by conduction or radiation. When the lubrication breaks down, the safe temperature limits of either the yarn or traveler might be exceeded. In the one case there are molecular changes to the polymer structure, or even surface melts of the fiber. In the other case, the metal structure changes; the metal changes color and eventually breaks. One solution is to run with a lighter traveler but if this is carried too far, the balloon collapses and there are ends down as a result. Of course the speed can always be reduced but that begs the question because we look to higher speeds to improve economic performance.

Yarn tensions are also responsible for a good portion of the excess end-breaks in spinning and this is why attention is focused by some on the ballooning mechanics (see Appendix 9). Figure 7.6 gives an example of tension variations in which the black line is the running average over a 0.2 second interval and the light gray points are the variations from this running mean [10]. The running average shows the variation caused by movements of the ring rail, with some superimposed variations due to changes in linear density. When the tension variations exceed a level indicated by *xx*, the tensions become high enough to pose a risk of breakage. The probability of an end-break is determined by the statistical distributions of yarn strength and tension. The height of the line *xx* is influenced by the strength of the weakest links in the yarn being spun. The points at risk are shown as small black crosses and the number of these should be rare if there is to be reasonable spinning efficiency. Klein [2] reports that the majority of end-breaks occur as the ring rail approaches its topmost position in the chase, rather than on the downstroke.

7.1.13 Mill balance

Returning to the question of productivity, let us establish a range. Compare the productivities per spindle when making 81s and 9s yarn, both with a TM of 4.0. The first is a fine yarn and the second is a coarse one.

Assuming the spindle speed to be 18 000 r/min and the efficiency to be 95%, the productivities are 0.012 and 0.314 lb/hr respectively (using the formulae in Appendix A1.5.1). Considering that a mill might produce, say, 20 tons/day (1867 lb/hr), at least 155 000 and 6 000 spindles, respectively, would be required. The way in which productivities alter with average count leads to an operational difficulty. Suppose the mill had been set up to produce 36s. The number of spindles required would have

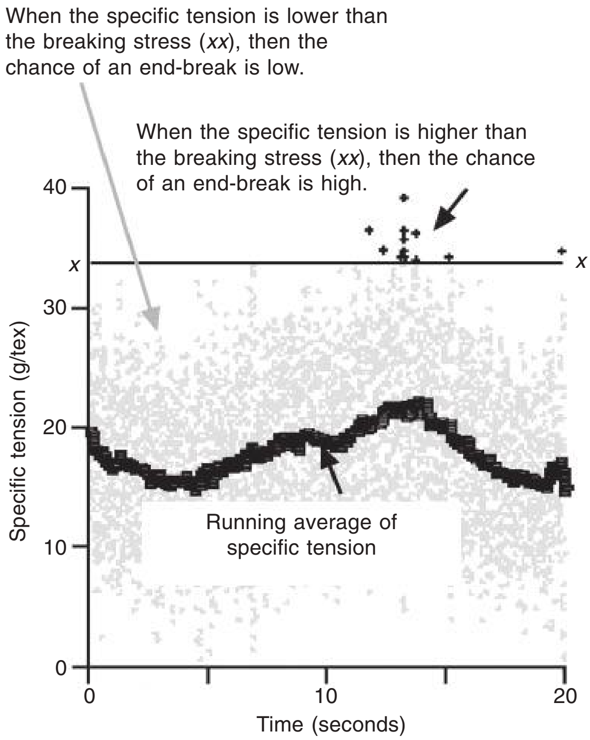

Fig. 7.6 Yarn tension in spinning

been about 48 000. If a heavier yarn such as the 9s were substituted, there would be 42 000 excess spindles, whereas, if the very fine 81s were substituted, there would be a shortfall of 107 000. In this exaggerated first case, over 87% of the ring frames would be shut down with an accompanying loss of employment for the operators. In the second case, also exaggerated, the mill would be capable of supplying only 30% of the requirement from production. The figures are exaggerated to make the point; normally the average count is kept reasonably near the design value. It is very expensive to change the so-called balance of the mill, once it has been set up.

7.1.14 Automation in ring spinning

At this stage, automation from sliver through to yarn will be discussed. Sliver handling is automated to different degrees according to circumstances. Nearly all modern cards and drawframes have automatic doffing. Some mills use automated guided vehicles (AGVs) to marshal the cans in the creels of the following machines. In rotor spinning, this segment of the costs plays a larger proportionate role than it does in ring spinning.

With roving, the usual solution is to use an overhead rail system with the bobbins suspended from carriers. In many of the systems, the transport system carries the bobbins from station to station, passing occupied positions and making exchanges for an empty bobbin where a full one is needed. There is a risk with this system that a few bobbins might circulate for a long time before they find a home. Periodic checks for such ‘joy riders’ prevent difficulties. With roving, it is necessary to control the loose ends during transport and this is normally accomplished by making a wrap of the end in a secure place before doffing. The use of AGVs is also possible.

Mechanical piecers have been introduced from time to time. They work well but they have not become established. There is a feeling that there is still a need for patrolling operators to clean, check on performance, and perform other duties.

Automatic ring frame doffing has been widely accepted and the most common system involves rails that reach from end to end of the frame. These rails are designed to carry the full bobbins during the doff, and the empty ones during the replenishment phase. The doffer rail carries apertures for each spindle and each spindle is equipped with a grasping device. The grasping device is often an inflatable cuff which fits over the bobbin and grasps it. The purpose is to lift the full bobbin from the spindle without damaging the yarn. Two series of pegs are mounted on a belt running the length of the machine. One series of pegs carries empty bobbins which have been mounted before the start of the doffing sequence. The ring frame is stopped automatically when the bobbins are full, then: (a) the ring rail is lifted clear after the ends of yarn have been trapped at the base of the spindle; (b) the doffing rail is dropped over the full bobbins; (c) the grasping devices are activated and the rail is used to lift the full bobbins from the spindles; (d) the full bobbins are deposited on the vacant pegs on the belt just mentioned; (e) the doffing rail then picks up the empty bobbins from the belt; and (f) the rail deposits these empty bobbins on the empty spindles. On start-up, the yarns should still be threaded through the travelers and the rotating bobbins should catch the yarn and start spinning automatically. In practice, a few ends fail to catch and have to be pieced manually. Thereafter, the belt moves towards the end of the spinning machine and the full bobbins are either removed or continue on to the winder. When the bobbins are transported directly from the autodoffer to the winder without human intervention, it is known as 'linked spinning'.

Clearly, some sort of quality control is needed because deformed or improperly filled bobbins are unlikely to unwind properly and it is best to discard them. The defects would be difficult to trace if not caught before winding. Consequently, the bobbins are gauged at the exit from the spinning machine and faulty ones are rejected. Looking to the future, monitors could be fitted to keep track of the number of end-breakages and other performance data. The cost of these monitors is high and few mills are willing to invest in them until there is a more assured way of translating the large volumes of data they provide into an effective control system, capable of yielding an economic gain. So far, the complex factors and interactions in the process are not well enough understood to permit accurate prediction of the outcomes.

7.2 Open-end spinning

7.2.1 Basic principles

The basis of open-end (OE) spinning is that fibers are added to an 'open-end' of a yarn, as indicated in Section 3.4.1. Twist applied to the newly added fibers converts them into yarn and the new elements of yarn are continuously removed from the twisting zone. The theoretical advantages of such a system are: (a) it is easier to rotate the small open-end of the yarn than it is to rotate a whole yarn package as in the case of ring spinning; and (b) the twisting and winding can be separated. The first point implies a tremendous potential for increased productivity and the second point means that the package size is limited only by the design of the winder, which leads to greatly reduced handling costs.

To produce an open-end, it is necessary to use a very high draft so that the fiber flow is reduced to just a few fibers in the cross-section. This prevents twist from running back into the fiber supply to produce false twist, which would defeat the object of the exercise. The technology has developed to the point where OE machines are fed with sliver and this eliminates the roving frame. A sliver might have (say) 20 000 fibers in the cross-section, and, if the fiber flux just before the open-end is as low as (say) 2, the initial draft would then be 10 000:1. It is not possible to use roller drafting alone to produce this sort of draft at the speeds required. Rather, it is more normal to use a toothed roller, which acts in much the same way as a licker-in in a card. The emerging yarn might have several hundred fibers in the cross-section and thus there has to be a condensation of fibers leaving the open-end. It follows that the essential phases in the spinning operations are as shown in bold font:

1 **Drafting**.
2 Fiber transport.
3 Fiber alignment etc.
4 Cleaning (if necessary).
5 Fiber **condensation**.
6 **Twisting**.
7 Yarn removal.
8 **Winding**.

In practice there have to be some intermediate phases as well and these are also listed.

7.2.2 Open-end systems

There are many embodiments of the basic idea of OE spinning and, although only one (rotor spinning) has taken a large market share, it is worthwhile to mention briefly a number of the other contenders.

The early mechanical systems of the nineteenth and twentieth centuries were too cumbersome to work at high speeds. Generally, it was the invention of the mechanical/pneumatic systems that led to workable prototypes, which had a chance of commercial development. An early variety of OE spinning used an air vortex device. Another variety was friction spinning, but although this reached industrial production, the fine yarn version did not develop fully due to lack of yarn strength and other problems. Friction spinning for coarse yarns and core spinning did become established for a segment of the market. One successful form of friction spinning was the DREF machine in which fibers are 'rolled' into yarn by a pair of condenser rollers as sketched in Fig. 7.7.

Rotor spinning itself is now well established. In the early days, a rotor was easy to piece up at the, then, low speeds, but it produced a yarn that was some 20% weaker than ring yarn. Because the yarn was acceptable for some uses, and because of the economy of operation, rotor spinning established a foothold despite these difficulties. A further disincentive was the high capital cost component of yarn produced; it could only be made to pay its way if low count yarns were made. Thus, there was pressure to increase the count range spinnable, by increasing the operating speed. The first commercial machines operated at 30 000 r/min, but, by the mid-1990s, speeds of 120 000 r/min were possible. Productivity raced ahead of capital costs to the point

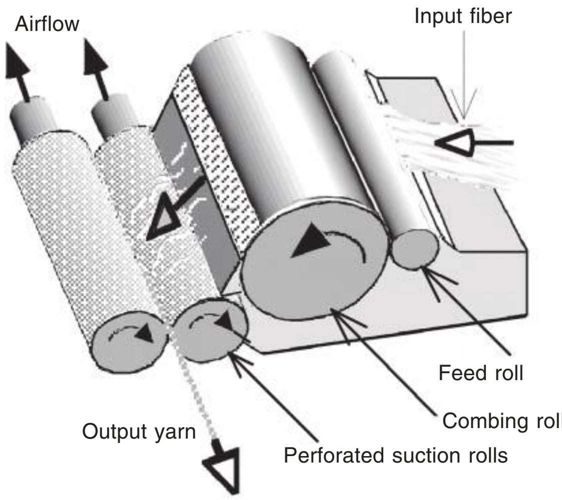

Fig. 7.7 Friction spinning

that the break-even count, discussed so much in the 1970s, was no longer an issue. That is not to say that the capital cost did not go up. For example, it was found that manual piecing was impractical at the high speeds now established; automatic piecers had to be designed and manufactured. Such further developments have a considerable cost that has to be passed on to the machine buyer in the form of higher absolute capital cost. Nevertheless, the capital cost of the machine/lb of yarn produced was reduced.

7.2.3 Rotor spinning

Rotor-type OE spinning was first used commercially in 1969 [11], but by 1995 it was a major part of the US yarn spinning capacity and had found widespread use elsewhere. At the beginning of the development, rotor spinning was offered for both short- and long-staple spinning but long-staple rotor spinning did not become established. Further discussion will be limited to short-staple rotor-type OE spinning.

7.2.4 Drafting in rotor spinning

It is possible to combine a rotor with a combing roll drafting system to make a spinning machine, so let us consider the drafting system before explaining the functions of the rotor. The combing roll drafts fibers in much the same way as does a licker-in of a card. Fibers are detached from a beard presented by a feed roll, as shown in Fig. 7.8(a); the detached fibers pass into the rotor at much higher speeds than the advance of the beard and thus there is a drafting action. To sustain the high exit fiber speeds, an adequate airstream is needed to carry the fiber forward in a sufficiently opened state to prevent twist from running back to the drafting system. If one required the ideal exit fiber flux of unity, the draft ratio in the combing roll would be equal to the number of fibers in the cross-section of the sliver feed and that could number tens of thousands. In practical terms, the fiber flux is usually greater than unity, but the value cannot be very high or the system would not work; draft ratios at the combing roll are usually measured in thousands. The fiber flow is later condensed inside the rotor as

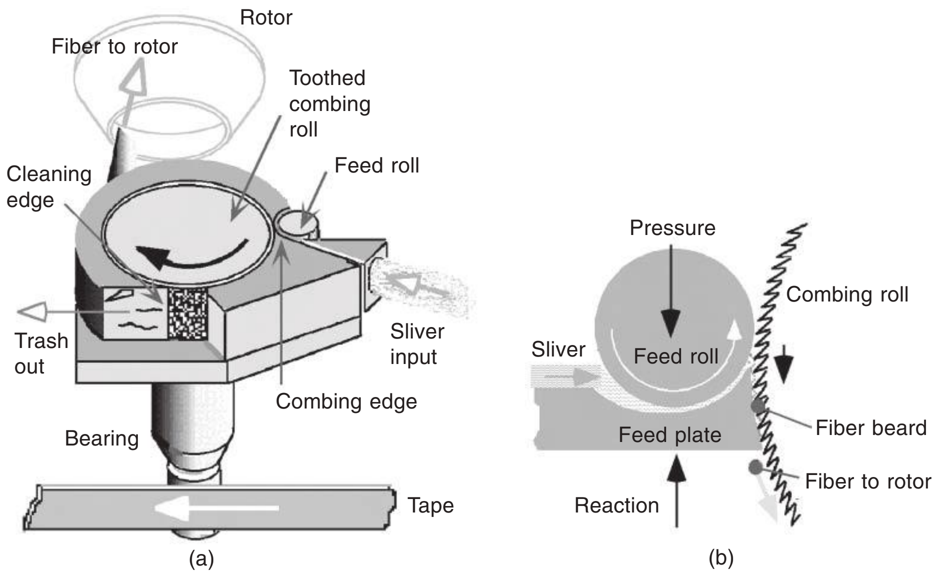

Fig. 7.8 Rotor spinning drafting system

a precursor to yarn. The overall draft ratio is that calculated from the ratio of linear densities of input sliver and output yarn, measured in compatible units; it is the mathematical product of the draft at the combing roll and the fractional draft (i.e. condensation) in the rotor.

Various feed systems are possible, but the one that has become established is the roll and table type shown in Fig. 7.8(b). Sliver is gripped between the slowly moving feed roll and a stationary plate; the passageway reduces in size to increase the pressure at the point where the fiber beard is formed. The action of the teeth of the combing roll on the fringe removes fibers; these fibers are then discharged into the rotor where the precursor to the yarn is formed.

The combing roll can be clothed with needles or saw-toothed wire but the latter has established itself firmly in the market. Hunter [12] notes in his survey that many find the pins superior to wire for opening capability and wear; he cites up to 60 000 hours' life when spinning cotton. However, hardened and ground card wire with a surface of diamond dust embedded in nickel has been developed since then [13]. Other sharp edges prone to damage are similarly treated with wear-resistant materials. Siersch [14] found that there were advantages to spirally wound saw-toothed clothing because the helix angle of the wire causes successive teeth to penetrate the beard in positions that move across the beard as the roll rotates, and this gives a good distribution of fiber separation. He found that saw-toothed wire gave lower CVs in the yarn than did comparable needle arrangements. Wire-wound clothing is recommended for cotton and cotton blends running at high throughputs, whereas pinned combing rolls are recommended for fragile fibers such as acrylics and rayon running at moderate output rates. The force acting on the fiber beard increases ever more rapidly as fiber length is increased; beyond a certain level, fiber breakage then becomes a problem. Thus, the device is best suited for short-staple fiber. The fibers can disengage the teeth soon after leaving the combing zone and travel along the inside periphery of the combing roll housing at a velocity lower than the surface speed of the combing roll [15] (the housing is shaped to allow for the fiber flow). Friction between the housing and the fiber slows the fiber until it reaches the duct that carries it to the rotor. An airstream is generated by the suction in the rotor, which accelerates the fibers and straightens them somewhat. Lünenschloss [16] states that the fiber velocity at the exit of the transfer duct is determined primarily by the negative air pressure inside the rotor (i.e. suction). Without an adequate airstream, the fibers relax, become disorientated, and tend to clump together.

It is desirable for the feed material being presented to the combing roll to be as free from hooks and tangles as possible, in order to reduce fiber damage. However, it is difficult to keep the entering fibers aligned as they are manipulated by the combing roll. Stalder [17] has shown photographs illustrating how a single fiber can lie across several rows of combing roll teeth before it is carried away into the rotor. Lawrence and Chen [15] showed that short fibers were removed, and that longer fibers abraded the edge of the feed channel.

Combing roll speed affects the yarn hairiness [18, 19] and can affect nep production. Too high an overall draft ratio can give high end-breakage rates but good trash removal; values in the order of magnitude of 100 are usually satisfactory. For cotton, the sliver weight depends on the sliver preparation and the yarn count, but common sliver weights vary between 50 and 70 grains/yd (≈ 3.5 to 5 g/m); for man-made fibers, the slivers should be about 25% lighter than with these.

Fiber orientation in the sliver feed channel is important in terms of yarn tenacity and evenness. For coarse yarns in which yarn strength is not very important, it is sometimes possible to use card sliver as the input to the open-end spinning machine. For such carded yarn, performance is enhanced if the sliver is drawn in the carding machine. Otherwise it is normal to use drawn sliver. Occasionally, combed sliver is used. Another way to lessen fiber damage is to reduce the number of fibers in the fringe being combed by the combing roll, and this is achieved by using a lighter sliver, which adds to the cost of production. This can be offset against the advantages of rotor spinning. Fine combed sliver is difficult to handle.

7.2.5 Combing roll performance

The cleanliness of cotton feedstock depends upon the degree of cleaning at the gin, opening, and carding. Cotton fiber ends tend to be damaged by the combing roll and at higher combing roll speeds there is fiber breakage. The combing roll speed is an important factor in this respect and this speed also affects the cleaning capability of the combing roll system (Fig. 7.9). A cleaning edge separates most of the trash before it can enter the rotor but it is difficult to remove all the dust (but often, when spinning man-made fibers, no cleaning edge is used). Separated trash passes to a 'dirt box', which is emptied periodically. Even when spinning man-made fibers, fiber breakage

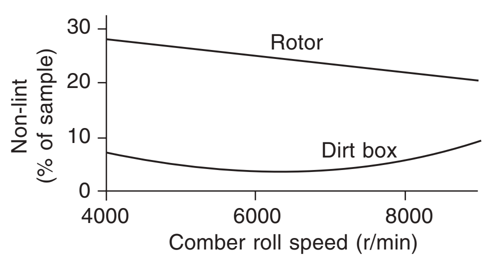

Fig. 7.9 Trash extraction

and the deposition of debris in the rotor is not eliminated. Polyester fiber finish, fiber debris, and oligomers are stripped from the fiber in passing through the combing roll and are then deposited in the rotor. Naturally, weak fibers are liable to breakage, but also damaged fibers have a tendency to pill. An optimum comber roll speed needs to be established for each product to give the best compromise between productivity and product quality. The clearance between the comber roll flanks and the casing should be strictly controlled [20], otherwise airflow can cause fibers to become trapped and jam the roll.

Unfortunately, dust and particles tend to be deposited unevenly, particularly if large particles enter the rotor. Uneven deposits cause periodic unevenness in the yarn and produce unacceptable moiré patterning in the fabric made therefrom. As trash builds up, the quality of the yarn suffers and drifts lower as time elapses; when the rotor is cleaned there is a sharp improvement. Changes in evenness, appearance, and strength are caused by these cycles of rotor fouling and cleaning. They pose significant quality problems unless controlled. This circumstance has sparked the development of automatic rotor cleaning, which, in turn, requires automatic piecing to be effective.

Cotton fibers can be worked at high speeds but man-made fibers are usually worked at lower speeds. The shape of the comber roll teeth is important because an aggressively forward-raked tooth, such as is used with cotton, can be seriously eroded by wear. This is especially true if it is used with dusty cotton or certain man-made fibers. Dusty cotton is sometimes found after particularly dry growing seasons. Improper or damaged wire can also produce neps, which can give serious quality control problems. Also, abrasive materials from fiber finishes, fiber debris, and silica dust from dusty cotton can cause excessive wear. Sharp edges (such as those at A and B in the line of fiber flow, Fig. 7.10(a)) and combing roll teeth (Fig. 7.10(b)) are subject to damage. It is desirable to avoid such finishes and fibers but, where this is not possible, the combing roll speeds, the sliver weight, and the rotor speed should be kept low.

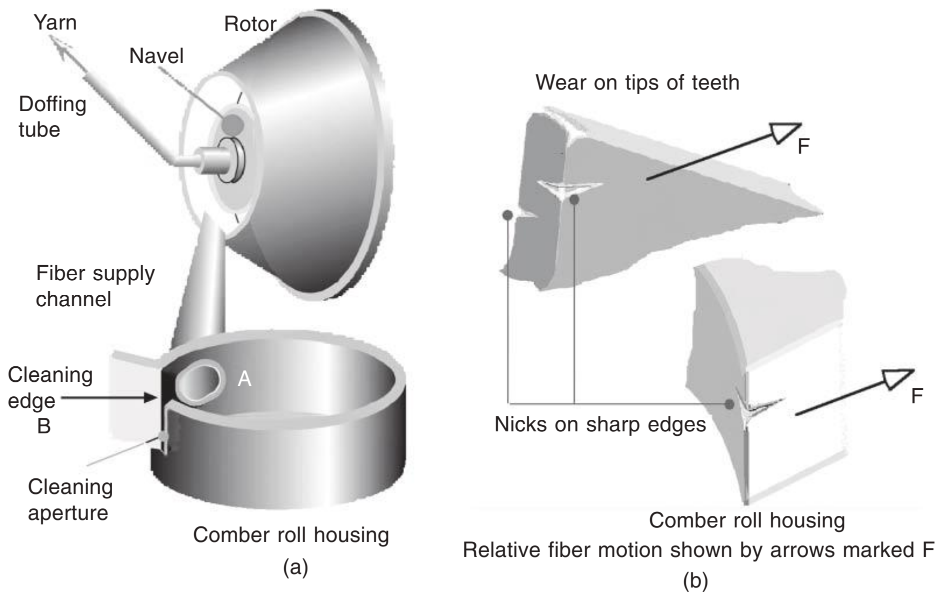

Fig. 7.10 Comber roll wear

Lawrence and Chen [15] describe how short fibers tend to be thrown out of the trash escape aperture while longer fibers are retained for a little more time on the combing roll wire. The suction applied to the rotor removes the fibers from the combing roll teeth but the fibers drag over edge B as they pass into the rotor. This causes wear; both edges A and B have to be reinforced with especially hard material. The fibers become damaged at these points also, with the result that dust and nep are sucked into the rotor. Not surprisingly, the extent of trash separated by the combing roll varies with the state of cleanliness of the sliver supplied as well as with the speed and design of the roll. Rotor machines do not necessarily have such cleaning devices. Machines without trash removal are more suitable for spinning man-made fibers, but there is still a build-up of debris in the rotor due to the accumulations of fiber finish and fiber debris. In all cases, the debris in the rotor causes a deterioration in the yarn characteristics so it is important that the rotors be cleaned periodically. The length of the period between cleaning depends on the type of fiber being spun as well as the speed and type of spinning machine concerned. The combing roll speed is particularly important in this respect. A 3 inch (≈ 76 mm) combing roll normally runs between 5000 and 8000 r/min; the higher the speed, the more fiber damage ensues and the more debris is deposited in the rotor. However, the higher combing roll speeds tend to give better trash separation. Trash build-up causes a gradual deterioration in yarn quality. In particular, yarn hairiness, nep, unevenness, and other fault rates increase. Barella [19] and many others found that regular cleaning of the rotor is required to preserve yarn quality.

Choking of the feed mechanism must be avoided. If too heavy a sliver is fed, or if the end inserted into the feed roll nip is doubled, it might overload the combing roll, causing it to jam. During running, badly stored sliver in the feed can cause a loop of sliver to be lifted from the can and to be fed into the drafting system. This produces a similar unfortunate effect. If such choking is allowed to persist and the machine continues to run for a long time, the whorl becomes overheated and so does the surface of the drive belt. The result is that the contact surface of the belt becomes glazed, causing slippage in all the combing rolls in the set. Such slippage might be uneven in time and from combing roll to combing roll. This has an adverse effect on yarn quality. Over long periods of time, overheating the combing roll assembly can cause the grease in the bearings to harden and add to the difficulties by causing some combing rolls to slip. Therefore, associated with choking is the possibility of bearing damage. Combing roll bearings with race tracks indented by the balls have been detected. Such damage increases the power requirements and increases the noise level in an operating machine. An increase in power demanded by a comber roll assembly increases the risk of slippage and of deterioration in yarn quality.

Most combing rolls are driven from a single tape or belt. Auxiliary pulleys, spaced along the belt, control the path taken by it and apply the necessary force between it and the whorls at the bottom of each drive shaft. These arrangements are discussed in Section 7.2.8.

Increases in combing roll speed are often associated with increased output. However, high combing roll speed and point populations can increase fiber breakage and lead to increased end-breakages in spinning, as well as a reduction in yarn strength. Some experimentation by the user is called for, to find the best compromise between machine productivity and quality for the particular product. An exceedingly high machine productivity does not necessarily produce the best financial return. Some trend curves for combing roll performance when spinning cotton are shown in Fig. 7.11.

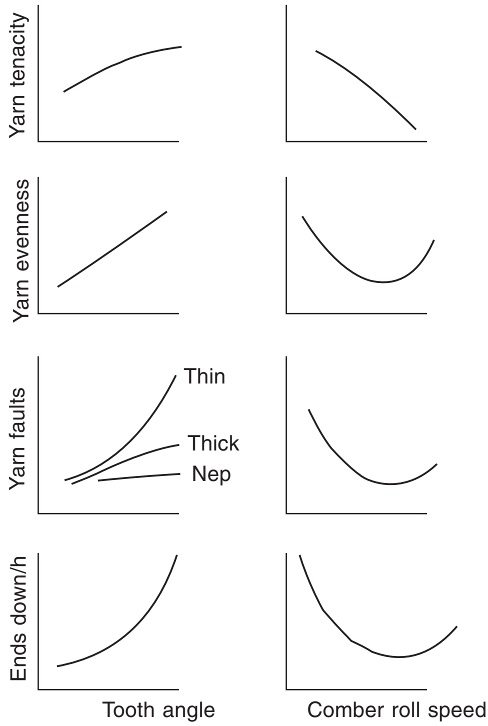

Fig. 7.11 Trend curves for a comber roll performance

7.2.6 Fiber flow into the rotor

Most machines will spin cotton or short-staple synthetic fibers. The trash in cotton is deposited in the rotor at a fairly rapid pace unless it is removed before entry into the rotor and it is difficult to remove all this trash by conventional means. Consequently some rotor machines have a cleaning edge or cleaning aperture built into the combing roll housing, as shown in Fig. 7.10. However, it is still of very great importance to clean the fibers well in the opening and carding operations, otherwise the deposition of dust in the rotor becomes a very severe problem with important economic consequences.

Fibers flow from the combing roll through a fiber transport channel and are assembled in the rotor, where yarn is formed. Fibers must be completely removed from the combing roll and be transported to the rotor without being crumpled, disoriented, or clumped together. This means that an airflow velocity exceeding that of the surface of the combing roll must be used. To get such an airflow, it is necessary to run the inside of the rotor at a vacuum of several inches of water.[5] Today, the practice is to use an external fan. The inside of the rotor gets hot and the fan fulfills the purpose not only of inhaling the fibers into the rotor but also of removing hot dusty air from it. The high temperature reduces the rh of the air inside the rotor and levels as low as 20% have been recorded. It is necessary to properly condition the input sliver. The ratio of air speed to that of the surface speed of the combing roll should be 1.5 to 2. (Some authorities suggest 1.5–4.) This is to ensure that the fibers are doffed properly; too high an airflow can increase fiber waste.

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5 An inch of water denotes a difference of air pressure equal to about 1/400 of an atmosphere.

The disposition of the transfer channel or duct with respect to the combing roll is important. Lawrence and Chen [15] showed that short fibers are thrown from the combing roll at the transfer duct opening, and travel along the tube with what was the leading end still leading. Longer fibers are dragged by the combing roll teeth over the edge between the combing roll and the transfer duct, and then they are aspirated into the duct with their erstwhile trailing end now leading. The hooked fibers entering the transfer duct have a shorter fiber extent than if they were straight and, if such fibers remain hooked or convoluted in the yarn produced, they reduce the strength of the yarn. Thus it is desirable that some fiber straightening mechanism be employed. For this reason it is common practice to use a tapered duct that accelerates the flow of air and fiber as it approaches the duct exit. This tends to straighten the fibers; however, observation of photographs shows that the acceleration is insufficient to remove all the hooks and other fiber deformations in the transit stage. Fortunately, provided the suction is not too strong, the surface of the rotor that first contacts the fibers emerging from the transfer duct will be moving faster than the fibers. This sliding contact tends to straighten the fibers [21] although they are rarely, if ever, completely straightened and parallel at this point. The speed of a fiber as it enters the rotor should be about 80% of that of the metal surface on which it lands; the transitional draft at that point should be between 1.25 and 1.4.

Fibers entering the rotor are deposited on the internal sliding wall (Fig. 7.12(a)) and move on this surface to the rotor groove, where they collect to make the fiber ring. Figure 7.12(b) shows the sliding path,[6] which is approximately fixed in space with the rotor moving relative to it. Except in zones where the fibers sliding up the inside of the conical portion of the rotor interfere with the outgoing yarn, fibers are usually laid in the rotor groove in an amazingly parallel, straightened fashion. The sliding wall is part of the transit system; surfaces must be well designed and they must be kept clean. Fortunately, the movement of the fiber cleans the surface.

It must be realized that the yarn rotates at high speed with respect to the sides of the rotor groove; centrifugal force presses the rotating yarn into the groove. Furthermore, the wedge action of the acute vee of the groove causes the centrifugal force to be magnified. Any abrasive particles that might be present then heighten the 'lapping' or abrasive action of the rotating yarn. For this reason, the inside surfaces of the rotor are treated to resist wear. Steel alloy rotors have been developed and it is now standard practice to diamond coat the surfaces. The condition of the inside of the rotors is of great importance.

Yarn is removed through a doffing tube.

7.2.7 Twist in rotor spinning

Real twist is applied to the yarn by the motion of the rotor acting on the yarn arm that passes from the rotor groove to the yarn withdrawal point inside the rotor. Each revolution of the rotor causes about one turn of twist to be inserted into the yarn, and $1/\tau$ inches of yarn are removed (τ is the twist in tpi). There can be movement of fibers with respect to the metal of the rotor during twisting. This is because the fibers are not firmly held by any discrete nip at this point. Twist usually runs back along the rotor groove and some fibers are laid onto an already twisted core of fibers. This

6 For economy of line in a complicated diagram, the picture shows fibers aligned along the sliding path, but this is not necessarily true as they can move crabwise along the path.

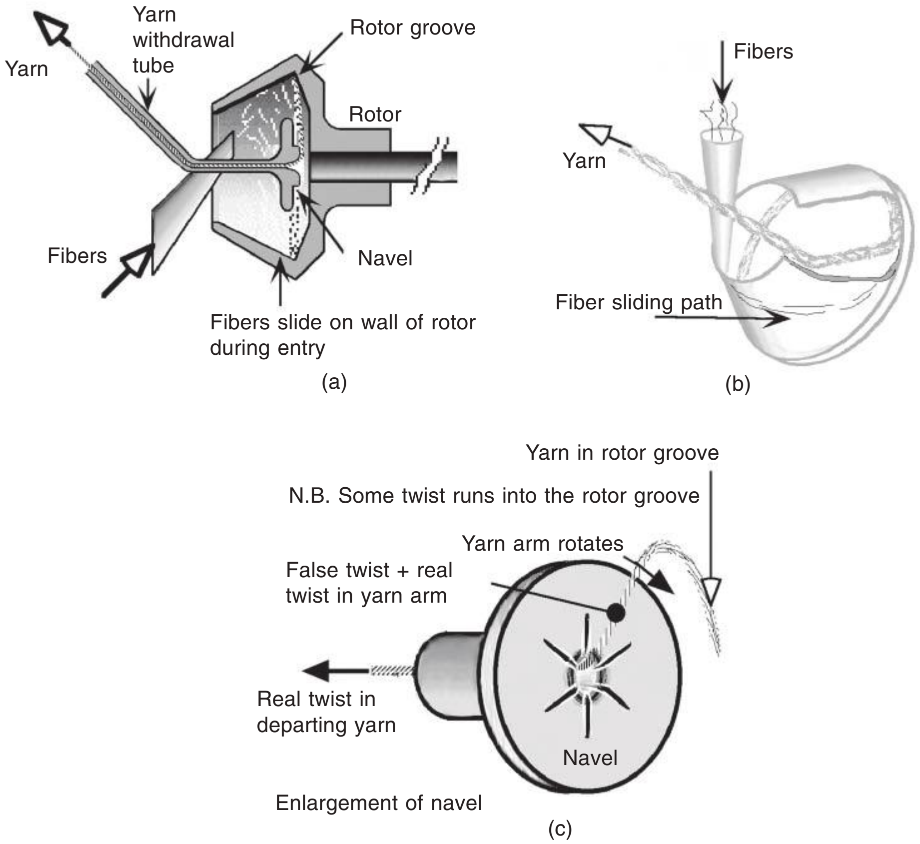

Fig. 7.12 Fiber and yarn in the rotor

affects the yarn structure. The center of the end of the yarn withdrawal tube is fitted with a non-rotating navel[7] through which the departing yarn flows, as shown in Fig. 7.12(c). Sometimes a separator plate is introduced to prevent the premature capture of the incoming fiber by the outgoing yarn. This makes a less desirable transport system because of the complexity of the passageway, but in separating the incoming fibers and outgoing yarn it fulfills a useful function.

The yarn entering the navel rolls on the inside surface. This rolling action produces a false twist in the section of yarn inside the rotor. The false twist is in addition to any real twist created by the movement of the rotor. Twist is trapped in the running yarn between the point of twist application and the nearest upstream twist trap. In the present case, the point of twist application is at the navel and the twist trap is on the collecting surface of the rotor. The flare radius of the navel affects the false twist generated, as shown in Table 7.1. Spinning performance and yarn character depend on the yarn twist inside the rotor (which is false twist dependent) rather than just on the apparent twist in the yarn delivered. Often, navels are grooved, as shown, to increase the false twist, but as speeds rise there is less need for this. Also grooved navels tend to make the yarn weaker as well as more bulky, neppy, and hairy, particularly

7 Experiments have been made with rotating navels, but they have not gained acceptance in the market.

Table 7.1 Effect of navel radius

Yarn linear density	**59 tex fiber**		**25 tex polyester fiber**	
Navel radius (inches)	0.06	0.2	0.06	0.2
Yarn tenacity (gf/tex)	12	21	22	11
Yarn elongation (%)	18.0	17.6	13.9	11.0
CV of linear density (%)	6.2	9.1	7.1	8.1

at high rotor speeds. The grooves cause the yarn to bounce off the surface of the navel for very brief periods of time. Yarn tensions measured inside the rotor are very close to the theoretical figure given by the formula $\omega^2 r_r^2 n$ but there are pulses due to the yarn riding over the grooves, if there are not too many of them. Unpublished work at NC State University showed that the number of pulses rose with the number of grooves until four grooves were cut. Increasing the number from four to eight gave only four pulses and this was interpreted to mean that the yarn jumped over alternate grooves.

False twist is also affected by how close the front surface of the navel is set towards the flat inner surface of the rotor. Local shear in the air is produced by the rotor wall moving close to the stationary navel. This shear can produce a small amount of false twist in the yarn. Enlarged portions of yarn can interact with this space if the gap is set too narrowly. Gages are used to set the distance accurately.

There will be differences in the coefficients of friction of the navel surface and the yarn; also the navels wear. It has become common to use ceramic navels because of their long lives but there can be unacceptable differences in the surfaces. As the navel varies, it causes the nature of the yarn, and the efficiency of the operation, to vary. Thus, it becomes important to make sure that all navels used in a given lot of yarn are similar, or operational and barré problems will result.

The range of usable twist multiples is much affected by these considerations; a typical set of twist multiple curves is given in Fig. 7.13. Generally the twists are higher than for ring yarn and the combination of the higher twist and the more disorganized yarn surface creates a rougher hand. At one time this was of major concern, but fabric finishing techniques have improved and the market has adjusted for the differences; the lower cost outweighs the tactile disadvantages. As mentioned earlier, end-breakage rates are, amongst other things, a function of rotor diameter and

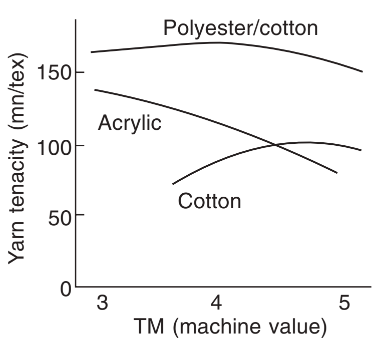

Fig. 7.13 Yarn tenacity curves for rotor spinning as a function of twist

speed. Whereas the larger rotors used in the 1980s gave minimum end-breakage rates/lb at about 70 000 r/min, the newest small rotors (down to 28 mm are reported) have minimum breakage rates at over 100 000 r/min. The minimum twist level achievable is of interest because low twist yarns have a good hand; also, the spinning machines have higher productivities at low twists. Generally, the minimum twist diminishes with rotor speeds up to about 70 000 r/min and then levels off; under some circumstances it rises at higher speeds. The lowest value of twist is a function of the radius at the base of the rotor groove and the type of navel in use. The navels might be grooved or non-grooved; they might be of steel or ceramic. Generally, the higher the rotor speed, the less need there is for grooved navels. As previously mentioned, ceramic materials are used to increase the life of the navels. The combination required for a given product is often initially determined by a manufacturer's recommendation, which is followed by trials to find that best suited for the job.

7.2.8 Rotor bearing system

A rotor spinning machine has multiple rotors driven by a single tape and, because of the very high speeds involved, special bearing arrangements are necessary. A common design is to support each rotor on an assembly of pulleys, which rotate at speeds lower than that of the rotor. Normal ball races are unable to survive at the highest rotor speeds now used. Air bearings have been tried, with various degrees of success, but the type of rotor support system most common now is similar to that sketched in Fig. 7.14. The supporting rubber-tired pulleys are mounted on ball races and these disks can safely rotate at the lower speeds.

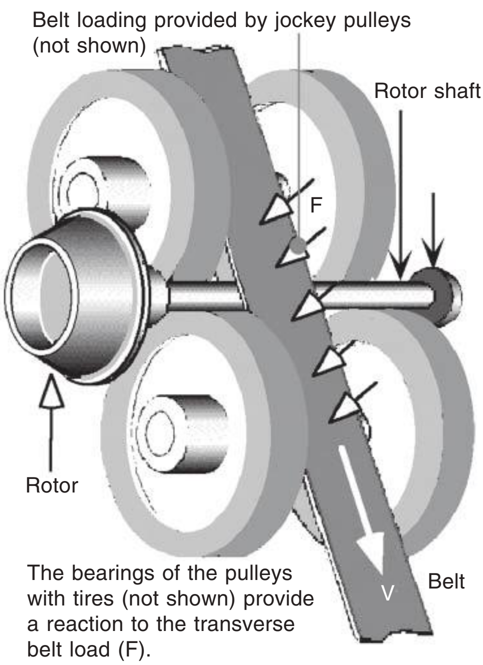

Fig. 7.14 Rotor support system

7.2.9 Winding on a rotor spinning machine

The winding function of a rotor spinning machine is separate from the rest. All that is required is that the yarn be taken up at a constant rate. The rate of yarn removal is determined by the surface speed of a pair of take-up rollers. The gearing between the fluted sliver supply roller and the yarn take-up roller determines the machine draft ratio. The yarn can be stretched involutarily, in which case there is a difference between machine and actual counts. The speed ratio between the rotor and yarn take-up roller determines the twist level. Unlike a ring frame, the winding and twisting functions are divorced and this permits the building of large yarn packages whose size is limited only by the capability of the winder. As previously mentioned, the yarn is then usually wound on a large cross-wound cheese that might (when fully built) weigh some 10 lb (≈ 4.5 kg). Some rotor machines are capable of producing yarn cones of about the same size. Use of these large packages reduces the yarn handling costs.

Rewinding (comparable to the winding from bobbin to cheese or cone in ring spinning) is usually unnecessary in rotor spinning because the number of yarn faults per package is usually low. However, it is difficult to anticipate which rotor will develop a fault, and when a faulty condition arises a great deal of yarn can be made before the fault is discovered. A cheese or cone running on the drive roller for long periods without yarn being laid becomes damaged by the drive surface. Therefore, some rotor yarn is occasionally rewound, but care is needed in rewinding because the yarn can be overstrained in the process. A better alternative is to monitor the rotor to detect a fault or an end-break immediately after occurrence and thus prevent the building of a bad package. Commercial devices cause the package to become disengaged with the drive roller when triggered by a fault; this is to prevent damage due to abrasion of the unchanging surface of the package during a non-productive period.

Winding on an open-end spinning machine differs from winding on a separate frame. In the former case, the yarn feed rate is set by the take-up roll at a constant value, whereas in the latter case the yarn is supplied on demand. Compensation for the change in length of yarn between the guide and the lay-on point on the package is needed in open-end spinning. A simple scheme is to use a bow such as is described in Section 9.1.6. The yarn diverted by the bow approximately compensates for the change in length just mentioned and preserves a reasonably uniform yarn tension. When a cone is being wound, a yarn storage system is required which is capable of compensating for the differing wind-on speeds as the yarn traverses between the small and large diameters of the cone.

The winder should control the yarn tension and maintain a uniform package density. In addition, a pattern breaker is required to remove unwanted variations in package structure, which arise as the diameter reaches certain critical measurements. Furthermore, cradle pressure control is required to compensate for changes in package weight as the package grows in size. A cradle lifter is often used to relieve pressure when an end breaks (this prevents scuffing of the surface of the package). Sometimes the yarn user requires a waxing attachment to apply paraffin (wax) to the yarn; this is particularly true where the yarn is for a knitting application. Further discussion of winding is given in Chapter 9.

7.2.10 Automation

Rotor machines are currently available that are capable of running at 130 000 r/min. The maximum depends on the fiber being spun. Cotton can be spun at the highest speed, acrylic at 20% less, and polyester and polyester/cotton blends at about 35% less (90 000 r/min). It is impossible to use manual piecing at such high speeds and automation becomes an operational necessity.

The rotor machine lends itself to automation, and patrolling robots that piece, clean, and doff are commonplace. The robots follow a track round the machine. One sort of robot patrols, opens up rotors, cleans them, and re-pieces according to program or need. Another sort patrols and doffs when required. Frequently, machines have automatic start-up programs and built-in monitoring systems that will read out the machine performance over any reasonable period.

Automatic doffing requires that a supply of empty tubes have a starter yarn bunch wound on each of them for start-up with the automatic piecer. Thus, there has to be a supply of empty tubes, a bunch winder, and a transport and loading system, as well as a system capable of removing the full bobbins in a safe and effective manner. The latter has importance because a damaged cone or cheese is rarely recoverable and it represents a considerable waste of effort and money. Damage is not restricted to a violation of the surface but also includes the loss of effective transfer yarn tails, which are so important to yarn users who tie packages nose to tail to reduce their package handling costs. Each package should have a starter and finisher tail disposed in a standard manner so that other machinery can find them.

7.2.11 Piecing in rotor spinning

Before an acceptable piecing can be made, the rotor has to be cleaned. Manual cleaning involves stopping the rotor, opening the front cover, cleaning, shutting the cover, and restarting; a time-consuming endeavor. Automatic methods of fulfilling these functions are now standard to all new machines. The dirt in the rotor is usually loosened by one or more blasts of compressed air through ducts in the rotor cover, or the application of a scraper, and suction carries the debris away [13]. If a scraper is used, the blade is made of a soft material to prevent damage to the rotor and the sacrificial wear of the blade means that it has to be replaced periodically.

Automatic piecing requires careful control of the opened fiber entering the rotor at start-up and the introduction of an end from the winder. After the inside of the rotor has been cleaned, new fiber is introduced and a ring begins to build up. To explain this, consider the series of pictures in Fig. 7.15. The end of the piecing yarn is shown as square cut. The steps are exaggerated for the purpose of explanation. It is assumed that the rotor has just been cleaned and that the thickness of the lines represents the number of fibers in the cross-section. In diagram (a), a starter yarn (or piecing yarn) is shown approaching the rotor groove; the fiber supply has just been started and a thin ring of fibers has been laid in the rotor groove. The yarn is sucked in by the vacuum and the air inside the rotor exists as a vortex. Thus, the yarn rotates about the rotor axis at a lesser speed than the rotor and, because of the twisting actions already described, the yarn end also rotates about its own axis. As the yarn is fed still further into the rotor (diagram (b)) the end is laid in the rotor groove and it tries to rotate and entangle the fibers already in the groove. The entangled end breaks into the fiber ring (diagram (c)). At an appropriate time, the yarn is withdrawn from the rotor at an appropriate speed. As the yarn is further withdrawn, the fibers continue to be supplied to the rotor groove and extra layers of fiber are laid over the break (diagram (d)). This process continues until equilibrium is reached. Meanwhile, the piecing contains a thick spot followed by a thin one and this is not acceptable. This is why the end is conditioned.

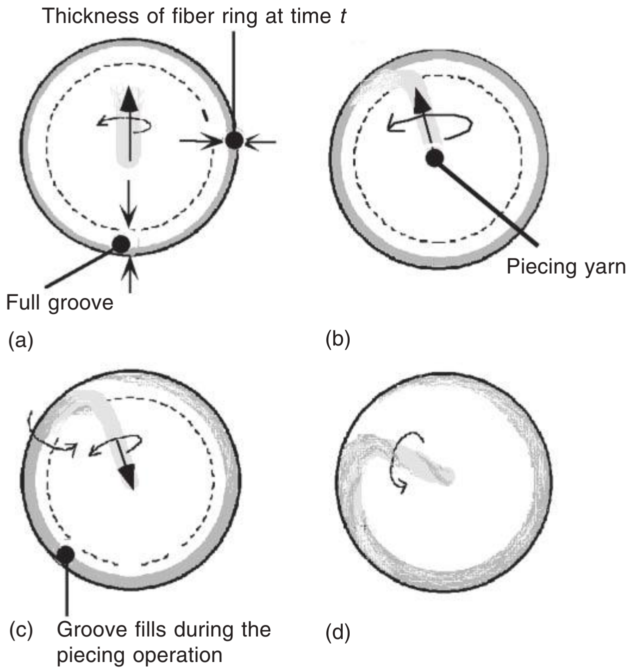

Fig. 7.15 Stages in piecing a rotor

For the purposes of explanation, let the circumference of the fiber ring be unzipped to permit linear drawings (Fig. 7.16). The timing of the piecing is important, especially at high rotor speeds. Thin spots break under the high tensions and, unless accurate timing is used, it is impossible to get spinning going. Because a human operator cannot reliably synchronize the stages in piecing at very high rotor speeds, automatic systems become a necessity. If a square cut piecing yarn is introduced into the rotor too soon and the rotor ring is thin, a very thin spot is generated in the piecing as shown in Fig. 7.16(a). If the yarn is introduced late and the rotor groove is nearly full to its normal operating level, a very thick spot is created. If the yarn withdrawal is started too soon, there is a thin spot, and if it is started too late, there is a thick one. Such a piecing is never perfect but it can be improved upon by tapering the end of the yarn introduced into the rotor, because this reduces the sudden changes in linear density, as shown in Fig. 7.16(b). Consequently, yarn end tapering is automatically carried out by the machine, often using a pneumatic stripping device. At first sight, some of the profiles shown do not seem to differ much. However, if the ordinates are plotted to include all three components at any point, the result is quite surprising; diagram (c) shows two such plots of the data for conditioned ends. The bad case shown is for early yarn introduction, which resulted in a distinct thin spot; the other case is a good piecing.

There is another good reason for conditioning the sliver end before piecing. End-breaks occur randomly and the time between the break and the piecing varies. While the end remains unrepaired, the combing roll is working the sliver end about to be fed to the rotor. Fiber alignment, as well as linear density of the fringe, is affected. To achieve standard conditions, the overworked sliver end should be discarded. The easiest way to do this is to feed sufficient fibers into the rotor in the normal way and then clean it before piecing. The machines are now designed to do this automatically.

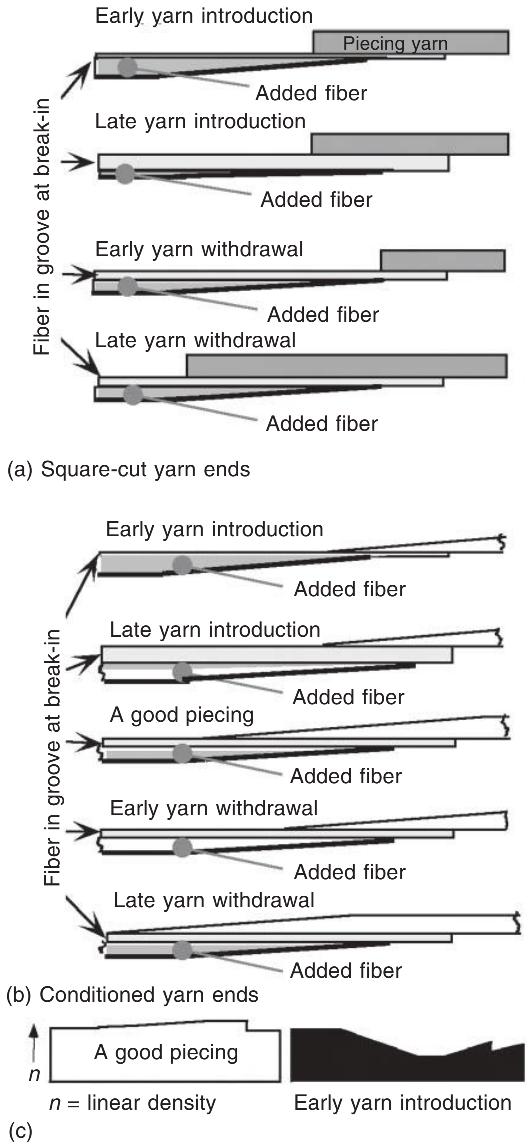

Fig. 7.16 Piecing diagrams

Some modern start-up devices reduce the machine speed for piecing. Other devices assign the piecer to control the initial yarn withdrawal and synchronize it with the accelerating machine before handing over control to the winder.

7.2.12 Fiber requirements

Bridging fibers can cause deterioration in yarn performance. The probability of a bridging fiber is the ratio of the fiber length and the circumference of the rotor; thus long fibers used in small rotors produce poor yarn. Conversely, within limits, short fibers can produce reasonable yarn. (Comber noils can be spun successfully in rotor spinners, which fact indicates that fiber length is not of paramount importance.)

Some experimenters have stated that removal of noil from the feed material by combing has little beneficial effect on yarn quality whilst others say that combing improves yarn quality sufficiently to justify its use. There is an optimum fiber length beyond which no further increase is beneficial; the precise value is determined by the rotor size and geometry as well as the nature of the fiber. In making medium and coarse yarns, some variability in length may be acceptable but it is worthwhile controlling the short fiber content when spinning fine yarns. Deussen [13] points out that the effect of fiber length should not be underestimated. Man-made fibers are cut at 1.25 inches for coarse and medium counts whereas 1.5 inches is preferred for fine counts. (For ring spinning, the standard fiber length for man-made fibers at all counts is 1.5 inches.) Poor length uniformity can degrade the yarn quality but not so much as with ring spinning. Highly crimped fibers tend to aggregate and behave as longer ones; generally, high crimp is undesirable. Fiber finish also plays a part but, although low friction finishes are desirable up to a point for man-made fibers, too slick a finish can lead to yarn unevenness. Distinction must be made between fiber-to-metal friction and fiber-to-fiber friction. The former should be at a minimum but the latter should be high enough to prevent fibers slipping within the yarn structure when it is stressed.

Generally, rotor spinning is now confined to short-staple spinning with relatively fine fibers. Fiber fineness plays a part not only in yarn strength, evenness, etc., but it also affects the hand of the product. For this reason, fine cottons have become quite popular with some rotor spinners. Experience has taught that a minimum of about 100 fibers is required in the yarn cross-section and the normal spin limit[8] for cotton varies between 24s and 50s cotton count (N_e). The spin limit is related to yarn strength; higher strength fibers tend to reduce the end-breakage rate and increase the spin limit (this is because it is the minimum strength of the strand that determines whether or not a yarn breaks rather than the minimum linear density). End-breakage rates can vary from 15 to 150 ends down per thousand rotor hours.

The practice in cotton marketing is to use micronaire as a measure of fineness, but this clouds the issue of spin limit because micronaire is affected by fiber maturity as well as fineness. The range of fiber finenesses now available for the man-made fiber components makes closer matching possible with natural fibers to make good blends. This is particularly true of polyester/cotton blends, which form a significant part of the market. Man-made fiber development has led to the production of finer fibers and the fineness has gone from the standard 1.5 denier to a range that includes values below 1 denier. The fine fibers are prone to nep but they spin reasonably well in rotor spinners except at the highest speeds. There is a tendency to break the finer fibers during spinning, which was demonstrated in a study by Looney [22]. Reducing the fineness of polyester fibers from 3 to 1.5 denier increased fiber breakage from 5% to 15%.

Fiber strength is an important parameter in rotor spun yarn because, in part, of the comparisons made to ring yarns. A graph of the relationship between a particular set of cottons and the yarns made from them is given in Fig. 7.17 as an example. (Some people use the term ‘C × S’, which means yarn count multiplied by skein strength, and it has the dimensions of tenacity.) At twist multiples higher or lower than the optimum, the yarn strength declines. The cottons shown varied in length from $1^{1/32}$ to

8 Spin limit is the count, or linear density, of the finest yarn which can be spun under the prevailing conditions. There are other definitions.

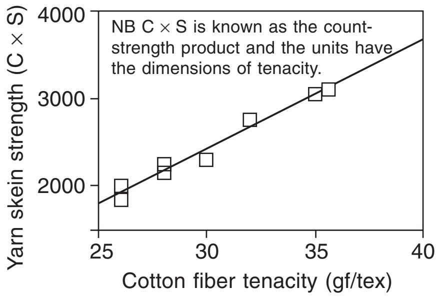

Fig. 7.17 Optimum rotor yarn tenacity as a function of fiber tenacity

$1^{3/8}$ inch (≈ 26 to 35 mm), the TM varied from 3.9 to 5, and the shortest fibers gave the lowest yarn strength. The most important attributes for natural fibers used in rotor spinning are fiber tenacity, fineness, and cleanliness, in that order. Fiber tenacity is reflected in the yarn strength, and rotor yarns tend to be weak. Fine fibers work better in rotor spinning than coarser ones. Dirty fibers create a problem in keeping the rotors clean. Polyester, especially when an optical brightener such as titanium dioxide is used, is somewhat aggressive and creates more wear than cotton. For man-made fibers, cleanliness includes freedom from excessive fiber finish, debris, and oligomer. With man-made fibers and blends of these with cotton, the factors can be ranked in the order: fiber finish, tenacity, fineness, and length.

An area of interest in rotor spinning is the spinning of acrylic fibers, which, with some machines, can be spun into yarn with a surprisingly low twist multiple. The yarns produced are soft and of interest to knitters who want even, knotless yarns with a soft hand and where strength is not of great importance. For this market, it is possible to make the yarns economically because the low twist permits high production. Economic success has been reported at counts as high as 30s cotton (45s worsted or 20 tex).

Another area of interest is the spinning of waste fibers. For example, cleaned comber noils provide a cheap source of fiber and, in certain markets, the strength is acceptable, but the dust must be removed before spinning because combing does not remove dust from the noils. In some markets, noil is added to virgin fiber and produces acceptable yarns; in some cases 100% noil can be used. The use of noil in this way is of particular interest to makers of combed ring yarns because of the ready availability of noil.

Blend yarns do not derive proportionate strength from the tenacities of the fiber components because fiber elongation also plays a role. Each component may be assumed to be extended by the same amount when a yarn is elongated. The load in each fiber is a function of both the elongation and the modulus of the fiber. A yarn made of a blend of stiff, weak fibers and extensible, strong fibers will usually fail when the weak fibers reach their breaking elongation. At that point, a strong fiber will only have contributed part of its strength to the composite at the time of failure. Thus, for example, a polyester/cotton blend produces an effect such as is shown in Fig. 7.18 [23]. However, if the percentage of weak fibers is small, the strong fibers might be able to bear the entire load when all the weak fibers have failed. This is not the usual case.

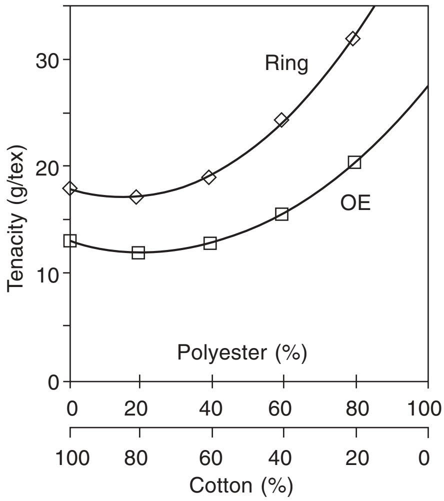

Fig. 7.18 Blend yarn tenacities

7.2.13 Maintenance

High speed precision machinery needs scheduled and thorough maintenance. It has been suggested that 2 to 3% of the initial cost of the machine should be spent on maintenance each year. Rotors and combing rolls are supposed to have operating lives of up to five years but lack of proper maintenance, or abuse, can significantly shorten useful life. The type of fiber being spun also has an influence. If the fiber is cotton, then freedom from silica contamination is very important; if it is polyester, the use of TiO_2 or any other abrasive additives is a factor.

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