8

Long-staple spinning

8.1 Introduction: Effects of lengthening the staple

Long-staple spinning was originally designed to work with wool and other long fibers, whereas short-staple spinning had been designed for cotton. Not only is wool much longer than cotton, it is much more variable in length. Wool fibers normally vary between 3 and 18 inches (≈ 76 to 457 mm) in length and between 8 and 60 microns in diameter. Therefore, the systems for wool must be able to cope with a rather wide range of conditions. It is also interesting that wool is naturally crimped at between 6 and 24 crimps/inch (≈ 0.2 and 1.0 crimps/mm); this is comparable to the levels introduced artificially in cut or stretch-broken tow. This means that one would expect more diversity in the machinery and processes used for long-staple opening and carding than found with the corresponding short-staple processing discussed in Chapter 5.

Man-made fibers are now used in blends but much of the appeal of wool lies in its special character. Many consumers are willing to pay high prices for 100% wool yarns. This applies in both apparel and carpet markets, and consequently there remains a healthy market in fabrics made from pure wool. This is in addition to the market for blends of wool with man-made fibers. We can divide the field into two without losing too much of the total breadth. The two fields, which will be the subjects of major discussion, are the worsted and woolen systems.

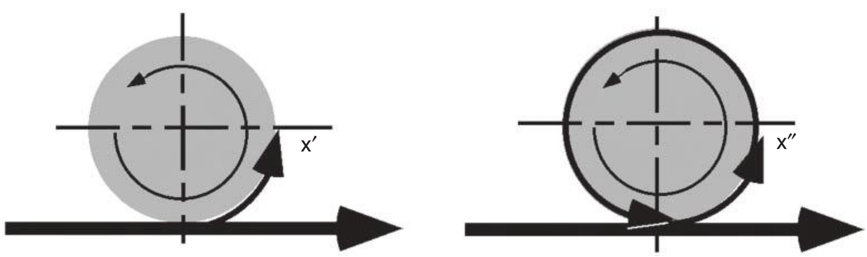
The worsted process as used for wool has similarities with the total short-staple process involved in ring spinning as discussed in Chapter 5 except that fiber cleaning has to be totally different because of the greasy nature of wool. The mechanical part of the worsted process applied to man-made fibers, like its short-staple counterpart, involves relatively little, if any, fiber cleaning. The worsted yarns produced by this system are twisted and have a much higher strength than the woolen yarns just about to be discussed. (Note: 'woolen' refers to the process and not the wool fiber.)

The woolen system is a short process designed to make relatively inexpensive yarns. Stages of drawing, combing, and roving are dispensed with and the yarns are spun directly from a card cylinder. The loss of the multiple doublings coming from drawing and combing is countered by paying great attention to fiber blending in the early stages of the process. Use of the woolen system has declined over recent years but a description is included because the technology contains the roots of many devices used in other processing.

8.2 Wool fibers and their preparation

8.2.1 Further effects of lengthening the staple

It is possible to improve fiber cohesion in yarn by increasing the fiber length; this allows a lower twist multiple to be used. The lower twist, in turn, permits higher productivity and yields a softer hand. Thus, there are a number of advantages to working with long-staple fibers as compared to the short-staple ones we have already discussed in Chapter 5, but there are limitations. Long fibers are difficult to manipulate and the chance of fiber damage increases with fiber length. There are interactions with the design of the machine; under certain circumstances, fibers that should flow past, will adhere to the surface of a roller and be carried round that surface, as shown in Fig. 8.1. If the fiber length is larger than the circumference of the roller, a roll lap is likely to be produced. The fiber may be trapped on the roller surface as shown in Fig. 8.1(b) instead of being carried away by the linear fiber flow. If this happens, other fibers tend to be caught by the trapped fiber and a ribbon of fibers accumulates around the surface of the roll. The ribbon is tightly packed and continuously builds up, often causing damage to the rolls; these are called lap-ups. Such lap-ups usually have to be removed by cutting them from the roll; this, too, can cause damage. The ratio of fiber length and roll circumference is related to the tendency to lap. In cases where fibers are incompletely separated, it is the tuft length that controls the situation. Consequently, if the length of a tuft is longer than the circumference of the roll, lap-ups can occur. Fiber finish and crimp can also strongly affect performance in this respect and these parameters must be closely controlled. Generally, when the roller circumference is about twice the fiber length and normal fiber finish and crimp are used, an acceptably low incidence of lapping is obtained. Thus, long-staple systems usually have large diameter rollers in their drafting systems. In addition the ratch settings have to match the fiber length. It follows that long-staple drafting systems are larger in all dimensions than their short-staple counterparts. Long-staple yarns are usually heavier than short-staple ones; this makes it desirable to use larger bobbins to reduce doffing costs and thus the twisting portion of the machine is also larger. An increase in size is nearly always associated with a decrease in speed. Therefore, it



Fibers adhere to rolls at x′
(a)

Fibers trapped under new layer of fiber at x″
(b)

Fig. 8.1 Roller lapping

should be no surprise to find that long-staple machinery is to a larger geometric scale, and is slower, than short-staple machinery.

Long fibers tangle more easily than short ones (a man with a crew cut has much less difficulty in combing his hair than does a person with long hair). Proper lubrication of the fiber eases the problem. Crimped fibers tangle more easily than smooth ones. The carding process aims to disentangle the fibers and separate them, but it is found that the flat-top card damages long fibers in attempting to disentangle them. Consider the carding action between two sets of teeth moving at different speeds in about the same plane. One fiber end is caught in one set of teeth and the other end is caught by the second set. Figure 8.2(a) shows a typical fiber snaking between the teeth on a surface from A at one end to B at the other. If there is already a tension acting at A, then the tension at B is given approximately by applying Amonton's Law.[1] Appropriate angles as well as the input and output tensions are as shown in diagram (b). It will be seen that the more sinuous the shape of a given fiber, and the closer the pins are set, the greater will be the accumulation of tension. In practice, the tension at A is generated by interfiber friction in the fiber supply, or an interaction between fibers and pins in a preceding section, or both. That at B is X times as much. A factor $Z = T_{out}/T_{in}$ is due to the fiber reactions against the pins just described, but another factor Y is affected by the fiber crimp and stiffness. (Hence the approximately equal symbol in the equation in the footnote.) The precise relationships between X, Y, and Z are not known. The reactions are caused by the in-built tendency for the fibers to take up a zigzag shape. Pressure from the teeth de-crimps the fibers as they are forced into the interstices, and this produces a friction force that contributes to the tension at A. In

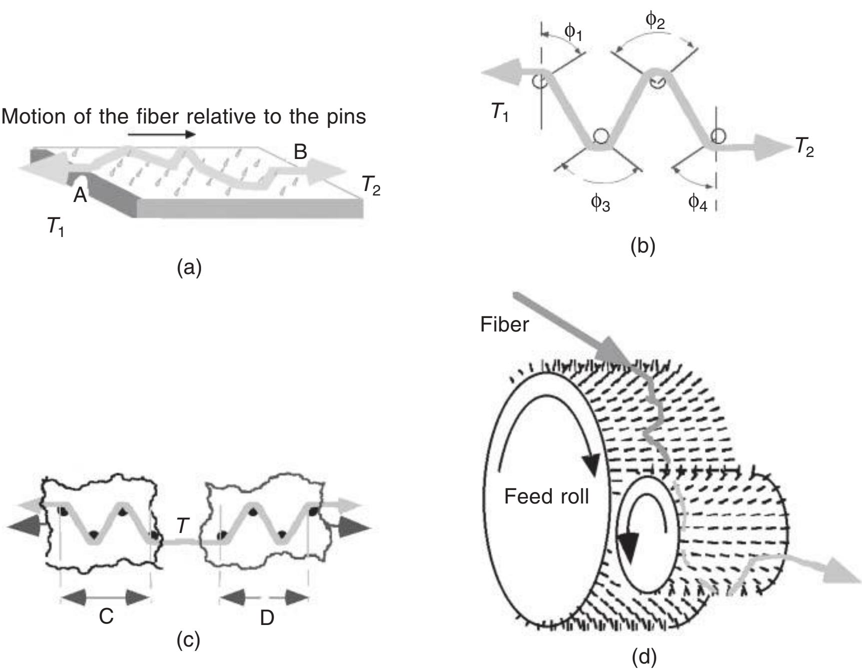


Fig. 8.2 Fiber tensions created by combing

1 $T_{out} \approx T_{in}\, e^{\mu\theta}$ where the angle $\theta = \phi_1 + \phi_2 + \phi_3 + \phi_4$ and μ = coefficient of friction.

any event, the output tension at B is heavily affected by the input value at A. The angle of wrap, the fiber crimp level, the pitch of the teeth, and the coefficient of friction also affect it. The lubrication and crimp are of increasing importance as the staple length increases beyond 4 inches. The cumulative angle of wrap is affected by how many zigs and zags there are along the length of the fiber. Beyond a certain critical length, fiber breakage will occur. Using a pinned feed as shown in diagrams (c) and (d) can double the critical fiber length; such systems are commonly found in long-staple machines.

8.2.2 Wool fiber cleaning in worsted mills

Wool is usually supplied to the mills as shorn or pulled fiber. Shorn wool is taken from living animals and pulled wool is from carcasses. These untreated materials are known as greasy wool because of the grease, suint (from old French 'suer', the verb 'to sweat'), and other animal excretions that coat the fibers. Together with vegetable and mineral particles, there can be up to 70% foreign matter in greasy wool. The wool grease (or so-called 'brown grease') coating the fiber contains a waxy material called lanolin, which is a valuable by-product useful in making ointments and cosmetics. Suint is dried perspiration that contains valuable potassium salts. Greasy wool will not yield to purely mechanical means of cleaning and therefore it is necessary to scour the fibers before further mechanical treatment. There were relatively few developments in the first half of the twentieth century; however, the problem then started to receive more attention, especially in the grower countries.

The traditional method of scouring is to divide the greasy wool and feed it to a fork frame (Fig. 8.3(a)). A procession of forks carries fiber through a succession of liquor troughs (or bowls) in which the fibers are washed and rinsed. The frame may be some 60 ft (≈ 18 m) long. The scouring liquor is traditionally an alkali (soda) soap solution, since it readily permits the recovery of lanolin, but this requires soft water, otherwise there are troublesome insoluble lime deposits. There is a diversity of ways of running the liquor through the frame and we can only describe one. Care has to be taken to control the temperature and the pH level of the liquor, otherwise the fibers will be damaged and the dyeability of the fibers affected. The degree of alkalinity or acidity is recorded by pH readings. Generally, the temperatures and pHs of the first stages can be kept high because the grease tends to protect the fiber. As the protective grease is removed from the fiber in its passage downstream, the temperature in successive bowls is reduced and the pH level is moved nearer neutrality. The final bath is merely a rinse in plain water, after which the wool is passed through squeeze rollers to remove most of the moisture. An average time for the wool to pass through the fork frame is 8 minutes. Scouring tends to make the fibers brittle unless they are oiled and the fibers are kept below about 120°F (≈ 50°C) during scouring.

The wool grease has to be separated from the scouring liquor to allow a reasonable run of the equipment. Once again there is a diversity of systems and it is only possible to describe an example in this book (see Fig. 8.3(b) for a simplified diagram). The liquor still degrades, and the scouring liquor has to be completely changed every few days. In addition, there is a need for liquor make-up and fresh water to rinse, and thus the process is a great consumer of water. Solids, such as sand and other heavy particles, are allowed to settle in tanks in the scouring liquor circuit and these solids may be intermittently pumped out or otherwise removed. Fiber loss into the scouring liquor causes a problem because fibers tend to bind the contaminants, and when they

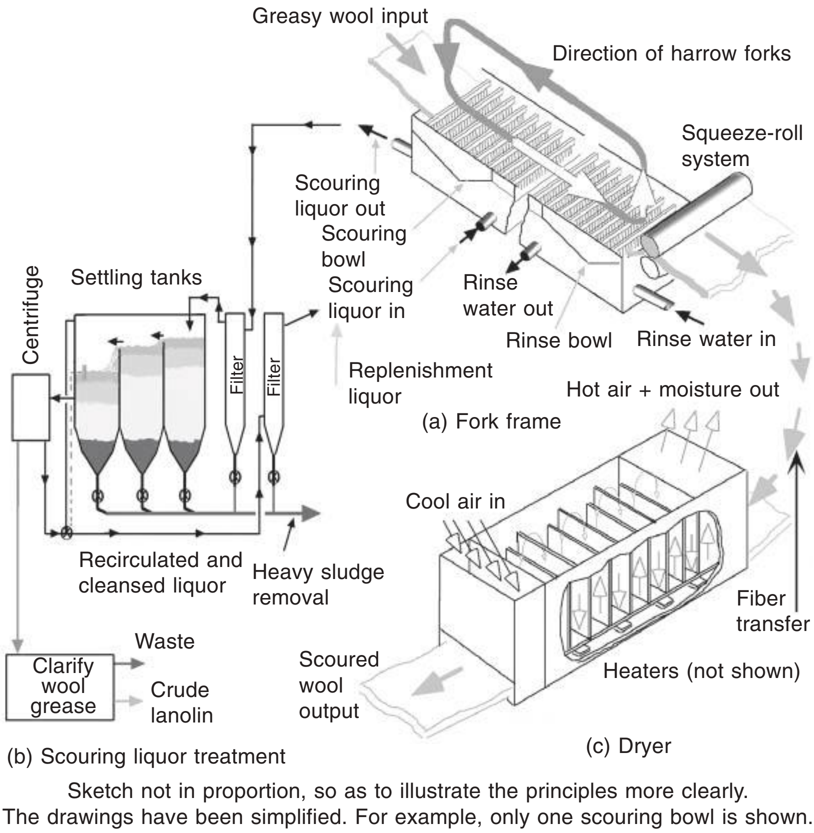


Fig. 8.3 Fork frame

decay, they become malodorous. Fatty substances contaminated with fiber and other light substances tend to float to the surface in the settling tanks, and sludge centrifuges may be used to remove these lighter solids continuously. (Centrifuges are machines for separating solids from liquid suspensions.) Disposal of the liquor not processed by the recirculation system is discussed in Section 8.2.5. The wool grease is separated from the contaminated fatty solids and clarified (see Fig. 8.3(b)), to be later refined by the purchaser. If a market exists for potash at a price sufficient to cover the costs of separation, the salts are converted to whatever intermediate the buyer will accept.

Some attention was given to solvent scouring but no significant market penetration was achieved. The use of detergents was once claimed to give whiter, loftier, and stronger fiber; detractors' claims and counter-claims were not so significant as the impact on costs and the convenience of being able to scour to the desired pH level. In recent times, the development of effective detergents caused costs to become competitive with alkali solutions. Whichever method is used for scouring, the main aim is to remove the wool grease at minimum cost with as little damage to the fiber as possible. Cost considerations are a large factor in the choice of method.

An important past problem was the felting of the wool during scouring, but suitable chemical treatments are now available to reduce the ensuing shrinkage [1]. Felting occurs because scales on the wool fiber act as ratchets, which favor movement of the fiber in one direction rather than the other. The result is that wool structures tend to become densely packed as the mass shrinks due to the relative movement of the fibers. Felting makes the disentangling of fibers difficult.

Some machines were developed in the mid-twentieth century to improve performance by increasing productivity and reducing the tendency to felt; one of these is the suction-scour machine. In this machine, wool passes round the lower surface of a number of horizontal, perforated drums rotating in the scouring bowl. A stream of scouring liquor flows from the outside to the inside of the drums and the wool floats near the surface of the liquor in a stream flowing from one drum to the next.

The wool leaving the scouring plant should have a moisture content of less than 40%. This means that, where aqueous scouring systems are used, the wool has to be passed through at least one pair of squeeze rollers (mangles) to reduce the excess moisture. The damp wool is then passed through a dryer in which hot air is circulated through the blanket-like layer of wool carried on a lattice conveyer. Cool air is admitted at the delivery end and is progressively heated as it passes through the fiber as shown in Fig. 8.3(c). This enables the dried wool to be delivered in a cool state. After chemical treatment, it is essential to oil the fibers before proceeding with further mechanical treatment. Scoured fiber is usually hot air dried and oiled to a level of 0.75%[2] to facilitate further working. It is interesting to note the need to oil the fiber after the surface has been rather drastically cleaned. Use of the wrong oil or the wrong quantity of oil can result in processing difficulties. See Section 8.2.4 for further discussion.

Where the vegetable matter among the scoured and oiled fibers is present only in moderate quantity it can be dealt with at the card. Dirtier fibers need some pre-cleaning. A partial alternative to the mechanical removal of vegetable matter is to destroy it by chemical action. Sulfuric, hydrochloric, or other acids (such as those produced by salts such as aluminum chloride when heated) may be used. These treatments reduce the unwanted matter to carbon and the process is known as carbonizing. Usually, the dirty scoured wool is steeped in acid, dried, and baked. Drying is accomplished by draining, mangling, and heating. The particles are then crushed and beaten out before diluting the acid and then neutralizing by soda washes. The dilution is necessary to prevent overheating the fibers due to the exothermic reaction during neutralization. Rinsing and drying follows it. Such carbonization gives some loss of fiber amounting to 5 or 6%. Also, there can be some loss in fiber strength, particularly if high drying temperatures are used. At 250°F (≈ 120°C), the loss in strength can be as much as 30%, but at 100°F (≈ 38°C) the loss is negligible. Again, it must be pointed out that there is a necessity to oil the fibers after chemical treatment to prevent fiber breakage and electrification.

It will be seen that the wet cleaning process is complex and it can be added that it is expensive to both install and run. This alone tends to make wool products expensive; consequently a great deal of care is usually taken to preserve quality.

The first mechanical cleaner in line is called a burr picker. A second cleaning is achieved by blowing air through the burr picker to remove light dust and impurities. One of the last opportunities mechanically to remove all but the last remnants of vegetable matter is in the carding operation. These mechanical operations are described in Section 8.3.2. Any residual vegetable matter left in worsted slivers is usually

2 A higher level might be used occasionally, especially if obsolete Noble combers are in use.

removed in the combing process. An extensive discussion of the variety of processes is given in the *Wool Handbook* [2].

8.2.3 Fiber cleaning for woolen mills

Many traditional woolen mills use recycled fibers and then there is no need to use methods described in the previous section, but there is a need to clean and sterilize the fibers. A shortened cleaning system is then used. However, if the mill wants to use virgin wool fibers, then a cleaning system such as that just described is required for at least part of the intake of fibers.

8.2.4 Fiber lubrication

The importance of proper fiber lubrication has already been stressed but it should be realized that considerable care has to be taken in the choice of oil and the method of application. There are many oils used (and even more claims, many of which are unsubstantiated) and such materials as olive oil plasticize, lubricate, and reduce electrification. Over the years, many competing oiling formulations have been derived and it is beyond the scope of this book to discuss them further. The oil is usually applied to a layer of fiber, another layer of fiber is added, then more oil is applied, and so on. Too much oil, or one that is too viscous, or one that becomes sticky over time, causes lap-ups and chokes with the result that the fiber becomes unworkable. Also insufficient lubrication or lack of plasticizer can cause an undue amount of fiber breakage in the mechanical operations. Such fiber breakage impairs operational efficiency and reduces the quality of the product.

Not only does the oil change the coefficient of friction, but it also reduces the tendency for the fiber to charge electrically. Insulated surfaces sliding over one another create electrical charges. All fibers are subjected to sliding contact with other surfaces during processing and thus the ‘oil’ has to possess some ability to allow an electrical current to flow to minimize the charge. If not, since like charges attract each other and unlike ones repel, the results are that (a) the fibers cling together and they are difficult to separate and (b) some fibers adhere to machine parts and cause uncontrolled fiber flow and breakage. Such fiber behavior can make processing exceedingly difficult and increase the probability of lapping and tangling. (It might be remarked that these situations provided the early makers of man-made fibers with some valuable insights as to what they had to do in the way of fiber finish to make their fibers capable of being worked.)

The presence of a sufficiency of proper oil can reduce the need for a high atmospheric humidity. Humidity also reduces the tendency towards electrification of fibers. For a *woolen* system with only small amounts of oil, the rh has to be at least 65% and a humidifying system becomes a necessity in many climates. Air at 65% rh and 70°F (≈ 21°C) holds about 5.2 grains/cu ft (≈ 12 g/m^3). The quantity of water that has to be sprayed into the atmosphere can be quite large and the cost significant. Table 8.1 gives some typical rh values at various processing stages in the *worsted* system. It will be noted that the rh values needed for carding and spinning in the worsted system are considerably lower than the 65% just quoted. Wool fibers in the worsted system are oiled.

When different sorts of fiber are to be blended, it is desirable that each sort of fiber be lubricated separately. Many man-made fibers already have fiber finish applied by

Table 8.1 Typical % rh in processing of wool

	% Min	% Max
Mixing and blending	65	70
Carding	60	70
Combing	65	75
Drawing (French)	65	75
Spinning	50	55

the fiber maker, whereas wool is scoured before mechanical processing. Most man-made fibers process reasonably well at 55% rh and thus the further importance of oiling the wool can be seen. Use of appropriate moisture contents and oiling help to keep the wool fibers pliable and resistant to rubbing. It has been explained that the lubricant has to perform some important functions but there are other requirements. The oil must be capable of being easily removed after it has fulfilled its purpose; it should not degrade, stain, or otherwise mark the fiber; it should not damage the machine in any way. It should be compatible with the finish on any man-made fiber used with it; both should be chemically stable under a variety of conditions during prolonged storage; and it should not produce any fire or health hazards.

8.2.5 Disposal of wastes from scouring

Disposal of the wastes from scouring is still a problem and traditional methods are no longer acceptable. Waste water from scouring is a particularly difficult effluent to deal with because it contains both organic and inorganic components. Inert sediments and vegetable matter produce little problem in this respect, but the wool grease and soluble organic salts do have highly significant effects. The polluting effect of such aqueous wastes is indicated by its biochemical oxygen demand (BOD) to achieve the decomposition of organic waste by aerobic bacterial action. The rate of discharge of these waste materials can thus be measured in pounds of BOD per day (or by the equivalent of that generated by a number of inhabitants of a community). The BOD rate depends upon the waste contents of the fibers, the level of production, and the efficiency of the waste treatment systems used. Several methods of treating wastes exist. Biological methods are low in cost and are capable of dealing with both soluble and insoluble impurities. However, they are sensitive to variations in ambient temperature, they can be adversely affected by poisoning, and they produce large volumes of sludge. Gravity settling of the sludge in lagoons is used to produce the biological action. If the sludge is spread on the land as a way of disposal, a large acreage is required. Flocculation of the liquors has not proved to be satisfactory on the small scale that most mills require. Evaporation of the water from the liquor followed by condensation to recover the water is another concept that has been tested and used at various places because it has the attraction of a reduction in water usage and a high yield of valuable wool grease. The cost of water is a severe burden in some areas of the world. An acid-cracking method is possible in which the suint liquors are evaporated and the residues of salt are calcined to produce saleable potash. However, the evaporation process can be expensive.

8.3 Worsted systems

8.3.1 Long-staple processing within the worsted family of systems

Within the worsted family of processing systems, there are many variations. These systems range from the traditional processes used for making high quality yarns from wool, to short processes that use man-made fibers solely and require no carding or combing. These systems use some of the same equipment at certain stages of their manufacture and it is convenient to use the adjective 'long-staple' when the process stage is useful over a wider range than might be inferred by the adjective 'worsted'.

8.3.2 Worsted system carding

Worsted yarns are made from long, lustrous varieties of wool and they are usually combed to improve the luster, smoothness, and strength of the yarn. Wool fleeces are sorted into pieces of reasonably uniform quality; these sorts of greasy wool are blended and, if necessary, deburred before being scoured. The scoured, dried wool is conveyed by an airstream (or by a lattice conveyor) to a temporary storage bin, or area, from which a lattice card feed draws fiber at a controlled rate. An automatic weighing system is usually used to control the thickness of the fiber fleece fed to a roller-top card (Fig. 8.4). Breast works, diagram (a), are used to feed fibers to the first main cylinder of a card of the sort shown to small scale in diagram (c). It was once thought that at least five licker-ins were needed to card wool, but the introduction of 'metallic' wire has reduced the necessity for so many. The so-called metallic wire refers to saw-toothed wire of the type illustrated in Fig. 5.12. Special metallic wire (Fig. 8.4(b)) is used to keep burrs and other extraneous matter on the surface of the cylinders and yet allow the fibers to be pressed between the rows of teeth. This arrangement permits the removal of the unwanted vegetable material by bladed burr beaters. Special wire-covered Morel cylinders work with burr beaters and are often substituted for the redundant licker-ins, to provide extra deburring stages. Morel beaters are equipped with special flat-topped wire to keep the fibers on the surface and so enhance the cleaning function. The main sections of these cards give little other opportunity for cleaning.

Burr beaters are in the range of 5 to 6 inches (say, 130–150 mm) diameter and run up to 2000 r/min. Atkinson and Saunders [3] showed that eight-bladed burr beaters, run at about 1000 r/min, were nearly as effective at removing seed/shrive and vegetable matter as similar beaters running at 2000 r/min. Eight-bladed beaters were preferred to two-bladed ones. Various blade profiles were used and high relief angles were used. Burrs were removed at up to 80% efficiency and seed/shrive at up to 60%.

Morel clearance and surface fiber density are of importance. The wool in the waste varies between 10% and 20%, the bulk being mostly vegetable matter. Efficiency of removal of unwanted matter depends largely on the speed of the beater, up to a limiting value of about 1800 r/min. Clearance between the burr beater and the Morel has an effect on efficiency; opening up the clearance by 2.5 mm drops the efficiency by about 15% [4]. On single swift cards, two Morel/burr beater pairs are placed in tandem between the forepart, or breast works, and the swift [5]. Deburred and roughly opened fiber is transferred from the last licker-in or Morel beater to the first main cylinder (or 'swift').

The main cylinder carries the fiber to the first worker/stripper fiber combination (Figures 8.4(b) and 8.5(c)). The surface speed of the worker (which is the larger of

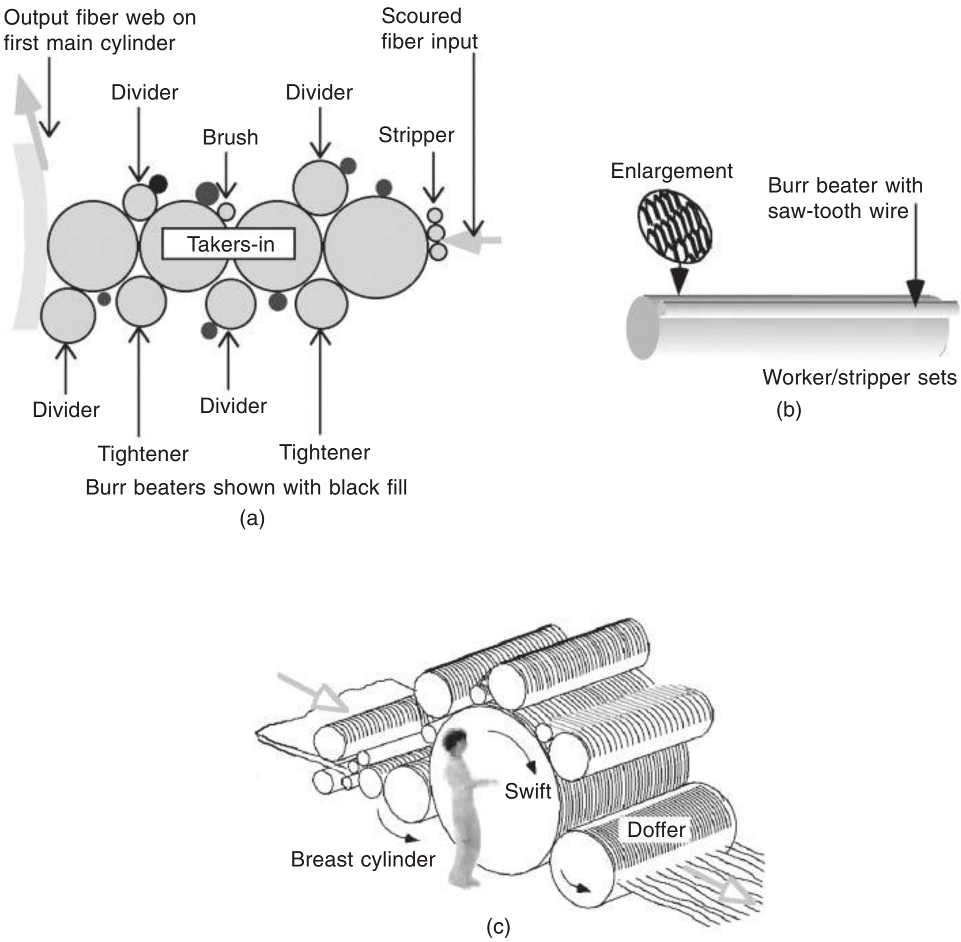


Fig. 8.4 Roller-top card

the two rollers) is less than that of the cylinder, and the teeth are angled to pick up fibers rather like a doffer. As the fibers picked up by the worker move away from the cylinder, the rapidly moving cylinder teeth comb out the trailing ends of the retreating fibers. The stripper runs at a higher surface velocity than the worker does, and this causes fibers to be stripped from the worker and to be drawn and combed again before being returned to the cylinder. Fiber can take various paths as indicated in Fig. 8.5(b). The surface speed of the stripper is less than that of the swift, so it acts rather like a licker-in, and the teeth are angled to facilitate the fiber transfer. Typical relative velocities of the various components, taken in the order that most fibers meet them, are shown in Fig. 8.5(c). Within the normal range of settings between the wire surfaces, there is surprisingly little effect on the production of noil obtained in later combing [5]. However, the speed of the set is important in determining the noil percentage which implies that it has an effect on fiber breakage. Robinson [6] suggests that fine worsted-style wools can be carded at higher rates than normal, provided an antistatic lubricant is used. It will be noted that worker/stripper sets replace the flats used in short-staple processing. Worker/strippers not only fulfill a similar function of dividing tufts, but also give greater longitudinal blending than can be achieved with flats.

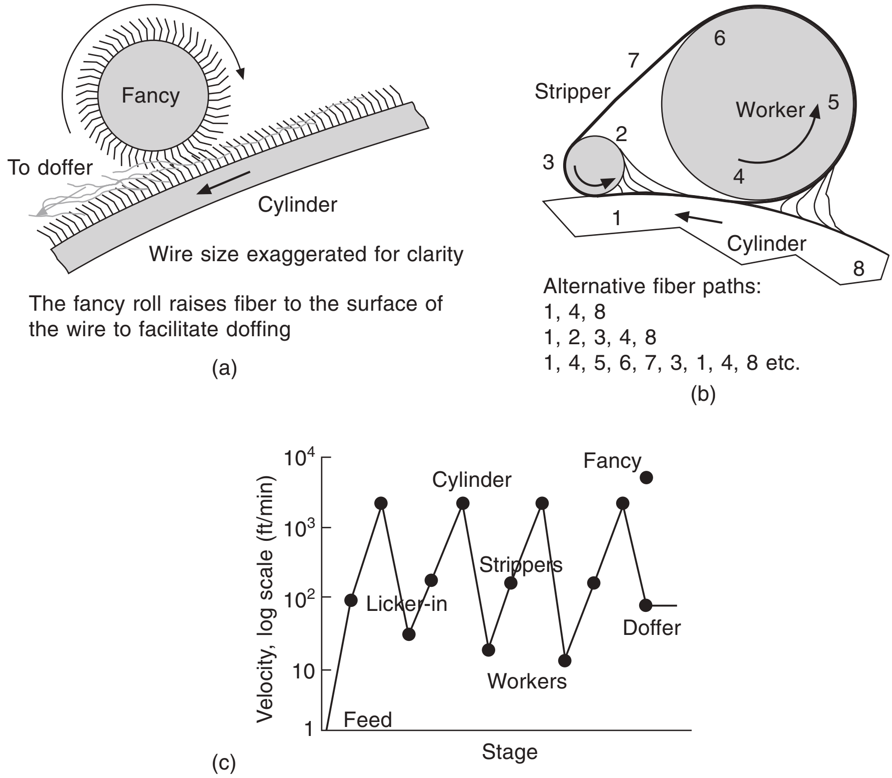


Fig. 8.5 Carding elements

The layers of fibers on the swift may be considered to consist of a component from the feed and a component of recycled fibers, due to the inefficiency of the doffers. The swift-to-doffer setting, and the speed ratio between them, affects the efficiency of fiber transfer to the doffer. The fact that there is a choice of fiber path at each worker/stripper means that there are longitudinal displacements of successive proportions of fiber and this gives a useful blending action. Errors tend to be smoothed out by these random lengthwise relocations of the fiber population. There are several stages of working and stripping on each main cylinder. Normally, several main cylinders are used in series in a normal carding set; consequently, there can be up to about a dozen worker/stripper stages in the total process. Incomplete fiber separation and entanglement of fibers in the material delivered by the card affects fiber breakage in later processes.

Web is transferred from one main cylinder to the next by means of an intermediate doffer cylinder. Often crush rolls are used at this point, to reduce the size of any small burrs left in the stock after the deburring phase of the process. Many of the crushed burrs fall out from the fiber because the crushing tends to break up the spikes and sharp edges of the burrs. Also, a Morel burr cylinder is often fitted at the transfer point. Fibers leaving the last worker/stripper tend to be deeply embedded in the cylinder wire, and it is necessary to raise the fiber to the surface to facilitate doffing. A ‘fancy roll’ (Fig. 8.5(a)) carries out this function and the member has long, flexible wire teeth. The surface speed of the fancy is higher than that of the cylinder, with the result that the fibers are raised and brushed forward to be better caught by the doffer. The doffer is of conventional design and operates much as was described earlier, except for the condensing stage.

8.3.3 Man-made fibers in worsted spinning

The production of man-made staple fibers has been addressed in Chapter 2 but some mention should be made of their use in worsted spinning. If the fiber is to be carded, the man-made fiber is supplied in bales. The unopened bales of fiber should be conditioned for two or three days before cutting the bands and removing the bale wrappings. An rh of between 55% and 70% is usually needed for this purpose. Since the fibers are clean, it is not necessary to risk nep creation by over-carding and ICI recommended low carding rates [7]. The sliver should not be 'backwashed', otherwise the risk of nep production in later processes is increased. Backwashing is a washing procedure which will remove fiber finish from the man-made fibers. Changes in frictional characteristics as compared to wool might require alterations in the back draft in combing. It is considered inadvisable to add oil or other lubricant to the sliver after combing. However, if the sliver is dyed or printed to produce special effects, the fiber finish is removed and a suitable dressing becomes needed to control static generation in subsequent processes. If the sliver becomes matted or compacted, a preliminary opening in a gill box is suggested.

Where the man-made fiber is to be blended with wool, it is advisable to do so in the preparatory gilling stages (Section 8.3.4) before re-combing. This implies that the slivers of wool and man-made fiber have been produced separately. When intimate mixtures of man-made fibers and wool are combed, mixed noil is produced, of variable fiber proportions, and this is of lower value than unmixed noil. Color matching might become a problem, but comb mixing is recommended for the production of high quality tops (i.e. sliver). Differences in coefficient of fiber friction also affect the slubbing (or roving) twist needed; lower values than those normally used for wool might be employed. This has economic advantages. In spinning, different ratch settings might be required from those used with wool. The spinning and folding twist levels required for a given end use are affected by the fibers used. Differing levels are necessary for the various man-made fibers, wool, and blends. Strength is not always the main concern; hand and appearance are often more important.

8.3.4 Long-staple drawing

A traditional drawing operation ('gilling') is carried out on pin drafters. Faller bars with pins in a comb-like configuration move similarly to the simplified fashion shown in Fig. 8.6(a). Two sets of intersecting faller bars are usual. One set enters from the top of the fiber stream, and the other enters from the bottom. There up to 100 such faller bars in a machine and about 30 of them engage the sliver at one time. Studies of pinning density and fiber loading have shown that increased pinning densities can lead to irregularity, probably because of the increased drafting forces produced. However, if the pin density is not increased to extreme levels, the pins act to control unstable fiber movement in the drafting zones. At each drawing stage, a number of slivers are creeled to form the input and this produces a useful doubling that improves long-term regularity and blend. There are usually four stages of drawing before spinning [4]: three stages of intersecting gills and a final stage on a rubbing finisher or speed frame (i.e. roving frame). The gill frames have a restricted productivity of about 2000 faller drops/min and there is an incentive to replace them with rotary gills, or caterpillar drafting or the like. These newer systems obviate the noisy, rectilinear motion of the faller bars. Also, caterpillar and chain gills are capable of a greater length of contact in the draft zones as shown in Fig. 8.6(b). They operate at up to four

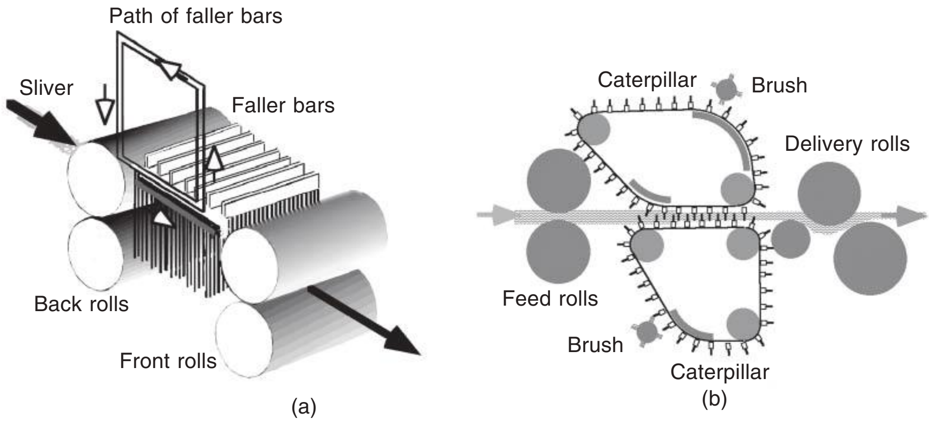


Fig. 8.6 Gilling

times the productivity rates of the traditional gilling frames. Automatic doffing (autodoffing) of the sliver cans is becoming well established with can sizes up to 60 inches (≈ 1.5 m) diameter.

The front roller system in a classical machine is a three-roll set. The drafting, feed, and sensor rolls are often pneumatically weighted and sometimes pneumatic sliver transport systems are used to carry the sliver to the front roll assembly. Sliver mass sensor systems are fitted to new machines and the electrical signals are used as computer inputs; the algorithms in the computer control the short- and long-term linear density variations. Stepless drive motors allow tension controls, as well as the differential speeds necessary to control drafts. Autoleveling systems are frequently used, especially on the first stage of drawing.

8.3.5 Top making

It is more common to make long-staple sliver ready for spinning or drawing elsewhere than it is in short-staple spinning. The combed wool sliver is a high value product and it is worth the extra cost of transport if the material produced by a specialist is of superior quality. Another reason is that the long-staple sliver is more durable because of the use of long fibers. It is common to add as much value as possible before shipping and the material shipped is known as a 'top'. These tops are frequently stored as a ball, in which the sliver is cross-wound onto an external package as shown in Fig. 8.7. This is made possible by the high fiber cohesion in these long-staple slivers.

8.3.6 Long-staple combing

Long-staple slivers are often combed to improve fiber orientation and the appearance of the final product. Blends of natural and man-made fibers may be made by combining ends of sliver in the drawing and combing processes.

Two main combing systems exist but the major one uses the Heilman or French comb, which has a rectilinear, intermittent action somewhat analogous to the cotton comb. The machines are larger than their short-staple counterparts and operate at up to 240 nips/min. Alternatively, tops may be made from tow by stretch-breaking as was described in Chapter 2. At the machine level, new arrangements of drive cams

Fig. 8.7 Sliver ball

combined with the use of lightweight materials have permitted increases in speed without substantially increasing the noise level or adversely affecting the performance of the machines. In modern machines, draw-off aprons control the emerging web, draw-off cylinders are equipped with lap detectors, combs are fitted with cleaners, and computers are used to control automation.

8.3.7 Long-staple roving and spinning

Roving and yarn may be made on equipment that is fundamentally similar to that described for making short-staple yarns. Draft ratios are higher as is the fiber cohesion. Fiber oiling has to be considered. As mentioned earlier, the increased fiber length in worsted systems means that the size of the rolls and the distance between them are correspondingly larger. Yarn counts are heavier and the yarn packages have to be correspondingly larger to prevent undue loss in production due to doffing. This means that larger flyer and ring sizes and lower speeds are used than in short-staple spinning.

In drafting, variable fiber length is often quoted as the most important factor in producing irregularity; however, increasing fiber crimp has also been shown to have a detrimental effect on the ends-down rate in spinning. There is an inference that high crimp causes irregularities. High drafting forces lead to the need for higher roll nip pressures in the drafting system, otherwise slippage between fiber and roll leads to irregularity. High pressures between rolls and soft surfaces in a drafting system tend to damage wool. Apart from the dangers of fiber lapping, it is desirable to use as large a diameter drafting roll as possible because small rolls produce high pressures. The diameter is limited, of course, by the roll setting and that, in turn, is related to the fiber length. Historically, various twisting systems were used that included ring, mule, and cap spinning; but the use of the latter two has declined and we need only concentrate on the ring frame. It is interesting to note that better results are obtained with increasing mean fiber length, but that variability in length seems to have little effect. Fiber diameter and percentage of short fibers correlate with the frequency of thick spots in the yarn [8].

8.3.8 Worsted spinning

In principle, long-staple ring spinning is similar to that described for short staple. Consequently, the descriptions will not be repeated. Yarn tension in spinning is a function of the yarn count, spindle speed, ring size, and some other factors. With the heavier counts in long-staple spinning, it is desirable to increase the ring size with the heavier yarns, not only to reduce doffing costs but also to reduce the incidence of knots or splices. To maintain an acceptable spinning tension, it is necessary to reduce the spindle speed and/or reduce the balloon size. It is here that collapsed balloon spinning finds its place (see Appendix 9). Differences in count and running conditions lead to means of controlling fiber flow that differ from those already described. Because of the wide range of products, there is a wider band of technology in long-staple spinning than in short staple. As examples: rings are sometimes lubricated; traveler designs are more varied; and travelers can be made of polymeric, composite, and steel materials. The large packages typical of worsted spinning require that the bobbin length be large. This implies a significant variation in spinning tension during spinning unless the bobbin is moved up and down during the wind, to keep the balloon length about the same. Some machines do this and some oscillate both the bobbin and ring rail for this purpose. The mechanical complication of this is repaid by a reduction of the variation in tension, which, in turn, leads to a more consistent product and a reduction in end-breakages.

Automatic winding has become established as has the use of electronic clearing, but the joining of end-breaks and cuts during winding is rather more difficult than with short-staple yarns. For medium length staple, splicing is feasible, as explained in Chapter 9. Splicing can give an almost faultless join but knotting is still often used for the heavier yarns. Many worsted yarns are plied and several forms of twisting are used. Traditionally, worsted warp yarns have had to be plied to withstand the rigors of weaving. Plied and quasi-plied yarns are made by ring uptwisting, two-for-one twisting, Sirospun processes (see Chapter 10), novelty twisting systems, and others; the products include not only simple plied but also certain fancy yarns. These fancy yarns have spiral, loop, nub, bouclé, ratine, flake, chenille, or other special effects, but they are too various and complicated to be explained here. In such a wide range of yarns, the requirements for fault clearing in winding vary enormously. It is obvious that the market expectations of a particular yarn must determine the levels at which faults should be removed, and any system must permit variation according to need.

8.3.9 Semi-worsted and related systems

There are two main divisions in long-staple processing of natural fibers and these are known as the worsted and woolen systems, both of which are based on systems originally designed for wool. As new man-made fibers have been developed, the tendency has been to blend them with wool, or to displace wool altogether (wool has become a relatively expensive fiber). The wholly man-made, long-staple yarns have become popular for carpets.

Attempts have been made to shorten process lines to gain some economic advantage. This philosophy has been applied to the worsted system, and although the solutions are somewhat diverse, it is possible to categorize them under the heading of ‘semi-worsted systems’. The most popular use is in carpet yarn manufacture and the count range is between 3s and 12s worsted. A typical system uses a one- or two-cylinder card set with appropriate deburring stages, and there may be six or seven worker/stripper combinations per card. Sometimes two doffers are arranged to give a split web and the left and right portions are converted to sliver. It is possible to use multiple doffers, each producing split webs. Care has to be taken when producing multiple slivers to balance the outputs to keep uniform sliver weights. Such multiple doffer split web cards are made at up to 100 inch width with productivities of up to 450 lb/hr. Often, two or three passages of drawing are used, according to the yarn count (above 10s worsted, say, three passages would be used).

In the post-carding processes, the first drawframe normally has an autoleveling attachment to even out the errors from carding. The first frame can have up to 12 slivers per head in the creel, so there is a considerable amount of doubling to improve the long-term regularity. The intermediate and finisher drawframes might take three slivers per head with a draft of about 8. Therefore, there is a progressive reduction in sliver weight from about 300 grains/yd at the card to about 50 grains/yd at the finisher drawframe delivery. The productivity of the first two frames is about 200 lb/hr but the finisher frame produces only about 60% of this because of the reduction in sliver weight. Tow-to-top sliver making systems have replaced the preparation up to and including the card in some cases but these modified systems are capable of dealing solely with man-made fibers. The yarn is usually spun from sliver. (Note: 100 in ≈ 2.5 m, 450 lb/hr ≈ 200 kg/h, 200 lb/hr ≈ 91 kg/h, 10s worsted ≈ 90 tex, 300 grain/yd ≈ 21 ktex, 50 grain/yd ≈ 3.6 ktex.)

8.3.10 Twisting and doubling

Yarn 'folding' is almost universal for worsted and woolen yarns or blends with wool [9]. Folding is otherwise known as twisting or doubling. (See also Chapter 3.) Long-staple fibers, when well drafted, display low fiber migration, and the peripheral fibers can easily be peeled off; folding stabilizes these fibers and improves the yarn characteristics. Weaving folded yarns is accomplished with fewer end-breaks and the fabrics contain reduced numbers of faults. Two-for-one twisting enables much longer lengths of twisted yarn to be produced without a knot or joint. This, too, improves weaving performance and reduces twisting costs; there is now even less burling and mending of the fabrics and this has helped to assure the penetration of two-for-one twisting in the industry. (Burling is the removal of yarn faults from the fabric.)

8.4 The woolen system

8.4.1 General comment

The woolen system often uses blends of fibers (sometimes with waste fibers) to make a relatively inexpensive, soft, hairy, and full yarn. Fibers used are usually short by wool standards and so are likely to felt. Fabrics made from woolen yarns are often deliberately milled or felted to make them dense with a napped appearance on the surface. Frequently, the yarn strength is low.

Layout of the processes is quite variable in this industry because of the diversity of raw materials. Even if all the components are wool, the fiber properties might vary widely and so might their state of cleanliness. To achieve consistency, it is necessary to blend thoroughly before carding and this might involve several stages. For example, a diversity of fibers might require that some fibers should be cleaned differently from others and each lot might be blended within itself. Even after scouring, color differences might be recognized that require further blending to even out the variations. The intermediate product resulting from the preparatory and blending process is known as a 'willeyed blend' and this product is the feed for the carding process. The card produces a condensed slubbing that goes direct to spinning. Woolen spinning has a short and efficient process line that is less complex mechanically than some of the other systems described. Since the process after the card feed is such a short one and the feed materials are so diverse, there is little further chance of rectifying unevenness (unless the material is reworked). Every opportunity is taken to blend the components because any reworking degrades the material and adds unnecessary expense.

8.4.2 Woolen opening

According to Richards and Sykes [10], wool can vary greatly in its state. The conditions range from clean to greasy and different amounts of dirt are sometimes embedded in the grease. The dirt may be only loosely associated with the fibers. The size of fiber clump can vary from locks to relatively large pieces. Thus, the amount of cleaning and/or opening needed for the different categories varies widely. Excess opening can damage or entangle the fibers and therefore it is sometimes necessary to process different lots of fiber by different equipment running under different conditions before any final blending.

The process of opening uses equipment not dissimilar to the types described for ginning and opening in short-staple spinning or in worsted spinning. Compared to the short-staple devices, the teeth or spikes used are larger but that would be expected in view of the increase in fiber length. Suffice it to discuss only the differences from types already described. The teazer (otherwise known as a wool willow, wool opener, or devil) has many similarities to the opening machines already described. A significant difference is that material is fed to the machine and is left for a predetermined time (the 'draw') to undergo opening within the machine before being removed. This is in contrast to the continuous flow systems described earlier. Another feature, not met with elsewhere, is the possibility of grease build-ups in the equipment. The picker opener is similar to machines already described and will not be further discussed. The Fearnought opener is akin to a coarse-toothed card because it has a cylinder, workers, and strippers. The teeth or pins are much larger than those found on cards. It is a thorough opening device and promotes blending but it is never used to disintegrate the wool pieces to single fibers or even to small tufts because this would interfere with carding.

If recycled material is used, yarn or fabric has to be decomposed into fibers. Briefly, the rags are shredded in a rag picker and then reduced further in a garnet to separate the fibers sufficiently for them to be carded. Naturally this process is rather severe and fiber breakage causes a considerable loss in fiber strength and may cause damage that will show up later. Thus, although it is acceptable for the class of product involved, there are hazards that are not usually found elsewhere. Yarns that have not been completely decomposed into fibers cause trouble in carding and subsequent processes. The so-called threads degrade the product. Some idea of the damage that can be done to recycled fibers is illustrated by Fig. 8.8 where it will be seen that close settings can severely shorten the threads, and by deduction, also the fibers. Recycled material is no longer widely used because of governmental regulations regarding the labeling of reused fiber: the introduction of many different blends and types of fiber has made the identification of the fibers in the rags difficult and this makes compliance with regulations difficult. Furthermore a great deal of the economic motivation has disappeared, and therefore the traditional woolen system is becoming rare. In modern times, large volumes of synthetic fibers are used in the blends. The opening process

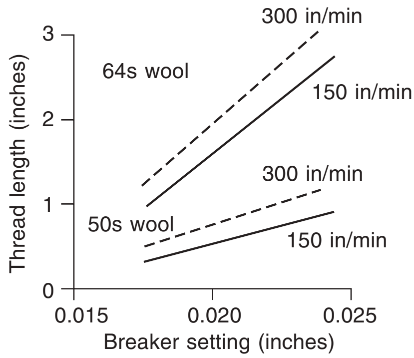


Fig. 8.8 Thread length

has been replaced by more conventional fiber opening and cleaning, using virgin or man-made fiber. Where virgin wools are used, layers of fiber are oiled to plasticize and lubricate them. The man-made fibers need little opening and cleaning; consequently they are introduced later along the process line.

8.4.3 Woolen blending

Hopper feeders are still used to blend fibers. The opportunity is often taken to stock-dye fibers. In such a case, the material then has to pass through squeeze rolls, a dryer, and an oiling section before further processing. After opening and cleaning the fibers to bring them to a compatible state, the main process of blending occurs. Sometimes this is manual but, increasingly, mechanical systems are being used.

In blending, good stock records and good housekeeping are prerequisites to satisfactorily uniform blends. Mistakes at this point usually involve reworking the material, which (a) is an unnecessary expense, (b) increases fiber damage, and (c) adversely affects carding. When reworking becomes unavoidable, it is preferable to take the material from the line before it reaches the Fearnought process, to avoid as much fiber damage as possible. With manual blending, human variability gives rise to additional error possibilities. A reasoned procedure, which takes into account the varying properties of the feed material and the needs of the product to be made, assumes an even greater importance. In manual blending, the components are spread as layers, in an order determined by the specified plan, to take into account mass and composition of the various feed lots. The thickness of each layer has to be as small as is consistent with an even coverage of the area of the laydown. Sometimes the feed lots are pre-blended by various means. Obviously this is a labor intensive and skilled operation. In a climate of high wages, mechanical devices will eventually replace the traditional methods. Modern methods favor pneumatic handling of the fibers and mechanical means of layering or mixing. One form of mechanical blending is the rotary spreader, which deposits a circular layer of fiber in a suitable bin or receptacle. Several feeds can supply the spreader at the same time. An alternative is to pre-blend intermediate lots into the final blend. If Z sections of intermediate lots are each built from the same feed lots and in the same proportions, then a blend with good long-term evenness will result. No matter what the magnitude of Z is, long-term differences are thus avoided. Various opening type machines can be used to improve the local blend, providing they do not break down the tufts too much or damage the fibers. It is possible to supply the willeyed blend directly to a Fearnought or other blending machine if the production rates are properly synchronized. Such a line can be integrated with an oiling system. A site to add the processing agent to the wool is needed. Scouring removes the natural lubricant.

8.4.4 Willeyed blends

A customary final blending is to pass the material through a Fearnought willey that blends what should be small wool pieces or tufts. Despite the care in preparation, willeyed blends still contain differences. Cleanliness can vary, especially if scoured wool is bought and added to the blends. The wool can contain varying amounts of coloration, processing lubricant, burrs, and other vegetable matter. Where man-made fibers are to be blended, no cleaning is needed and the materials are blended at the latest possible stage. Such blending is almost an irreversible process where separation of the fibers becomes quite impractical and the possibilities of reworking become correspondingly smaller. The question of what lubrication is needed for such blends is heavily dependent on the fiber finish applied by the man-made fiber maker. Inhomogeneity arises if the wool pieces are large or the building of lots has been irregular. Sampling and testing inhomogeneous feed lots and the resultant blends are important parts of the technology, the variability; and characters of the feed lots determine sampling rates.

The material is often baled and stored until required for use in further processing. Alternatively, it is stored in large bins, in which case pneumatic fiber transfer systems can be used. The material within each of the bales or storage bins should be as nearly homogeneous as possible in tuft size, fiber composition, and cleanliness. Of course, if stock-dyeing has been used, the variety of dye shades increases the difficulty of stock and quality control.

8.4.5 Initial woolen carding

Conventional woolen cards are fed by card hoppers that usually have a weighpan device to control the mass flow of fibers. Fiber is carried from the main storage bins by lattice feeds to the hopper. The action of the hoppers removes much of the variability that comes from manual feeding. A hopper feeder has two or more bins as part of its structure, together with the necessary moving lattices. Fiber from the large bin is carried on an inclined lattice, which supplies fiber to the smaller weigh-bin. Rakes are used to roughly level the fiber sheet on this lattice and the fibers, which are removed tumble back into the bin. The tumbling action gives a degree of blending and the action of the pins opens the fiber masses somewhat. However, the tumbling can cause aggregation of fiber clumps to unacceptably large new ones. In such cases, the danger of choking becomes greater. The solution is to use appropriate lattice speeds so that the excess removed is not too large. Controllers are used for the lattice drivers and this improves the accuracy of control, especially at high production rates.

The contents of the weigh-bins are dumped periodically (several dumps/minute) on another moving lattice and the flow control is based on the mass of fiber in each weigh-bin. Often the dumping rate is partly determined by the lattice speed. There can be several hoppers, all of which dump their discharges on a common lattice feed, which goes to the card to give another stage of blending: in this case, the dumping times of the various hoppers are co-ordinated. Devices using strain gages and/or other sensors are displacing mechanical weighing systems, and the electrical signal outputs facilitate the use of computer control. Such computer control is capable of leveling several consecutive weighings to deliver a moving average of the input fiber mass and this reduces long-term irregularity in the slubbings. There is a trend to the use of chute feed systems, often in co-operation with a type of hopper feed; this reduces the need for labor and might provide a site for control.

Since the card feed is one of the few practical points for mass flow control, further measurements of the feed sheet thickness are made and there are a number of methods available to do this. The use of a dancing roller, with sensors to detect changes in height, is one way that gives an average across the width of the sheet. Measurement of the penetration by ultrasonic or gamma beams through the sheet provides an alternative source of control signal. In these cases, it is necessary to either (a) choose measurement sites that sample the sheet accurately across the width, or (b) use a scanning device which moves to and fro across the width of the sheet. One reason for the extra control stage is that changes within the hopper can produce errors, especially if there is a tendency for the feed system to choke. Evenness also is needed in fiber proportions and state. The action of pinned rolls can not only fractionate the material delivered into different fiber types and clump sizes, but also cause agglomeration of smaller clumps into larger ones [10]. Varying quantities of dirt, oils, residual grease, and other materials can influence performance and it is quite likely that the measurements used to control the fiber flow will not properly reflect these causes of error. Moisture and some processing agents evaporate over time and this is another cause of variation, especially if water sprays are used in blending. Careful human monitoring is needed to ensure that the blend is within the limits of uniformity in all respects.

8.4.6 First stage in woolen carding

Woolen cards (Fig. 8.9), like worsted ones, nearly always have roller tops because they are less likely to become clogged than non-rotating elements. Locks of fiber can be handled with relative ease by the worker/stripper in combination with a swift (i.e. cylinder). It may be recalled that the workers and strippers perform a blending function because fiber is not immediately removed from the worker/stripper sub-system. The lag in fiber transfer acts to mix early arriving fibers with later ones, as well as to perform the fiber opening and orientation actions of the sub-system.

To give some idea of the dimensions of these cards, a typical swift is about 5 ft (≈ 1.5 m) diameter, the workers and strippers about 8 inches (≈ 0.2 m) and 4 inches (≈ 0.1 m), respectively, and the whole card set might be 20 yd (≈ 18 m) long. The width can be several yards (meters) and the swifts might rotate at up to 200 r/min. These card sets are enormous pieces of machinery and they can process material at speeds up to 500 lb/hr (≈ 227 kg/h), although the range of speeds and sizes varies considerably. Carding forms a large part of the processing set-up in woolen spinning. This means that if a card set becomes non-operational, a large fraction of the production is lost.

Woolen carding is noted for the wide range of equipment groupings and the best that can be done in limited space is to describe a typical set-up. Such a set-up might include a feed system, a breast with perhaps three workers and strippers, a scribbler with perhaps four sets of workers and strippers, a cross lapper, a two-swift carder (i.e. two-cylinder card) with a total of about eight workers and strippers, crush rolls, and a condenser that produces the slubbings. Let us start the description at the feed end. A silhouette of a typical first unit of a set is given in Fig. 8.9.

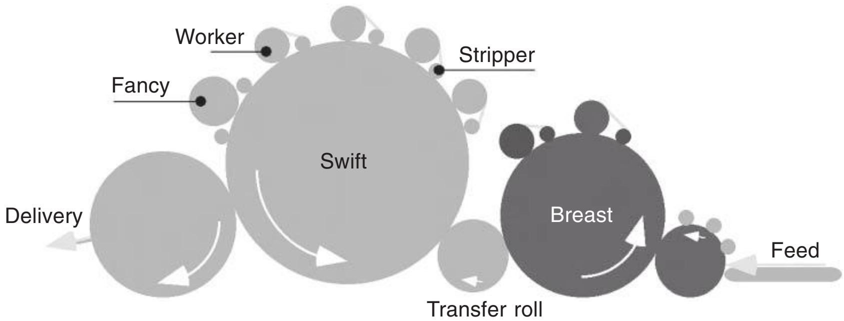


Fig. 8.9 Typical first carding unit of a woolen system

Weighpan hoppers (not shown) drop fiber onto a moving lattice that forms the feed to the card set. The feed rolls are often pinned to grip the fibers without undue compression. The items shown in dark gray may have fairly coarse garnet clothing, whereas later sections may have flexible wire. Garnet clothing is a metallic wire similar to that used in short-staple processing, but with larger teeth. The delivery from this unit may pass to a scribbler (breaker card), which has a similar swift/worker/stripper arrangement, although the swifts are usually larger. The delivery from the last swift of the first carding unit is doffed and passes through a crush roll set. At this point, embrittled vegetable matter is reduced to powder and drops out of the web as it passes through to the carder by way of a cross-lapper.

8.4.7 Cross-lapping

The woolen system differs from the worsted in several different ways. One of the most important differences is that the output often consists of a number of slubbings, each drawn from a narrow band of fiber from the card web. A slubbing might be taken from a region ranging from one selvage to the other. It is highly undesirable for the material to vary over that range otherwise the slubbings would be dissimilar. It is therefore essential that the web be even across its width. One way of improving the across-width evenness is to cross-lap, using a Scotch feed or similar device, somewhere between two of the main cylinders (usually between the scribbler and the carder). The principle is illustrated in Fig. 8.10. Web enters at W on a feed lattice oriented perpendicular to the paper and oscillating in the direction X. The web is laid zigzag fashion on another moving lattice, which moves in direction Z. The direction of oscillation X is usually roughly perpendicular to the direction Z. In many practical set-ups there are two such cross-lapping sections. Web-feed lattices are arranged to complete the changes in orientation of the body of the sheet, so that the feed to the next machine is again in line with the original flow.

8.4.8 The carder

The cross-lapped web then passes to the carder (finisher card), a diagrammatic arrangement being shown in Fig. 8.11. As before, each cylinder has its quota of workers and strippers and the theme of blending continues. It has to be mentioned that many stages of division of fiber tufts are required. Interactions between the swifts, strippers, and workers throughout the system cause tufts to be broken down into smaller ones and thence (mostly) to single fibers. Fortunately, there is incomplete

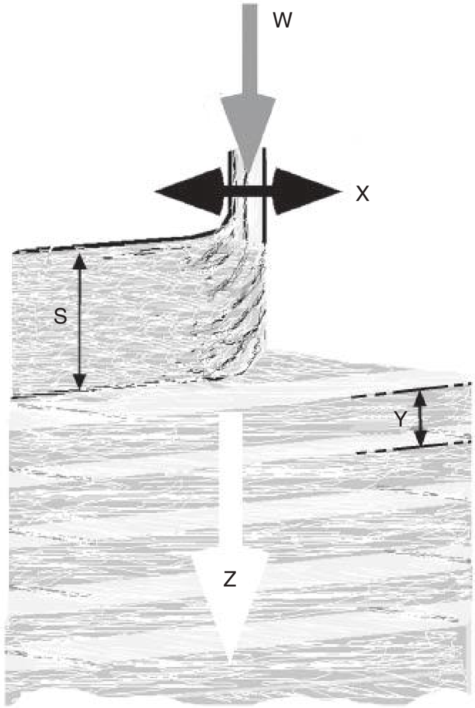


Fig. 8.10 Cross-lapping

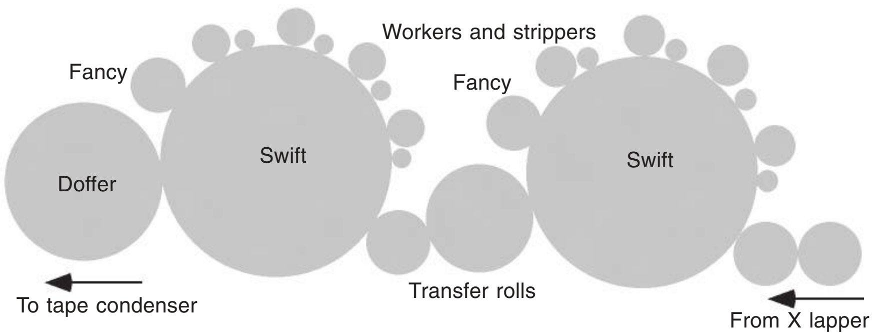


Fig. 8.11 Carder

doffing at these various interaction points and a typical fiber lock recirculates many times; the fiber receives several hundred stages of opening and blending before it leaves the system. The carder delivers web to the tape condenser and all these major units are set in line to make a continuous system.

Dirt gathered under the card has to be removed and safety regulations require the machine to be enclosed. Manual cleaning requires a shutdown if a risky cleaning operation is to be avoided; consequently pneumatic systems are likely to become more prominent. Management of the carding system takes skill and experience.

Flexible wire has not been discussed elsewhere because it is obsolete in short-staple spinning, but it still serves an important function in woolen spinning. In working wool, the fine wires are effective in teasing fibers apart without undue damage. The wire population density varies according to use but it ranges from 100 to 800 points/inch^2 (≈ 0.15 to 1.24 points/mm^2). Wire, usually of round cross-section, is embedded in a base material that is mounted on the surface of the element concerned (e.g. swift, worker, doffer). The cross-sectional area of the wire is small compared to its length and this is what gives it its flexibility. The shape is cranked as shown in Fig. 8.12(a) because it is necessary to have an adequate angle of attack, α, and the angle, β, is chosen so that the height does not change under load. The clearance between co-operating wire surfaces might be as little as 0.008 inches (≈ 0.2 mm) and there is little tolerance for reduction. Changes in the height of the wire alter the setting, and if the setting is reduced, very expensive damage can occur.

Properly selected and maintained wire is important. Another problem associated with flexible clothing is its tendency to load. Fiber becomes embedded deep into the wire and, after a time, this can impair the efficacy of the card. For this reason it is necessary to use a 'fancy' to bring fibers to the surface. The fancy is made of long, flexible wire, and the wires penetrate those of the swift. Despite the fancy, the wire will still load in time. Periodic stripping or fettling of the wire is necessary, which means that fiber trapped by the card wire is removed. Depending on the fiber being processed, it is possible to card between 1000 and 8000 pounds (≈ 450 to 3600 kg) of fiber between fettlings. A card behaves abnormally after fettling until a sufficiency of fiber has been deposited in the wire to give equilibrium conditions. Thus, maintenance involves not only the grinding of the wire, but also the cleaning of the wire interstices (i.e. fettling) and re-establishment of equilibrium conditions. An overloaded surface will not collect fibers and the process begins to break down. As the loading increases beyond a certain limit, the weight of the web diminishes and so does the eventual yarn count. Loading of the cylinders also affects the opening power of the card and it has to be controlled to produce a good yarn without slubs or defects.

The cylinder, worker, and stripper speeds have to be adjusted to suit the fibers being processed. Excessive worker and stripper speeds damage the fiber because of the increased rates at which the fiber tufts are drafted. Workers on the finisher swift (cylinder) should be limited in speed to prevent irregularities, but those on earlier

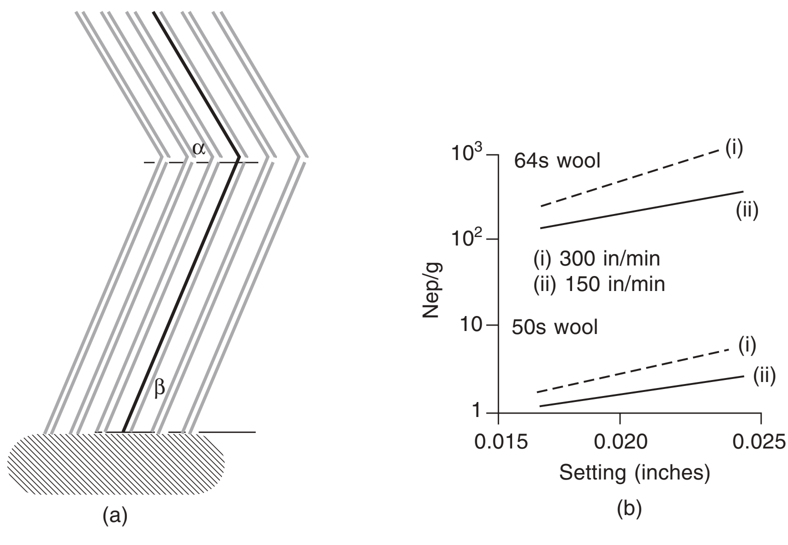


Fig. 8.12 Flexible wire and nep

cylinders might be speeded up to increase the opening effect. Doffer speed and feed rates affect the loading, as do the settings, and these affect performance. Production rates depend on the speed of the swift. Settings and speeds become critical.

The mechanism of transferring fibers calls for comment. The surface speed of the swift is much faster than that of the worker or doffer, and the fibers on the web surfaces are layered like overlapping tiles, with straightened ends projecting forward. Portions of the fibers on the doffing surfaces are brushed by the others on the swift to produce fiber hooks, which affect subsequent processing. The size of the doffer has little effect on the fiber transfer rate, providing the surface speed is kept constant. Moreover, the direction of doffer rotation does not affect it either [6].

As with short-staple spinning, the condition of the wire is important, as are the settings. Worn wire leads to high nep production, which has just as deleterious an effect on quality as in the other systems. The settings are somewhat more difficult to maintain because the wire is not always as rigid as with the systems previously discussed. A definite trend for increased nep was shown as the settings were increased in the experiment portrayed in Fig. 8.12(b). The designation of the wool as an *X*s means that the wool is suitable for spinning to an *X* count of yarn. Thus a 64s wool should be capable of being spun to a 64s yarn. It is a designation of the expected spin limit.

The web leaving the doffer presents another of the easily accessed control points. The web thickness can be measured by various means and the doffer speed can be controlled using the signal from the transducer. Photoelectric web thickness measuring equipment used to adjust the doffer speed can be used to improve the productivity; this is called the autocount system. There is a considerable inertia effect and no short-term control is possible. Limits on the loadings on the swift mean that the average speed of the doffer has to be coupled with the input to the system. Very long-term errors cannot be controlled from signals obtained solely from signals derived from the web; long-term control is better done at an earlier stage. To obtain more accurate control, signals can be obtained from intermediate positions by measuring the fiber on the swifts or doffers using scanning, flat laser beams, or other devices. There is a band of error wavelengths that can be controlled from signals generated by transducers on the card, providing that the long-term average mass flow is also controlled. The web is still a major source of error in woolen yarns. Apart from linear density, long-term variations in the amount of oiling or opening or blending adversely affect the operation; fiber loss or degradation varies accordingly. The blending length of the card set, although very long, is still limited, and the card set cannot remove all these errors. A blending length is defined as the length of web over which variations will be attenuated to a prescribed level. A short blending length implies that the integration process in the card merely ‘smears’ the variation over a short length and even longer-term variabilities pass through almost unsmoothed. The woolen card set is deliberately designed to have a very long blending length. This is because all irregularities in composition and thickness of the web are passed directly to the slubbing and may show up as variations in linear density, color or some other attribute. Thus, every opportunity has to be taken to improve evenness.

One of the several purposes of the card set is to remove unwanted material and the machine is quite efficient at doing that. If, however, the percentage of unwanted matter varies widely within the blend, its removal produces a complementary irregularity in the fibers delivered to the tape condenser (see following section). If the feedstock is properly prepared, this is not too much of a problem, but unless experienced, the workers in preparation might not realize the importance of their work. In addition, the card set can still contribute its errors to the products. Errors produced in, or near, the tape condenser show up as relatively short-term errors in the slubbings. Consequently, there is a very wide spectrum of error and there is no drawframe doubling to even them out. Thus, it has to be again emphasized that there needs to be a great deal of attention to evenness at all stages.

8.4.9 The tape condenser

A prominent difference between the conventional woolen and worsted systems lies in the card delivery. Traditionally, a woolen card set delivers slubbings rather than sliver, and the slubbings are converted to yarn in a spinning machine. However, some woolen systems produce sliver, much of which is used for sliver knitting. The system is also used for non-wovens. These last two uses do not involve yarn and will not be further discussed.

The slubbings or ropings are like roving but have no recognizable twist. A woolen card delivers up to 200 such slubbings, which are created by splitting the web into a number of similar ribbons of web that are rubbed to give the needed fiber cohesion.

Consolidation of the fibers at this stage helps retain the shorter ones and avoid undue fiber loss; the number of active tapes is related to the yarn count required and the web thickness. The system of separation of the sheet into tapes is designed to limit fiber damage, but inevitably there is some short-term irregularity caused by the process. Card web is laid onto a series of tapes, which separate the ribbons (Fig. 8.13). There are a variety of tape arrangements possible but the figure of eight pattern is probably the most popular. The tapes have to be durable and retain their surface characteristics over long periods of time. Slick or greasy spots on a tape can cause local irregularities in the web being divided and so can wear at the edges. Variation in tape tension is another factor, particularly between banks of condensers. The web selvages are usually too uneven or of the wrong weight and are usually discarded or reworked. The useful ribbons are about 1 inch (25 mm) wide and they pass to pairs of rubbing aprons that roll them into ropings. The whole assembly is called a tape condenser. Each slubbing is taken up on a spool and these go direct to spinning. The

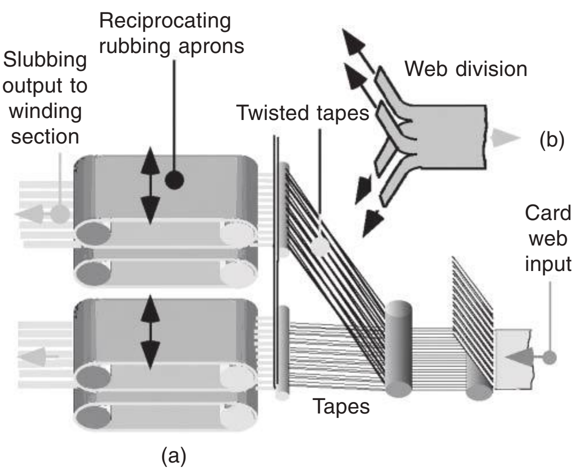


Fig. 8.13 Woolen condenser with rub aprons

material at this stage is fragile and needs careful handling. Out-of-true carding elements, periodic differences in loading, wire sharpness, etc., produce periodic error in the slubbings that can be measured in the laboratory. Truly periodic errors can be recognized and the source of error can usually be determined. However, there is often a larger and more distributed random component for which diagnosis is difficult. Experience and trial-and-error tests are needed to find the sources of these types of errors. Of course, with such a wide range of fiber properties, high levels of random errors are to be expected.

A card set stores a large volume of fibers during operation because of the size of the elements involved and the degree of loading. This has advantages in averaging medium-term errors but it causes significant inertia in the system, which is particularly noticeable on start-up. As the fiber delivery rate alters, so does the wire loading; it moves exponentially to some steady value. Stability is not achieved for several minutes. Care has to be taken in disposing of the slubbings produced during start-up or shutdown procedures. For a five-part card, the transient can be as high as 8 or 9 minutes.

8.4.10 Woolen spinning

Slubbings are usually formed into groups of cheeses on a mandrel and the assembly is referred to as a bobbin. These are then transported directly to the spinning machine, which is often in the form of a ring spinning machine. (Mule spinning still survives in some areas but space precludes a discussion of this.) Bobbins often have flanges to protect the material, because the cheeses are soft and are vulnerable to damage. Denser packages are preferable, because of the more efficient use of space, and it then becomes possible to dispense with the flanges on the bobbins. However, the denseness of the cheeses is quite dependent on the tension that the slubbing can bear, as well as on the wind structure. Undue tension can cause uncontrolled drafting and end-breaks; this represents a limit to the possibilities. Winding lag has to be avoided to get the improved package density that arises from a precise lay. One solution is to use a grooved tension plate. The objective is to lay the material directly on the surface of the cheese, near the nip, between the spool and a drive roll.

Emerging practice is to transport a series of bobbins by endless chains, and creel them in the spinning frame automatically. Arrangements have to be made to ensure that a given lot of slubbing arrives at the proper spinning frame and obviously computer control has a part to play in this. Direct spinning from the slubber has not found favor over the years, probably because of the lack of flexibility inherent in such a system.

In spinning, a strand's weakness makes necessary special precautions in order to locally strengthen the yarn at the weak points. In drafting, false twist is introduced to bring the drafting point closer to the nip of the delivery rolls than otherwise would be possible with large rolls. The false twist runs to the twister surface. Consequently, the effective ratch setting is between the twist transition point and the nip of the delivery rolls. A typical system is shown in Fig. 8.14. The false twist spindle runs at anywhere from 20% to 60% of the main spindle speed. Higher percentages apply mostly to the higher speed spindles [10]. The lower part of the drafting section usually comprises a series of rolls that are fairly conventional. Fiber control is also needed in drafting. Fig. 8.14(b) shows a typical set of rolls. Rolls A and B are the ones shown in diagram (a). D is a fiber control device that fulfills much the same function as an apron in short-staple spinning. The distance between D and E is a function of the fiber length.

The output is twisted and wound by a ring spinning machine similar to those

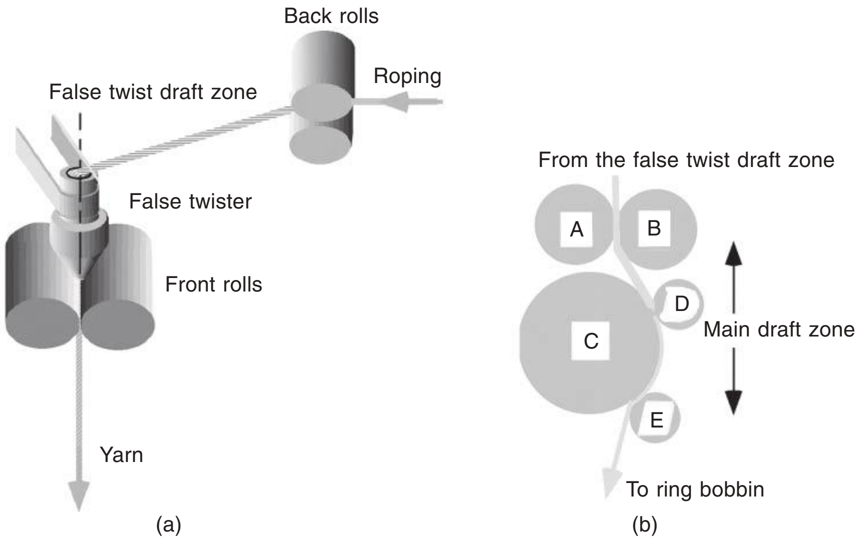


Fig. 8.14 Control of fibers in woolen drafting

already discussed. The tensions caused by spinning are reduced by using collapsed balloons or balloon control rings. Woolen yarns are used as both singles and ply yarns. In this trade, plying is known as doubling. Since woolen yarns have the characteristic of being soft, with good insulation properties, singles yarn has a market for hand knitting yarns and garments where those qualities are prized.

8.5 Bast fiber spinning processes

8.5.1 Conversion of stems to sliver

The process of converting flax, jute, and hemp consists of hackling, preparation, and spinning. The first step (i.e. hackling) is to (a) split and separate the fibers that are gummed together at the start of the process, (b) disentangle them, and (c) parallelize them as far as possible. The remaining broken, shorter, raveled fibers form a tow, which is a byproduct of the process and regarded as inferior. Yarns are also made from this tow. Traditional hackling was performed by hand, using spiked boards, but more modern practice uses machinery. The first stage of hackling is known as roughing. A principal component of a roughing machine is a moving band carrying spiked bars containing hackling stocks, which work on the 'stricks' of rough flax and carry out the first rough separations. Successive stages have ever finer teeth, more closely packed to finish the process, the finest pitch being about 60 pins/inch (≈ 2.4/mm). Fiber bundles are moved from one hackling band to a neighboring finer-toothed one for further processing. This process continues until the bundle reaches the finest hackling band. The root ends are hackled first, the 'combed' end is clamped, and the other end is hackled in a manner similar to that just described. The tow made during these processes is stripped from the teeth of the bands by brushes whose surface speed exceeds that of the pins. The stricks of hackled fiber are then sorted into different qualities; smoothness, luster, hand, and cleanliness are factors that determine the quality.

Fiber bundles of similar quality are fed to spreading frames which transport sheets of fibers to a drawfame for a gilling operation similar to that already described. The lengths of flax on the spread sheet entering the drawframe must overlap to give cohesion and evenness; also, several parallel sheets are used to give a doubling that reduces unevenness. The output of the drawframe, just as in the other similar processes described elsewhere, is referred to as sliver and is stored in cans. In all, it is practice to use at least four drawings and to creel between four and twelve slivers to give a large amount of doubling. It is common to use a cumulative doubling ratio approaching 1500:1. (It will be remembered that the doubling ratios for each stage are multiplied together to calculate the cumulative doubling ratio.)

Manufacture of yarn from tow follows a different process. First, the tow contains shives (woody material) and other impurities, which have to be removed. Opening and cleaning equipment is somewhat similar to that used in short-staple spinning. It is then carded using one- or two-card sets, depending on the quality and cleanliness of the input material. The card sliver is then drawn and spun in similar fashion to that used to produce other bast fiber yarns.

8.5.2 Spinning bast fibers

Spinning can be done using one of two systems. The dry spinning system is used for coarse yarns; a roving stage similar to those already described is used to produce an intermediate product. Sometimes another flyer spinning system is used to produce the final yarn and sometimes a ring frame is used. Wet spinning is used for finer yarns. The rove (roving) is passed through a trough containing hot water and the rest of the spinning is carried out wet. The water dissolves the gummy substances and provides freedom for the fiber to slide in a controlled fashion in drafting, with the result that evenness is much improved. Twistless spinning of cotton using wet drafting showed the same effects [11]. Spun yarn is then usually wound into hanks containing 300 yd. These hanks are referred to as leas or cuts. The grist (count) is calculated by the number of leas/lb.[3] There are other count systems, which will not be enumerated. The hanks are dried and then worked by twisting and untwisting them to dispel the wiry feel of the yarn; this breaks down the gummy adhesions, which give the wiry hand. Fine linen yarns are often bleached before passing to the lace maker or weaver. Linen thread involves the plying of very fine linen yarns.

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3 This is yet another yarn count system to add to those described in Appendix 1.

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