5 Materials Preparation Stage III: Drawing, Combing, Tow-Top Conversion, Roving Production

In Chapter 3, a card sliver was described as a thick, untwisted rope of fairly randomly oriented fibers of various configurations. Depending on the fiber fineness, a card sliver of, say, 4 to 6 ktex may have of the order of 20,000 to 30,000 fibers at each cross section throughout its length. In comparison, yarns of 5 to 200 tex may have around 50 to 500 fibers in their cross sections. To produce yarns of such counts and with acceptable properties, fibers in a card sliver have to be straightened, aligned, and parallelized so that the sliver count can be appropriately reduced to obtain the required yarn count during spinning. The processes within stage III are the usual steps employed in preparing the carded material for spinning.

5.1 DRAWING

Definition: *Drawing* is the term applied to the operation involving the doubling and roller drafting of slivers.

Definition: *Doubling* is the combination of several slivers that are then attenuated by a draft equal in number to the slivers combined, thereby resulting in one sliver of a similar count.

Definition: *Roller drafting* is the process of attenuating the count of a material using a combination of pairs of rollers.

Before describing the basic features of drawing machines, it useful to consider the principles of doubling and roller drafting, particularly as the latter is also applicable to roving production (which is one of the stage III processes) and to several of the spinning processes described in Chapter 6.

5.1.1 PRINCIPLES OF DOUBLING

This involves placing several slivers in parallel (usually 6 or 8) and roller drafting the combination using a draft equal to the number of juxtaposed slivers. Doubling serves two purposes. It enables the reduction of sliver irregularity and improves the blend or mix of the fibers.

The effect on sliver irregularity can be explained by a simple example. Assume the measured average counts of cotton slivers from a set of six cards are 4.85, 4.95, 5.25, 5.42, 5.05, and 5.13 ktex with the cards being set to give a (calculated) count of 5 ktex. Although some of the sliver counts are close to the set count, the spread may be outside the required limits. If these slivers are combined and attenuated by a draft of six, the resulting sliver count would be 5.1 ktex. The sum total length of the original six slivers would therefore be much closer to set count. We refer to the 5-ktex sliver as the outcome of a doubling of 6. Let the following be the sliver counts of five lots of six slivers resulting from five similar doublings of 6: 5.15, 5.09, 5.05, 4.95, and 5.12 ktex. Then, doubling these along with the 5.1 ktex sliver would result in a sliver count of 5.08 ktex. This would be the outcome of a doubling of 36 of the original slivers. A third repeat would give a doubling of $(6 \times 6 \times 6) = 216$. In general terms, the number of doublings is given by the expression S^R where S is the number of juxtaposed slivers and R is the number of repeats. Theoretically, the limiting value of R will be where no further reduction in the irregularity can be obtained. In practice $R = 2$ or 3 is usually accepted as sufficient.

Since the measured sliver counts are based on 1- to 5-m lengths, then the above illustrates the effectiveness of doubling in reducing the medium- to long-term range of sliver irregularity. With respect to short-term irregularity, we will need to consider the effect of doubling on what is termed *drafting waves.* This is dealt with in the next section, on the principles of roller drafting.

To appreciate the blending effect of doubling, the physical meaning of S^R will be explained. Referring to our example of when $S = 6$ $R = 1$, if three of the six input slivers were black in color and the remainder white, and the side-by-side combination was of alternating colors, then the output sliver would consist of six fiber ribbons of alternating colors. Each ribbon would be one-sixth of the count of its original sliver. The second repeat of doubling, when $R = 2$, would result in the output sliver comprising 36 fiber ribbons of alternating colors, each 1/36 of the count of its original sliver. As fewer and fewer fibers of the same color are grouped together with successive doublings, the general color of the output sliver turns grey. Figure 5.1 illustrates visually the blending achieved by this procedure, and it can be seen that $R = 3$ gives a reasonable blend. When considering a larger number of colors, the chosen values S and R *will* need careful consideration.[1]

5.1.2 PRINCIPLES OF ROLLER DRAFTING

The basic principles of roller drafting concern short-term irregularities, although (as we will see later), in the early stages of applying roller drafting, autoleveling is used to minimize medium- and long-term irregularities.

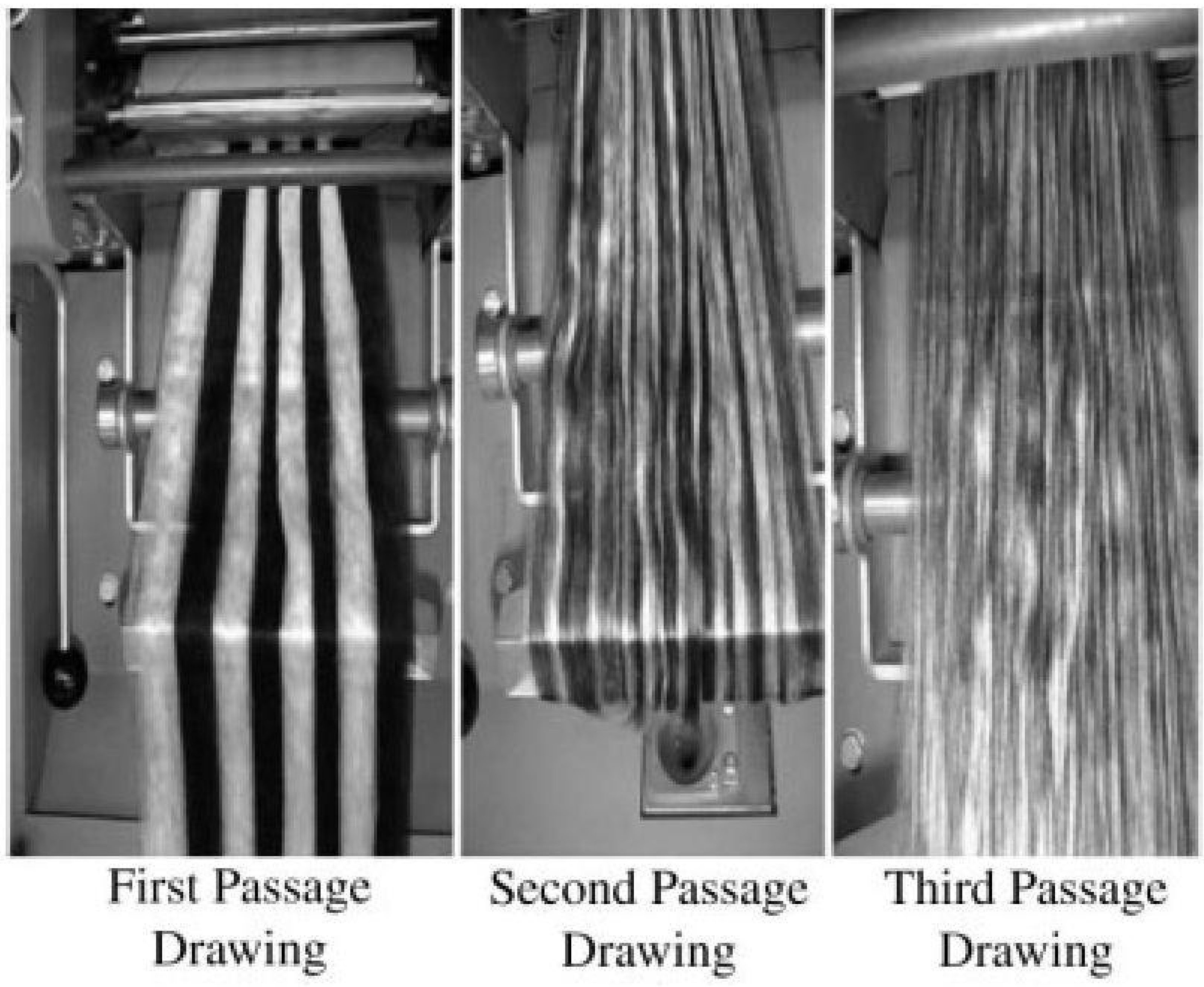

FIGURE 5.1 **(See color insert following page 266.)** Drawframe passages with eight-sliver feed and a draft of eight. Example of blending by doubling and drafting: drawframe blending.

In discussing the irregularity of textile materials, such as card slivers through to yarns, much of what is explained about the drafting of one material state is applicable to drafting of the others. It is therefore useful to explain the basic principles of drafting by referring to these different material forms in a general way, calling them *linear fibrous assemblies.* The irregularity of an untwisted or twisted linear fibrous assembly is recognized by variations in its linear density or count and by variation in the thickness along its length. The latter is often visually conspicuous in yarns.

5.1.2.1 Ideal Drafting

In Chapter 1, it was explained that drafting involves reducing the linear density of slivers and rovings through attenuation whereby fibers are made to slide past one another. It was also explained that drafting increases the irregularity of the material. The increase in irregularity is associated with the way in which fibers move through the drafting zone during their sliding action. To gain an understanding of this, it is useful to consider first the case in which no increase in the irregularity should occur. This situation may be called *ideal drafting*.[2]

Figure 5.2 depicts a single-zone drafting arrangement. The material entering is reduced in thickness as it passes through the drafting zone. For ease of explanation, let us assume that the front rollers B run at three times the surface speed of the back rollers A. Let the fibers in the material be of the same mass M_f (in g) and length L_f (= 3 cm), and let there be N fibers in a length L_1 (in cm) of the material. Thus, the input count of the material is

$$T_{in} = \frac{M_f N 10^5}{L_1} \tag{5.1}$$

Figure 5.3 shows a section of sliver in which it is assumed that the fibers are arranged end to end in the material with a lateral spacing of a. Let us consider the

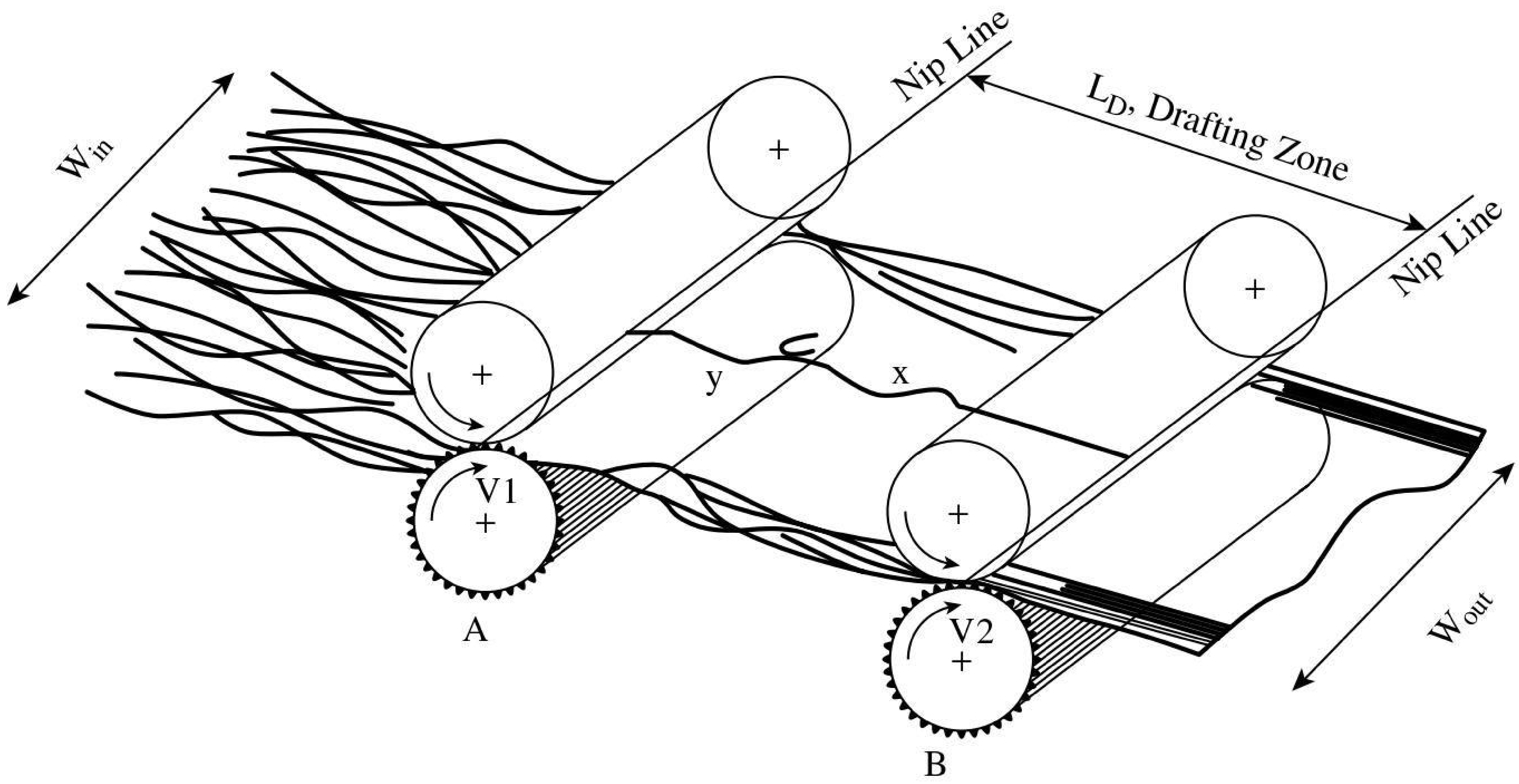

FIGURE 5.2 Single-zone drafting arrangement.

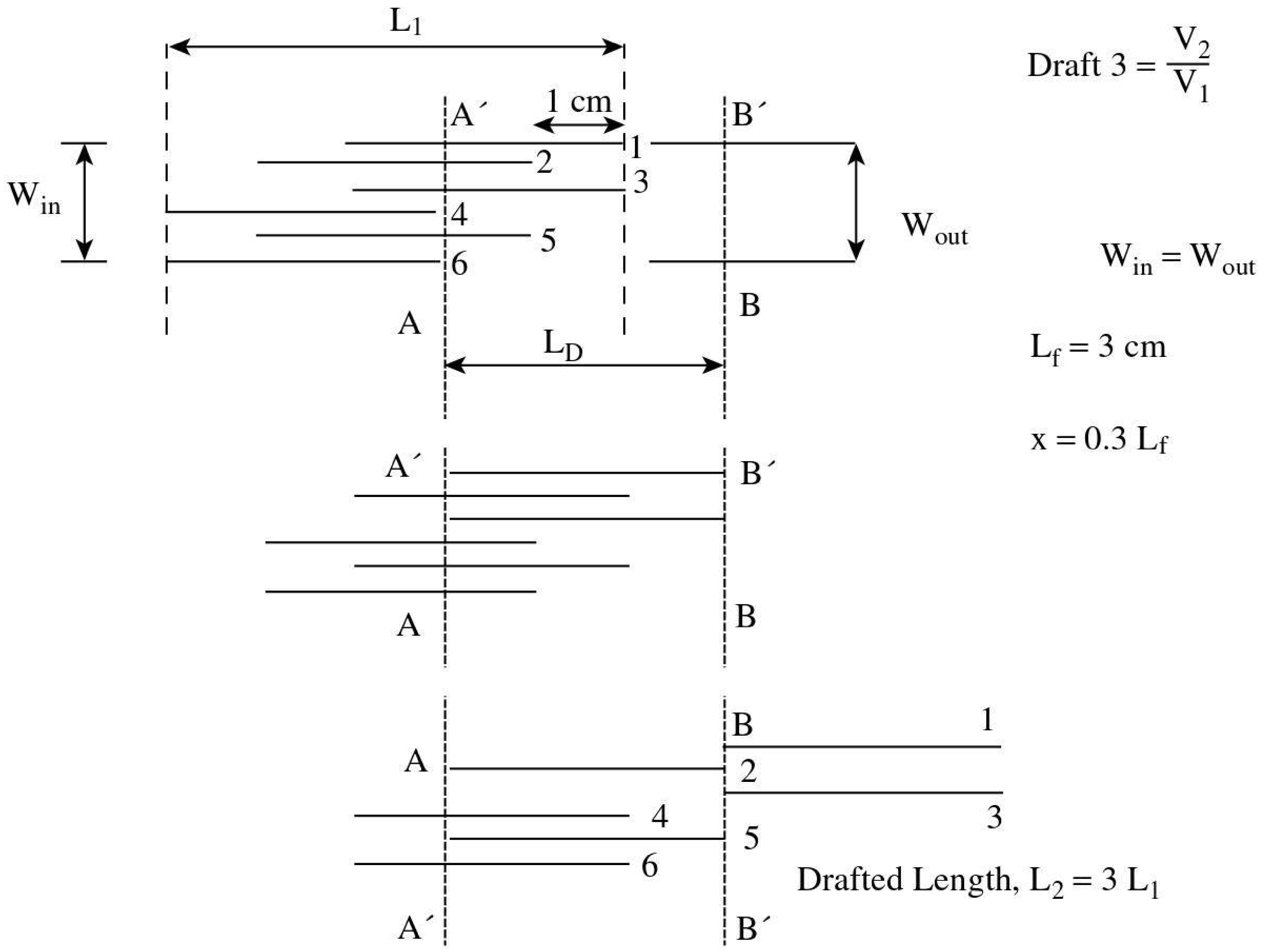

FIGURE 5.3 Representation of perfect drafting.

movements of the fibers numbered 1 through 6. Successive pairs have their leading ends staggered by 1 cm. That is to say, the fiber pairs are equally spaced. This size spacing is not realistic, but using it should help to make the description more easily understood. When 1 and 3 reach the nip line BB′, 2 and 5 and 4 and 6 will be, respectively, 1 and 2 cm behind. On reaching the nip line BB′, 1 and 3 will be accelerated to the surface speed of roller pair B. Since these rollers are three times faster than the roller pair A, then by the time fibers 2 and 5 reach BB′, 1 and 3 will be leaving this nip line. However, 2 and 5 will be accelerated to the same speed as 1 and 3 and will leave the nip line just as 4 and 6 arrive. Note that, when 4 and 6 leave BB′ with the same speed as the previous fiber pairs, the distance between the leading ends of successive pairs has increased three times. This means that the drafted sliver length $L_2 = 3L_1$. The number of fibers in L_2 will still be N and the mass of the drafted length NM_f. Thus, the count has changed to

$$T_{out} = \frac{M_f N 10^5}{L_2} = \frac{T_{in}}{3} \tag{5.2}$$

Although the input and output widths of the material are the same, the vertical interfiber spacing has increased, indicating that the output must be lighter than the input. However, the output retains the irregularity of the input, because the leading ends of the fiber pairs remain equally spaced.

The equal spacing between the fiber pairs is retained with drafting, because the fiber speed changes from that of the back rollers only when, simultaneously, the fiber leading ends are nipped by the front rollers A, and their trailing ends released by the back rollers, B. This is ideal drafting, and it does not cause an added component to the input irregularity. The effect of the perfect draft is to increase the distance between the leading ends of fibers by the multiple of the draft. Therefore, any variations in the fiber distribution along the length of the input material merely reoccur in the drafted length.

Thus far, we have considered the ideal drafting action from the view point that the total number of fibers in the length L_1 must be present after drafting in L_2. If the number of fibers in the cross sections of L_1 and L_2 are, respectively,

$$n_1 = \frac{M_f N 10^5}{L_1} \cdot \frac{L_f 10^{-5}}{M_f} \quad \text{and} \quad n_2 = \frac{M_f N 10^5}{3L_1} \cdot \frac{L_f 10^{-5}}{M_f}$$

then

$$n_2 = \frac{n_1}{3}, \text{ or } n_2 = \frac{n_1}{D}$$

where D = the applied draft

Figure 5.4 illustrates the changes in the number of fibers in the cross-section along the drafting zone from the back to the front-roller nip lines. The length inside the drafting zone of the fibers moving at the back roller speed will be equal to those moving at the front roller speed. These fiber groups are referred to as the *back* and *front beards*. It follows that the total surface area of fibers moving with the back roller speed will be D times greater than the total surface area of fibers moving at the front roller speed. The interfiber friction relating to the two surface areas account for the drafting force associated with the attenuation of the material.

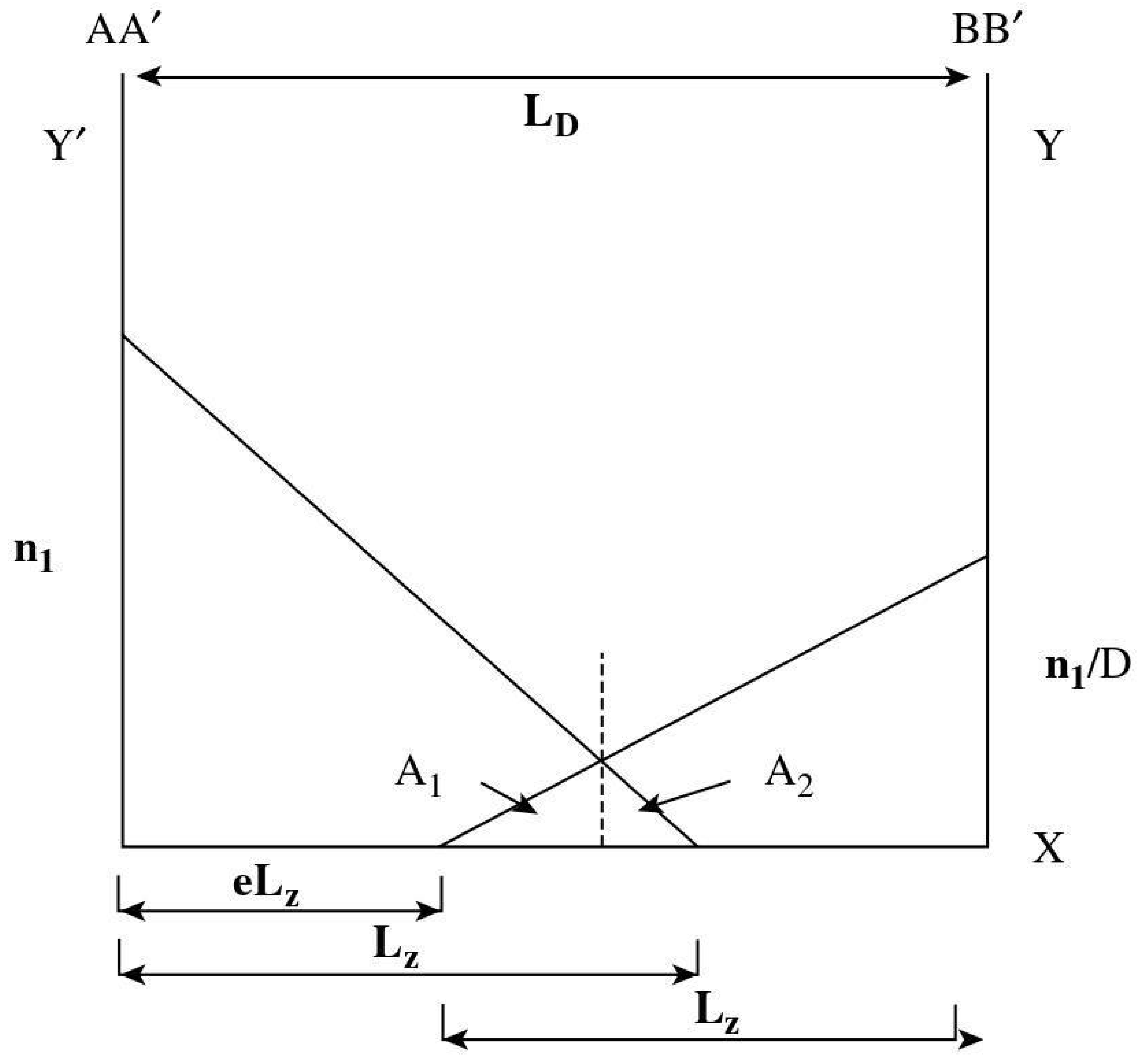

FIGURE 5.4 Changes in the number fibers in the cross section from AA′ to BB′.

Based on the concept of perfect drafting, El-Sharkawy et al.,[3] used the following assumptions to derive a simple relationship between the drafting force, F, the number of fibers in the cross section of the input material, n_1, the fiber length inside the drafting zone, L_z, and the draft, D.

Two assumptions are made.

1. The drafting force is dependent on the level of interfiber contact between the back and front beards.
2. The fiber arrangement in the input material conforms with the requirement for perfect drafting, with n_1 and the fiber-to-fiber contact being constant throughout the length of the material.

From Figure 5.4, the taper of the back and front beards, respectively, are given by[4]

$$Y' = n_1\left(1 - \frac{x}{L_z}\right) \text{ (from } x = 0 \text{ to } L_z\text{)}$$

and

$$Y = n_1\frac{(x - eL_z)}{DL_z} \text{ (from } x = eL_z \text{ to } L_z\text{)}$$

F will be proportional to the number of contact points between the two beards, which in turn are proportional to the sum of the areas A_1 and A_2.

$$A_1 = \frac{n_1L_z}{2}\frac{D(1-e)^2}{(D+1)^2} \qquad A_2 = \frac{n_1L_z}{2}\frac{(1-e)^2}{(D+1)^2}$$

Hence,

$$F = Kn_1 L_z \frac{(1-e)^2}{(D+1)} \tag{5.3}$$

where K = a constant of proportionality

5.1.2.2 Actual Drafting

During actual drafting, irregularities attributable to the characteristics of the fiber being processed and to machine defects are superimposed on that of the input material, thus making the drafted output of a higher unevenness.

Effect of Input Material Characteristics

We saw that, for perfect drafting, fibers in the input materials are assumed to be straight and parallel. All are of the same length, with their leading ends equally spaced, and those on the same horizontal line are placed with the leading end of one following the trailing end of another. This may be consider the ideal fiber assembly for drafting. (Rao[5] reports a mathematical model for the ideal sliver and its application to the theory of roller drafting, to which the reader may wish to refer.) In reality, we are aware that there is a distribution of fiber lengths in a card sliver and that these lengths are not straight, and not all are parallel. Owing to the lack of straightness and parallelism, it is more useful to consider the term fiber extent, illustrated in Figure 5.5.

Definition. Fiber extent is the distance between two planes that just encloses a fiber without intercepting it, the planes being perpendicular to the general direction or axis line of the linear assembly of the fibers.[6]

Instead of the spacing between fiber leading ends, we can consider the spacing between leading ends of fiber extents, noting that, for a straight fiber, both are the same. Figure 5.6 shows that the fiber configurations in card slivers observed by Morton and Summers[7] and Sengupta and Chattopadhyay[8] have differing fiber extents. Thus, there is unlikely to be equal spacing between leading ends of fiber extents in the card sliver.

If the drafting zone length is set less than the longest fiber extent, then, in drafting the card sliver, as the leading ends of these fiber extents are caught by the front

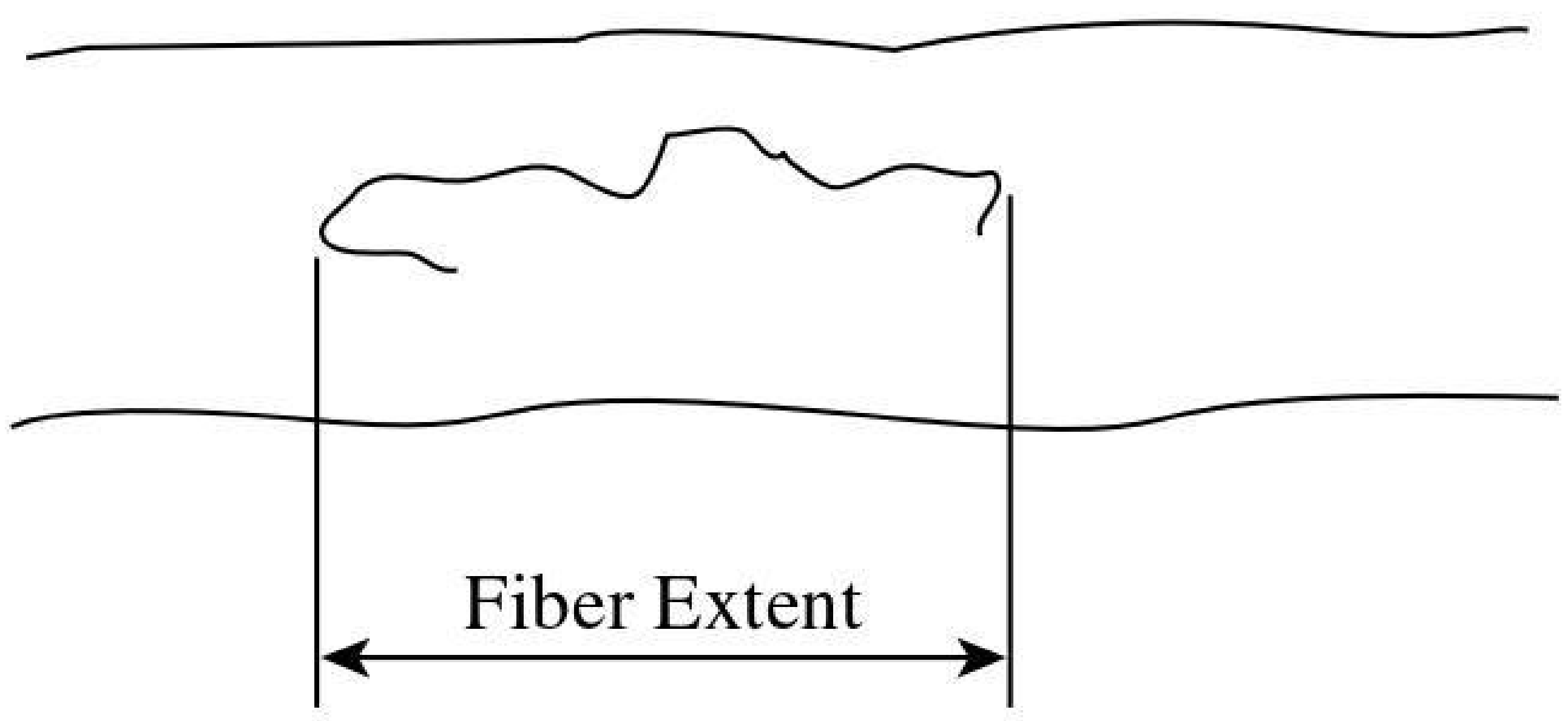

FIGURE 5.5 Fiber extent.

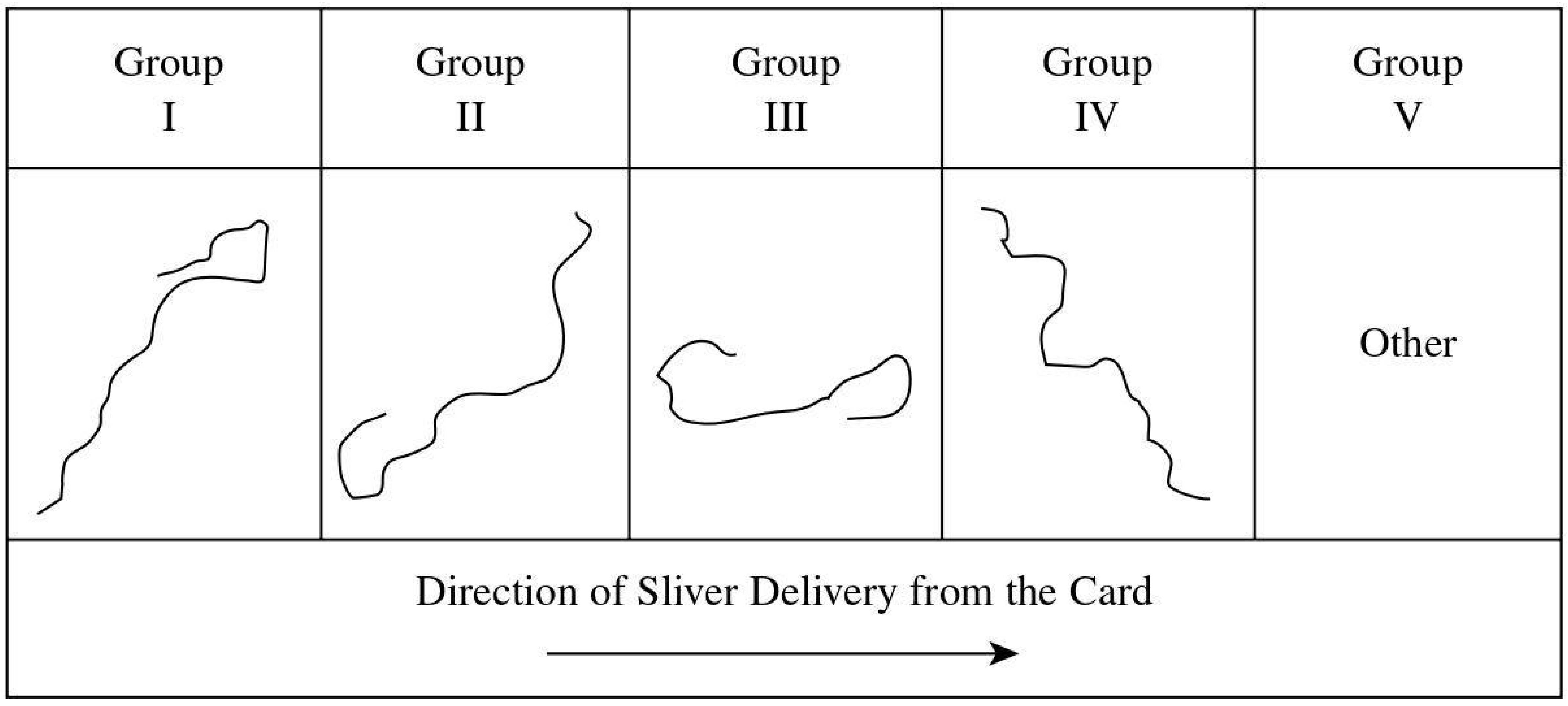

FIGURE 5.6 Fiber configurations in doffer web and card sliver.

rollers, their trailing ends would still be held by the back rollers. Such fibers will be stretched, with some reaching their breaking extension, but the result generally will be groups of undrafted fibers in the output from the front drafting rollers. The combination of the front-roller speed and the recovery from stretch of longest extend fibers gives the effect of material spewing out from the front rollers.

Drafting Wave

If the drafting zone setting is such that the trailing ends of the longer extents are released just as their leading ends are nipped, then spewing does not take place. However, there will be fiber extents that are not nipped by either back or front rollers. These may be called *floating fibers.* On being released from the back-roller nip, these floating fibers will initially travel at the back roller speed, but their subsequent speed of movement to the front rollers will depend on frictional contact with the surrounding fibers. The surrounding fibers that are nipped by the front rollers will try to accelerate the floating fibers while the surrounding fibers nipped by the back rollers will tend to slow the floating fibers. Those floating fibers that are in closer contact with the fibers nipped by the front rollers will be pulled as a group from those held back by the fibers nipped by the back rollers, and they will reach the front rollers earlier than in the ideal case. The front rollers therefore accelerate a thicker group of fibers, leaving a thin length momentarily behind. The fibers in the thin length subsequently reach the front-roller nip and are accelerated to leave momentarily a thicker length behind, and so the process is repeated.

Many floating fibers move prematurely with the speed of the front rollers, either by cohering or entangling with fibers that are positively gripped by the front rollers. The process is cumulative; the greater the number of fibers moving forward with the speed of the front rollers, the more floating fibers are likely to be drawn forward prematurely by interfiber cohesion. In this way, a comparatively large number of floating fibers will be drawn forward at one time to give a thick place in the issuing sliver, and this will be followed by a corresponding thin place that is a result of the loss of fibers by premature movement. The cycle will give rise to a periodic succession of thick and thin places along the length of the material.

Observations of Floating Fiber Motion

Several techniques[9–13] have been used to study the motion of fibers in the drafting zone. Figure 5.7 illustrates the general findings. The figure depicts two things. First, the profile of the number of fibers in the cross section at intervals along the length of the material within the drafting zone AA′ to BB′. When compared with Figure 5.4, a significant difference between the fiber distributions can be seen. This difference is caused by the presence of floating fibers. Second, Figure 5.7 also shows the typical change in speed of a floating fiber as it leaves the control of the back roller pair, at time t_b, and moves to the front rollers, where it is accelerated to the front-roller surface speed in a time t_f. It can be seen that, between moments where a fiber leaves the back rollers and is directly accelerated by the front rollers, its average

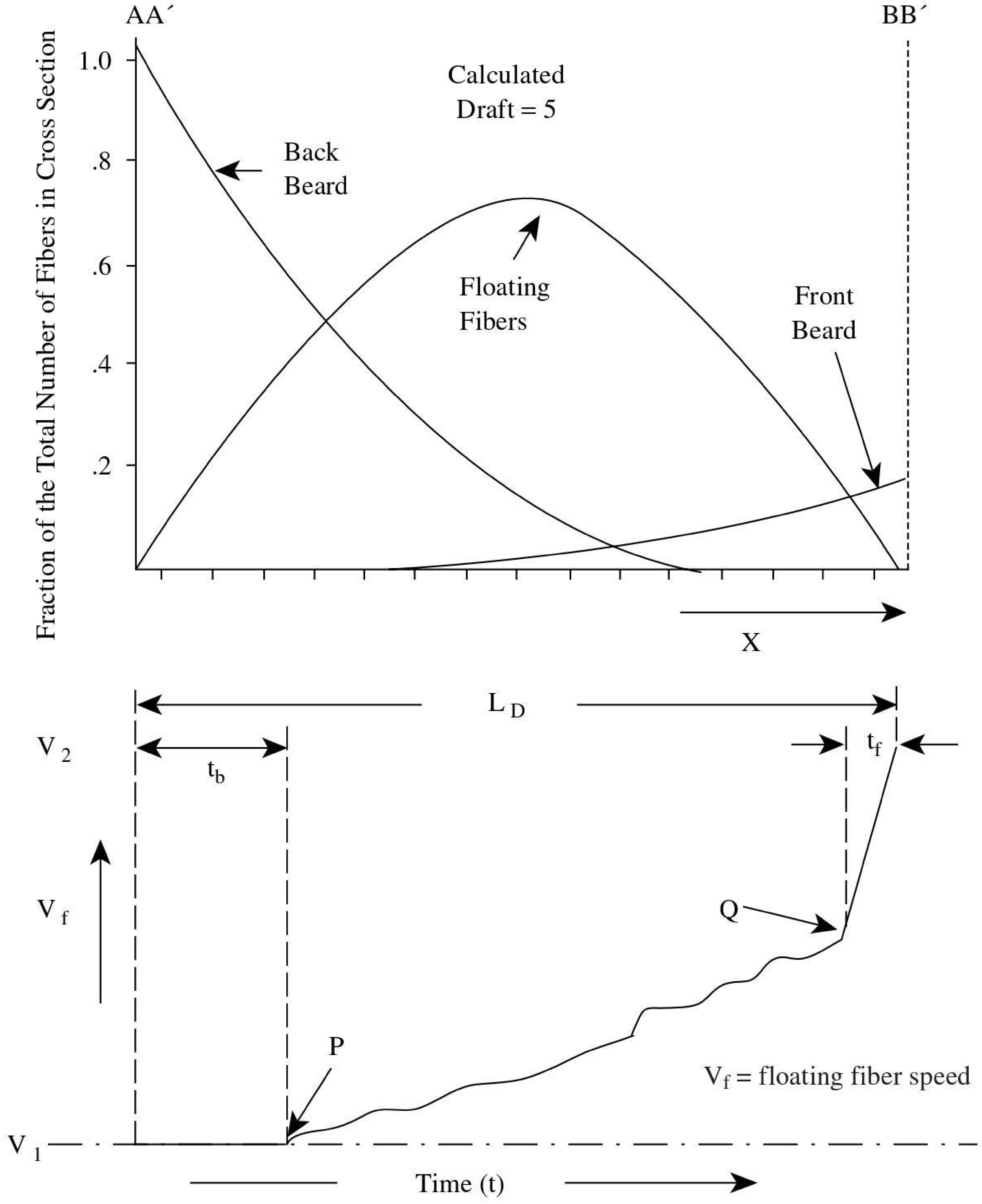

FIGURE 5.7 Changes in the number of fiber in the cross section within the drafting zone from AA′ to BB′.

speed differs considerably from both roller pairs. This speed is not constant. This is because the fiber will depend on its contact with neighboring fibers, and there are moments when forces from friction contact with the front beard cause the fiber to accelerate and when the larger size back beard slows the fiber to near the back-roller speed. It was found that, although the speed limits P and Q in the drafting zone vary from fiber to fiber, the frequency distribution of the mean speeds over this region of a large number of fiber observations had a narrow spread. This indicated the average speed to be similar for the majority of fibers.

The effect of floating fibers is to produce a succession of thick and thin places in the output length where some fiber extents have been drafted in the ideal manner. The thick and thin variation has a sinusoidal waveform and is therefore called the *drafting wave*.[14] The drafting wave gives an irregularity additional to that of the input irregularity.

Many studies have been made to develop quantitative explanations of drafting wave irregularity as a rigorous approach to drafting theory, from the viewpoint of either a mechanical process[14,15] or the statistical nature of fiber movement[15–20] based on the assumption that the speed of floating fibers changes from back- to front-roller speed at some nonfixed point in the drafting zone. In this moving boundary concept, the movement of the change-point causes the irregularity. Several works have involved using mathematical models in computer simulations of the drafting process.[20–23] Both practical and theoretical studies have investigated wavelength and amplitude with regard to their dependence on such factors as size of draft, fiber characteristics, and roller settings.

In practice, the amplitude and wavelength may be determined from Uster irregularity measurements. However, both are very variable because of the irregular motion of the floating fibers, and so it is simpler for the Uster CV% of the input and output to be measured and compared. The difference between the squares of the CV% indicates the added irregularity attributable to the drafting wave, provided that no irregularities resulting from machine faults (see below) are also present. We shall take this approach in considering factors influencing the irregularity caused by the drafting wave.

Drafting Force

Various sliver draftometers have been described in the literature for measuring drafting forces.[24–29] Some use sensors to monitor movement of the drafting rollers, which are mounted on pivots or a flexible plate. Others use transducers to measure the power demand of the rollers during drafting. Generally, it was found that the drafting force has a wave-like variation of a similar wavelength and amplitude to the irregularity associated with the drafting wave. The mean drafting force decreases with the openness of the input material and the degree of parallelism and straightness of the constituent fibers. Fiber crimp is an important parameter; the drafting force increases exponentially with crimp level. With respect to the drafting of card sliver, the force is greater when the majority of hooks are trailing rather than leading. This directional effect persists throughout subsequent repeated drawing operations. With worsted card slivers, up to 1% add-on of most lubricants rapidly reduces the drafting force; 100 cp silicone oil was found to be very effective.[28]

Drafting force increases by only a small amount with throughput speed but is dependent on the static and kinetic friction of the fibers, increasing as these increase. When the roller setting is less than or close in value to the maximum fiber length, the drafting force is high; it decreases as the roller setting is increased.

According to Equation 5.3, the drafting force should decrease with increasing draft. However, observations have shown that, initially, the drafting force increases to a peak value at a very low draft (< 2) before decreasing hyperbolically with increased draft. See Figure 5.8.[26] However, the product of the drafting force and the set draft is always a constant, referred to as the *drafting constant.* The initial rise in the drafting force is likely to be present at the start of drafting, irrespective of the set size of draft. If the draft is >2, the peak value is reached momentarily before the drafting force falls off to a steady-state value. The peak value is attributed to the force needed for straightening and aligning hooked and crimped fibers and to overcome the interfiber frictional resistance to the movement of fibers past one another. The force decreases once the nipped fibers start sliding past those under the influence of the back rollers. When the set draft is <2, the steady-state value of F is near the peak value. Therefore, as the set draft is increased, the tendency is for the steady-state value to initially equal the peak value of the transient state. It then decreases with further increases in the set draft.

Equation 5.3 shows that the drafting force is proportional to the mean fiber length (L_z is proportional L_f) and fineness (in respect of n_1), and therefore it is proportional to the total length of fibers (or the number of fibers) nipped by the front rollers and accelerated to the front roller speed. Hence, the reason given for the force decreasing with set draft is that the front rollers at higher drafts accelerate fewer fibers, and the resistance to their acceleration is lower, requiring a lower force to overcome it. Increasing the number nipped by the front rollers by increasing the count of the input material will cause the drafting force to increase disproportionately to the increase in count. This is because the greater compactness of the input material will increase the interfiber frictional contact.

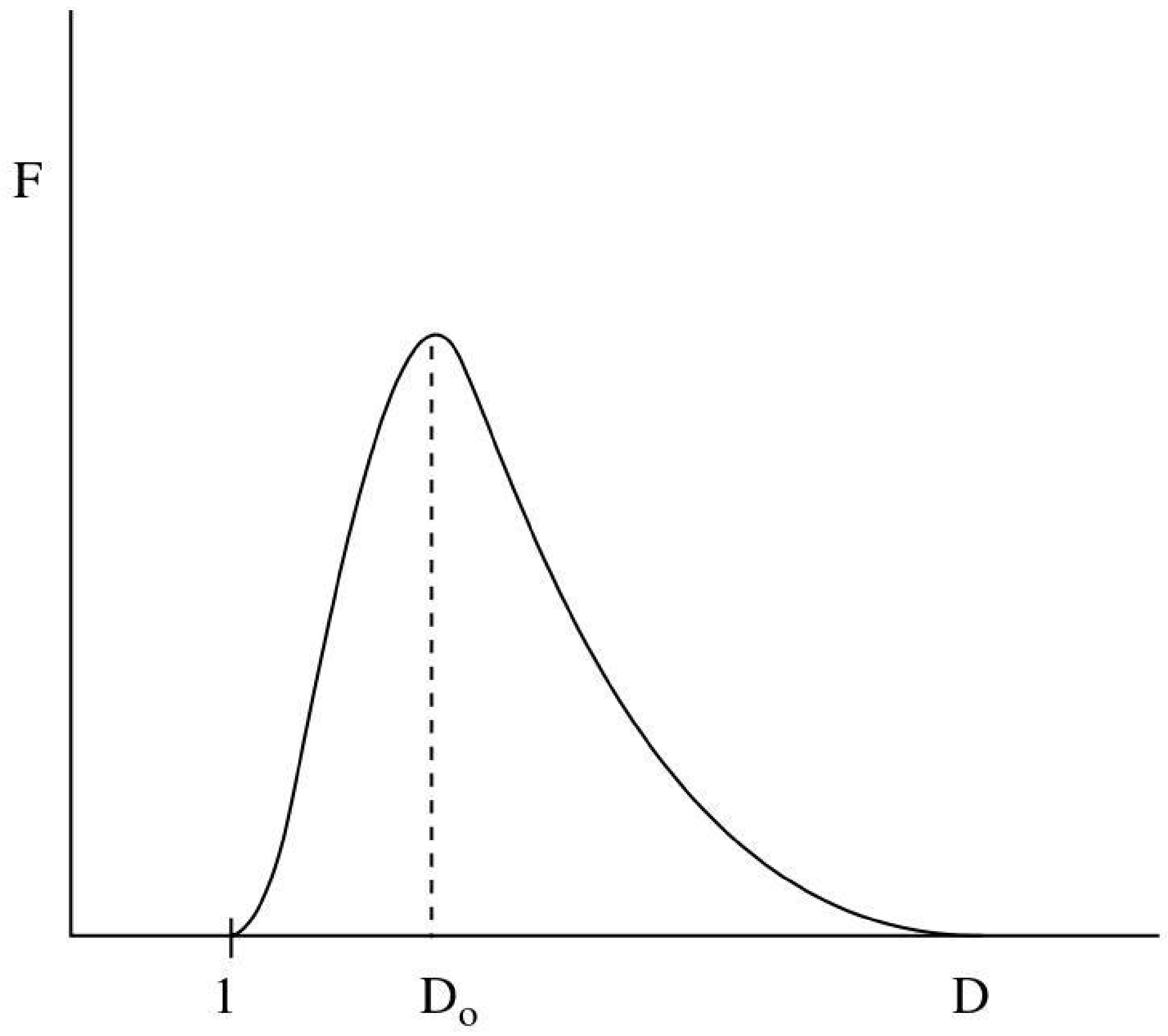

FIGURE 5.8 Relationship between drafting force and set draft.

In Figure 5.8, D_O is the set draft corresponding to the peak force. Up to this value, there is no fiber slippage — just a simple straightening out of fibers and extension of the input material by $D_O - 1$. To allow for this, Equation 5.3 becomes

$$F = \frac{K n_1 L_z (D_O - e)^2}{D - (D_O + 1)} \tag{5.4}$$

This draft D_O raises the issue of the relationship between the set draft and the actual draft applied to the input material.[3] If, as indicated in Figure 5.3, $L_2 = D L_1$, then the increase in length because of fibers slipping past one another is L_1 $(D - 1)$, as it is assumed that the structure (the fiber arrangement) of the input material is inextensible. Thus, $D = 1 + \varepsilon$, where ε is the permanent strain. However, because real fibrous structures show elastic properties at low drafts, the actual draft, D_A, that causes permanent strain will be less than D and is given by $D_A = 1 + (\varepsilon - E)$, where E is the limit of elastic strain for the input material. Waggett[43] describes a method for determining the elastic properties of card and drawframe slivers. As mentioned above, the elasticity of input materials is governed by fiber entanglement as well as the fiber characteristics. Therefore, with repeated drafting of sliver, D_A should get closer in value to D. Figure 5.9 shows that D_A/D varies with increasing set draft D, as expected.

It is the accepted view that the initial extension of the input material by the drafting force generates drafting irregularities.[30–42] This factor has been included in derivations to predict the irregularity spectrum for various mathematical models of input material.[33,37] The reduced elasticity of a material being drafted has been found to result in a lower output irregularity.[30,31]

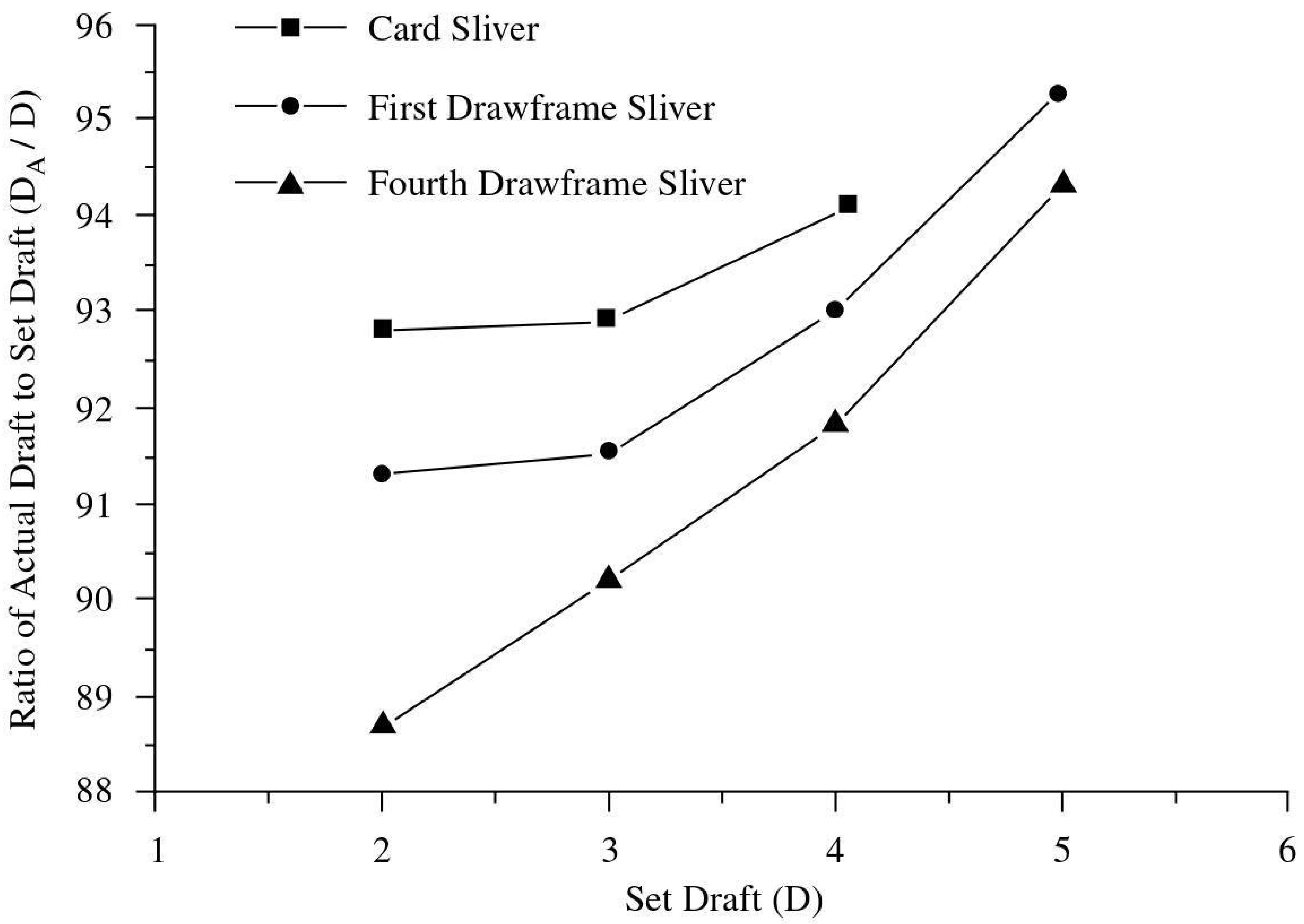

FIGURE 5.9 Relationship between D_A/D and D.

5.1.2.3 Factors Influencing Drafting Wave Irregularity

The factors determining the single zone drafting wave irregularity are

- The size of draft
- The count of the input material
- Multiple inputs or doubling
- Roller or drafting zone setting
- The degree of parallelism, length, and fineness of fibers in the input material

Size of Draft

It can be reasoned that the higher the single zone draft, the fewer the number of fibers in the cross section that will be drafted in the ideal way and therefore the more pronounced the thick and thin places and the greater the irregularity of drafted material. Figure 5.10[80] shows, as an example, that the square of the relative variance of irregularity increases linearly with applied draft such that

$$CV_O^2 = CV_{IN}^2 + a(D-1) \tag{5.5}$$

where CV_O, CV_{IN} = relative variances of irregularity of the output and input material, respectively
a = slope of the line
D = applied draft

Thus, the coefficient of variation attributed to the drafting wave is $\sqrt{a(D-1)}$.

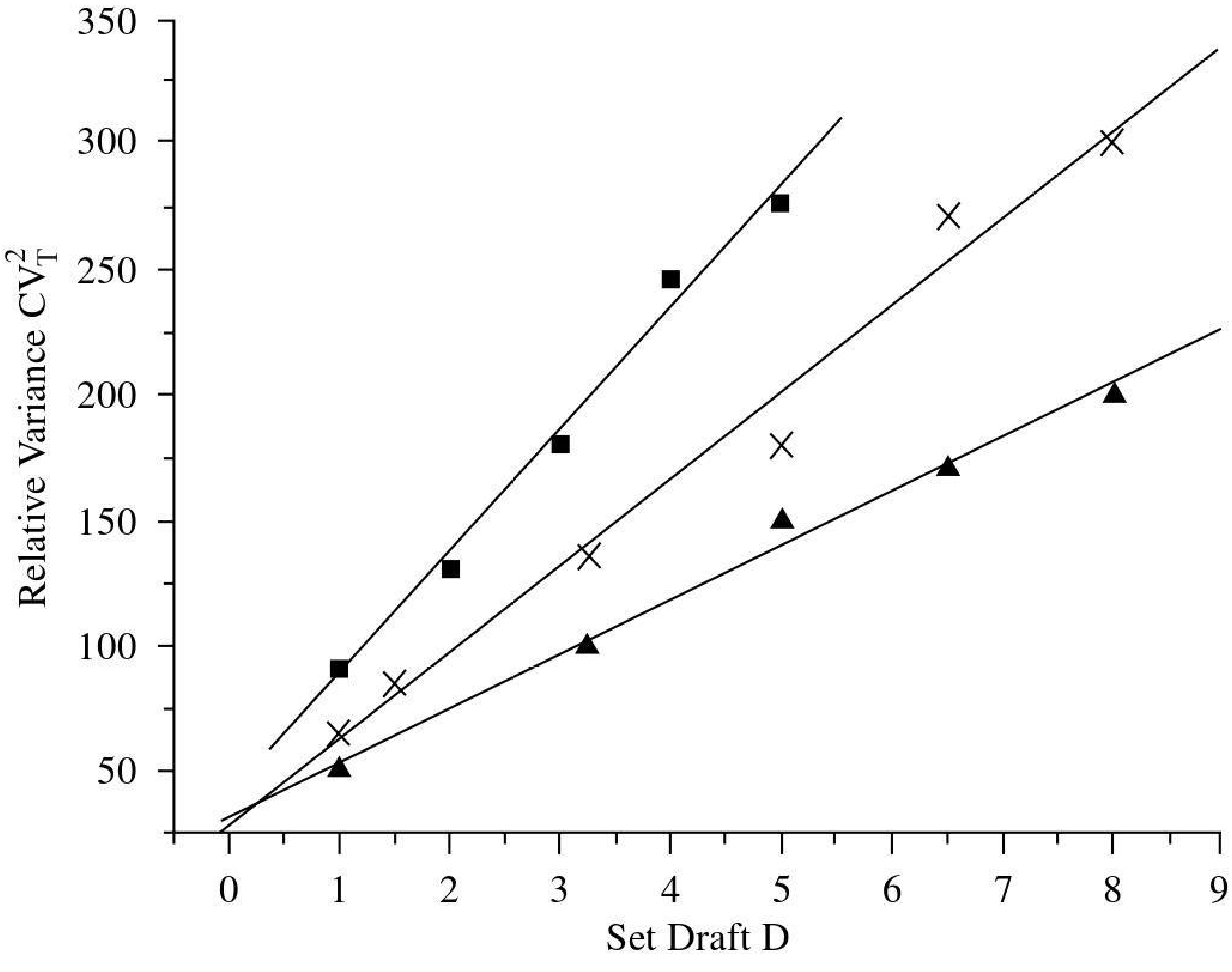

FIGURE 5.10 Relative variance as a function of set draft.

Input Count

The slope a can be seen to decrease with the count of the input material. Strictly, the equation should have a third squared relative coefficient of variation. This results from a small tension draft of 1.2 applied to the material just before it entered the drafting zone. The effect of this draft is not evident in the coarsest count input material where a sizable number of fibers are present. The higher is the number of fibers present, the smaller are the values of a and the coefficient of variation of the drafting wave. The simple reason for this is that, with more fibers present, more fibers will be drafted in the ideal way. There also will be a greater number of floating fibers, but the spacing between successively leading ends of floating fiber extents is likely to be more random. This will lead to strips of the heavier count, and therefore thicker input material, having effectively their own drafting wave. These sub-drafting waves will tend to be out of phase, making thick parts in the strips become staggered and come alongside the staggered thin parts as illustrated in Figure 5.11.[56]

Doubling

A multiple input feed gives the action of doubling. This has the advantage of reducing the irregularity, CV_{IN}, entering the drafting zone such that

$$CV_{IN} = \frac{CV}{\sqrt{N}} \tag{5.6}$$

where N is the number of inputs each with a coefficient of variation of CV.

In addition to reducing the combined irregularity of the input, doubling implicitly has the effect of increasing count. Thus, during drafting, the drafting waves in the individual inputs tend to form separately from one another; the thick parts do not coincide but become staggered to juxtapose the thinner parts, as described earlier. Therefore, the equation for reduced irregularity by doubling also applies to the drafting wave. Thus, with N inputs each and with CV coefficients of variation,

$$CV_{AO}^2 = \frac{CV_O^2}{N} = \frac{CV_{IN}^2 + a(D-1)}{N} \tag{5.7}$$

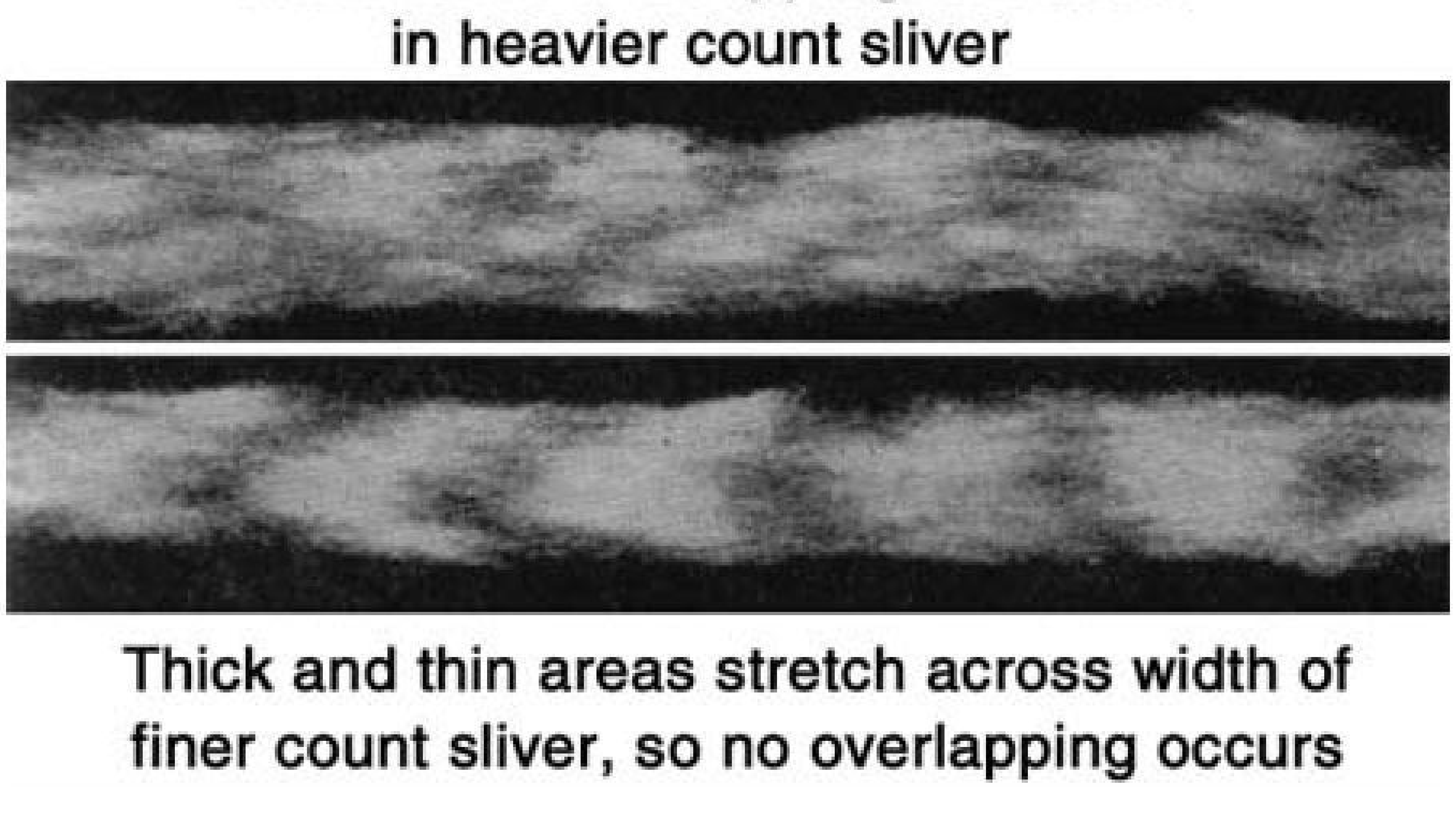

FIGURE 5.11 Drafting waves in slivers.

$$CV_{AO} = \frac{CV_O}{\sqrt{N}} \tag{5.8}$$

where the subscript AO means "actual output."

That is to say, with the doubling action, the output irregularity, CV_O, that would be obtained from a single input feed is now reduced by the product of the reciprocal square root of the number of doublings. This assumes, again, the absence of variations resulting from machine faults.

Fiber Straightness, Parallelism, Fineness, and Length

Fibers usually have some degree of interlacing when they are not straight and parallel in the input material. The greater the amount of interlacing, the more the resistance to the sliding of fibers past one another, and the tendency for fibers to be pulled toward the front roller pair in clumps. This obviates the positive effect associated with increased count. The finer the fibers, the greater the number present in the cross section of the input material, and the more difficult it then is to deal with the interlacing. However, in the drafted material, there will be more fibers in the thinner parts and, consequently, the drafting wave will be less pronounced. From their observations of the drafting of card slivers, Grover and Lord[44] suggest that the average length of floating fiber groups is likely to decrease with repeated drafting because of a progressive reduction in the amount of interlacing.

During drafting, the interfiber friction tends to straighten and align fibers as they slide past each other. Merchant[45,46] explains that, in the straightening and alignment of fibers entering the drafting zone, the drafting action removes trailing hooks preferentially to leading hooks. The reason for this is that the trailing hook of a fiber is in frictional contact with a large number (n_1) of fibers in the back beard, which exert a drag on the hook as the leading end of the fiber is accelerated to the front roller speed. The leading hook of a fiber, with its trailing end nipped by the back roller, will have much fewer ($n_2 = n_1/D_A$) fibers in the front beard trying to straighten the hooked length as they slide by. For similar reasons, fiber hook removal increases with increased count of the input material[47] and with increased set draft.[48,49]

Thus, in repeated drafting stages where fiber hooks are in a trailing direction entering the drafting zone, more and more fibers will be straightened with their fiber extents becoming equal to their full lengths. The associated drafting wave with each repeat stage will be smaller, and, if doubling is used at each repeat stage, the output CV will show a decreasing trend.

Irrespective of the positive effect of fiber straightening, the drafting wave will depend on the fiber length or span length distribution and on, in particular, the short fiber content of the distribution, since short fibers will always be floating fibers. For cotton, measured data from a digital fibrograph (see Appendix) have been used in the following expression to obtain calculated estimates of the percentage of fibers likely to become floating fibers:[50,51]

$$\text{Percent floating fibers (\%FF)} = (S/L - 0.975)100 \tag{5.9}$$

where S = 2.5% span length
L = 12.5% span length

Depending on fiber grade and process conditions in opening and cleaning and carding, reported figures for %FF range from 10 to 70%.[50] Fiber breakage in the preparation processes is therefore of significance to the drafting wave irregularity. For man-made fibers, fiber breakage also has a negative effect, since such fibers are usually supplied with a square distribution.

By analyzing the thin and thick places in drafted lengths, Waggett[22] has shown that the bulk of floating fibers during drafting are likely to be short fibers, since longer fibers have sufficient cohesion between themselves and other neighboring fibers in the back and front beards to reduce any irregular motion. However, a worsted staple diagram can include very long fibers so that, when the drafting rollers are set to prevent spewing, the remaining fibers behave as floating fibers. Generally, it may be said that the irregularity of a drafted material is strongly linked to the irregularity of the constituent fiber distribution.

Roller Settings

Figure 5.12 is a typical example of how the coefficient of variation changes with roller setting. It is evident that the minimum irregularity was obtained at setting less than the maximum fiber length. At greater settings, a rapid increase in irregularity occurs, because longer fibers as well as short fibers become floating fibers, and the distance over which short fibers float increases, both factors giving a more pronounced drafting wave.

The reason why spewing does not present a problem at the setting for minimum irregularity is that the number of maximum length fibers is usually small (<<5%), so only a few fibers would be nipped by both roller pairs. However, to ensure against spewing, a setting slightly wider than that corresponding to the minimum $CV_T\%$ is

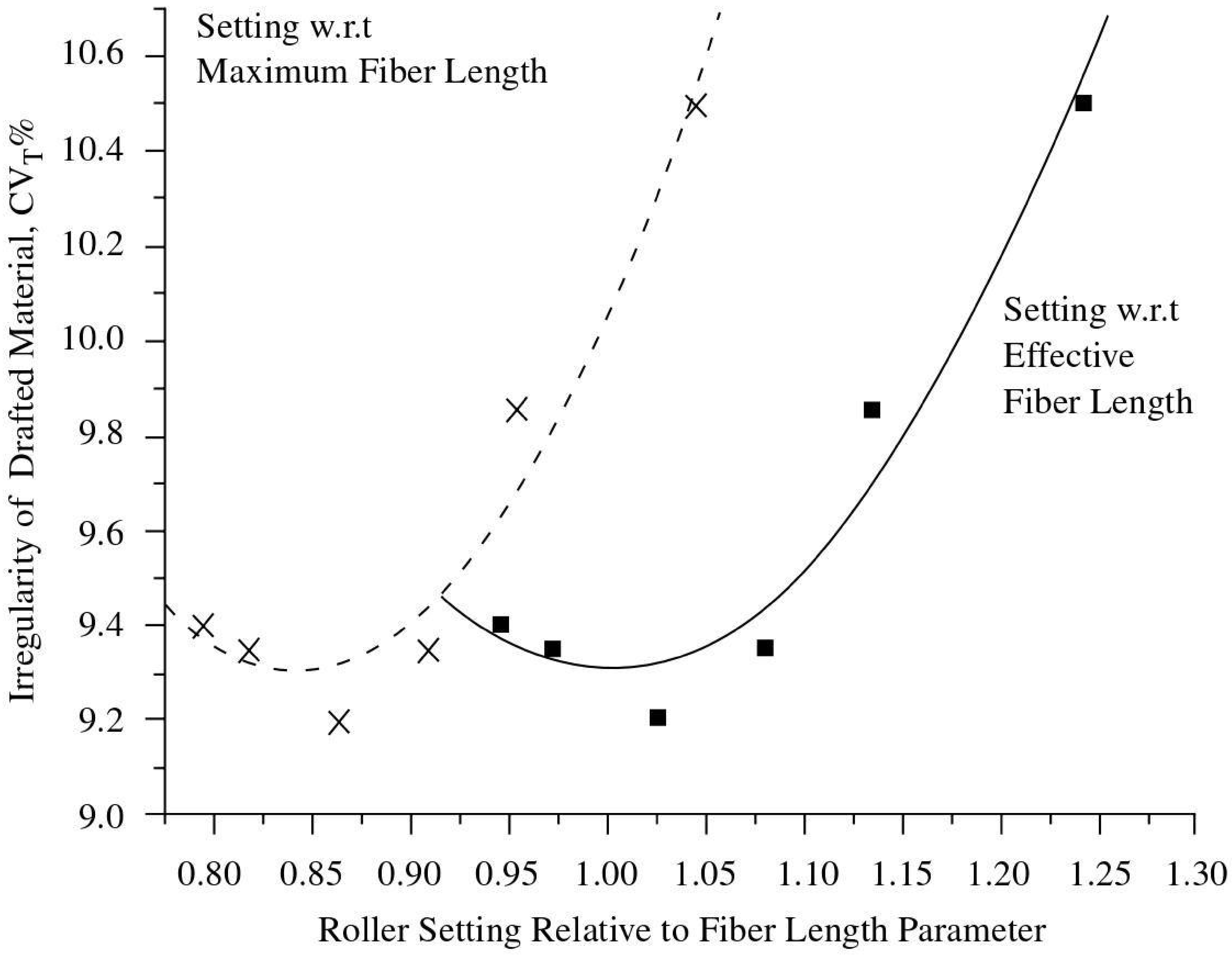

FIGURE 5.12 Effect of roller settings on irregularity.

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commonly used. As described in Chapter 1, the effective fiber length or (for short-staple) the 2.5% span length may be used for drafting zone settings. When there is likely to be low fiber parallelism and straightness, careful consideration has to be given to the optimal setting with regard to the fiber extent distribution.[53]

5.1.3 EFFECT OF MACHINE DEFECTS

The irregularities that may be caused by machine defects are usually independent of those caused by the material characteristics. However, irregularities caused by uncontrolled stretching of the input or output material may be influenced by fiber properties and parallelism. Although modern machines are well designed and constructed, wear can lead to mechanical defects and the following three types are of importance.

5.1.3.1 Roller Eccentricity

As Figure 5.13 shows, roller eccentricity essentially means that the actual centre of a roller, in this case the top roller, is offset from the axis of rotation, and this causes the radius of rotation to vary during each revolution of the roller. Consequently, roller eccentricity causes the nip of a roller pair to fluctuate, and this alternatively increases and shortens the drafting zones. Usually, the effect of such movement of the back-roller nip line is negligible, but it is of much significance with the front-roller pair.

In the case of the front rollers, the number of fiber-leading ends nipped by the rollers will vary in a regularly repeated manner, resulting in thick and thin places in the drafted material. The forward movement of the nip line increases the spacing

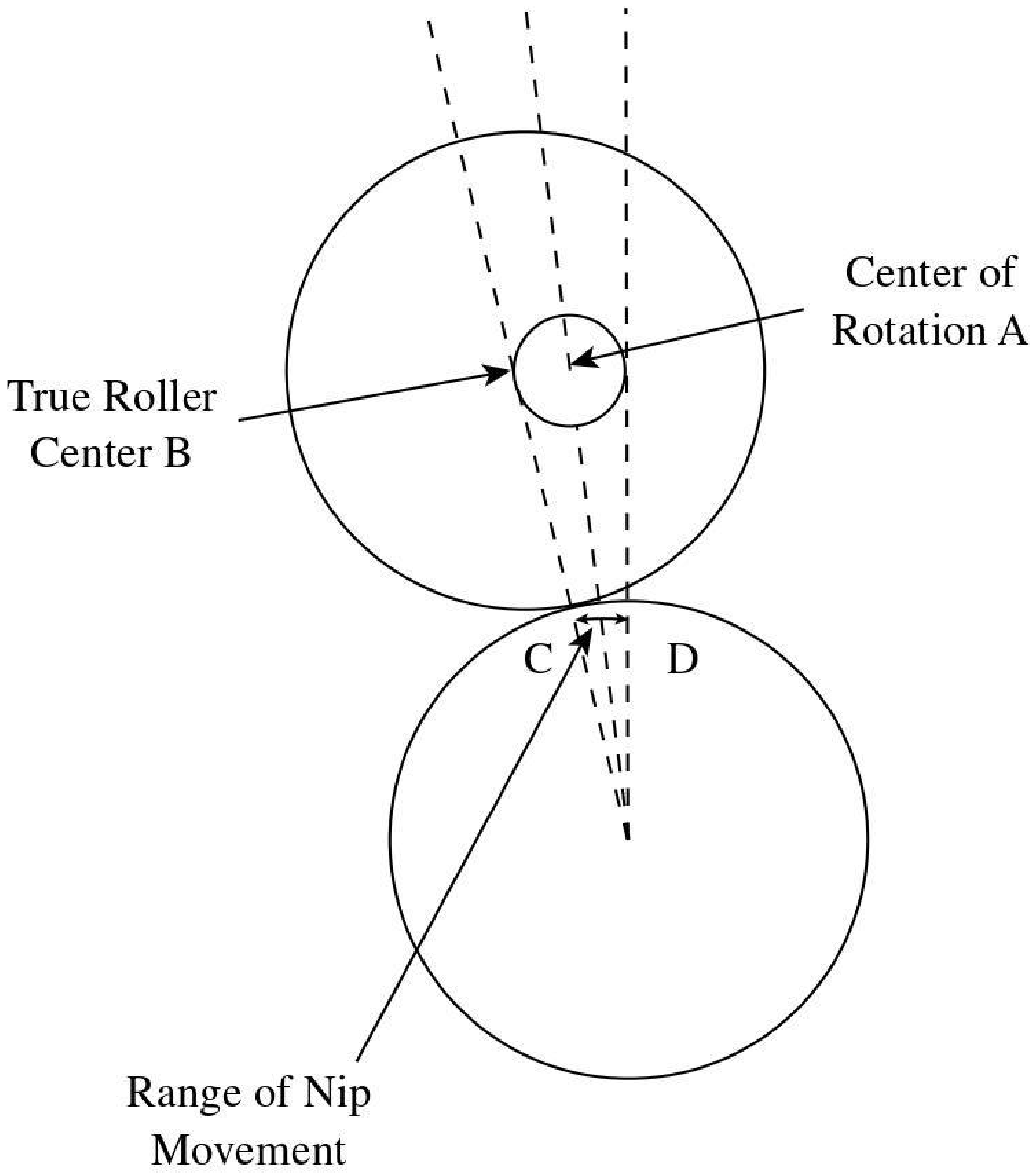


FIGURE 5.13 Eccentric top roller causing periodic roller nip movement.

between fiber ends to produce the thin places, and the backward movement produces the opposite. This gives a periodic variation, with a wavelength equal to the roller circumference. The amplitude of the periodic variation will depend on the amount of nip movement, which is likely to be small. Importantly, therefore, the irregularity value (i.e., CV%) of the drafted material may not be greatly affected and, unwittingly, may seem to be low, particularly if steps have been taken to minimize the effects of the material characteristics discussed above.

The Uster spectrogram will, however, indicate the periodic fault.[54] Such a fault that occurs in one drafting action will also be present in the output material of subsequent roller drafting(s), which may not be affected by machine faults. Similar to other irregularities, the wavelength of the periodic fault would then increase by the multiple of the draft(s) and is identifiable in the corresponding Uster spectrogram.

The eccentricity of a bottom roller is more severe than that of a top roller. This is because the bottom roller is directly driven so that, as well as introducing the nip movement, the varying radius of rotation would also cause the roller surface speed to fluctuate regularly. The result would be a larger amplitude of periodic fault as compared with that caused by an eccentric top roller.

5.1.3.2 Roller Slip

Roller slip may occur either at the back or front roller pair. Since the bottom rollers are directly driven, it is these that are likely to slip. The bottom rollers drive the fiber beards and top rollers. If there is insufficient pressure at a roller nip, the bottom roller slips by and does not impart the correct surface speed to the fiber bread and the top roller. Changes to the top roller surface speed caused by bottom roller slip will introduce irregularities into the output material. Clearly, the thicker the fiber beard between the rollers, the greater is the chance of bottom roller slip. Roller slip is therefore usually associated with inputs of high linear densities.

Periodic changes in the speed of bottom rollers, causing periodic variations, can result from faults in the drive system and from worn bearings.[54]

5.1.4 THE DRAWING OPERATIONS

Having reviewed the basic principles of drafting, we can now consider how they are applied to drawing operations in the short-staple, the worsted, and semi-worsted preparation processes.

The drawing operations are primarily concerned with converting card slivers into drawn slivers in which fibers have been straightened and aligned with a high degree of parallelism. It is essential that the short-, medium-, and long-term irregularities of drawn slivers are as low as possible, with no periodic variation present. To minimize the drafting wave, the motion of potential floating fibers must be controlled, and, to ensure minimum long-term irregularities, autolevelers are also employed.

Effective control of floating fibers can be achieved by increasing the interfiber friction. Although it is possible to apply suitable additives to fibers to increase this friction, the preferred alternative is to do so mechanically, as this is a simpler approach that gives more predictable control. There are four basic means of mechanical control: directly applied pressure or tension; the use of pins; twist; and a combination of applied pressure and twist. In sliver drawing operations, use is made of applied pressure or of pin control. The other two means of control are used in the follow-on process stages and will be considered later. For effective pin control, the drafting zone has to be of a length suitable for a pin device to fit between the back and front roller pairs. This means that pin control is used for the worsted and semi-worsted processes, and direct pressure is used for short-staple processing.

The machines used for drawing are called either *frames* or *boxes*. In short-staple processing, we refer to the drawframe, whereas, in the worsted or semi-worsted process, drawing is performed on a gill box.

5.1.4.1 The Drawframe

In the explanation given of the principles of drafting, only a single-zone drafting arrangement was considered. This is because, when more than one zone is used, the principles still apply to each individual zone. However, the application of multiple zones can enable the control of the effects of material characteristics on drafting irregularities described above.

Figure 5.14 depicts the essential features of a drawframe with a two-zone drafting arrangement and shows a modern machine with a six-sliver input and automatic can changing at the output. The use of six or eight doublings depends on fiber length and size of draft. The shorter cotton lengths are found to process better from the use of six doublings with a draft of six; eight doublings may be used for longer staples.[55] Table 5.1 gives typical performance figures. Drawframes have much higher production speeds than revolving flat cards. Therefore, only a few machines are needed to achieve a process balance with card sliver production.

TABLE 5.1
Typical Performance Figures for Drawframes

Features	Specification
Number of deliveries	Usually 1 or 2
Drafting systems	3-over-3 with or without pressure bar 4-over-4 Other combinations
Number of doublings for feed to drafting system	Usually 8, ranges 6–10
Max. input feed (g/m)	Up to 50
Max. delivery speed (m/min)	Up to 1000
Autoleveler regulating range (±%)	Commonly 25

With three roller pairs defining the geometry of the system shown in the figure, it is common to refer to the arrangement as a *3-over-3 system.* Several other arrangements are used or have been in used,[56,57] the more traditional being the *4-over-4 system,* but this arrangement is considered to be unnecessary where less than ten of draft is to be applied to the input slivers. Essentially, whatever the geometry, the

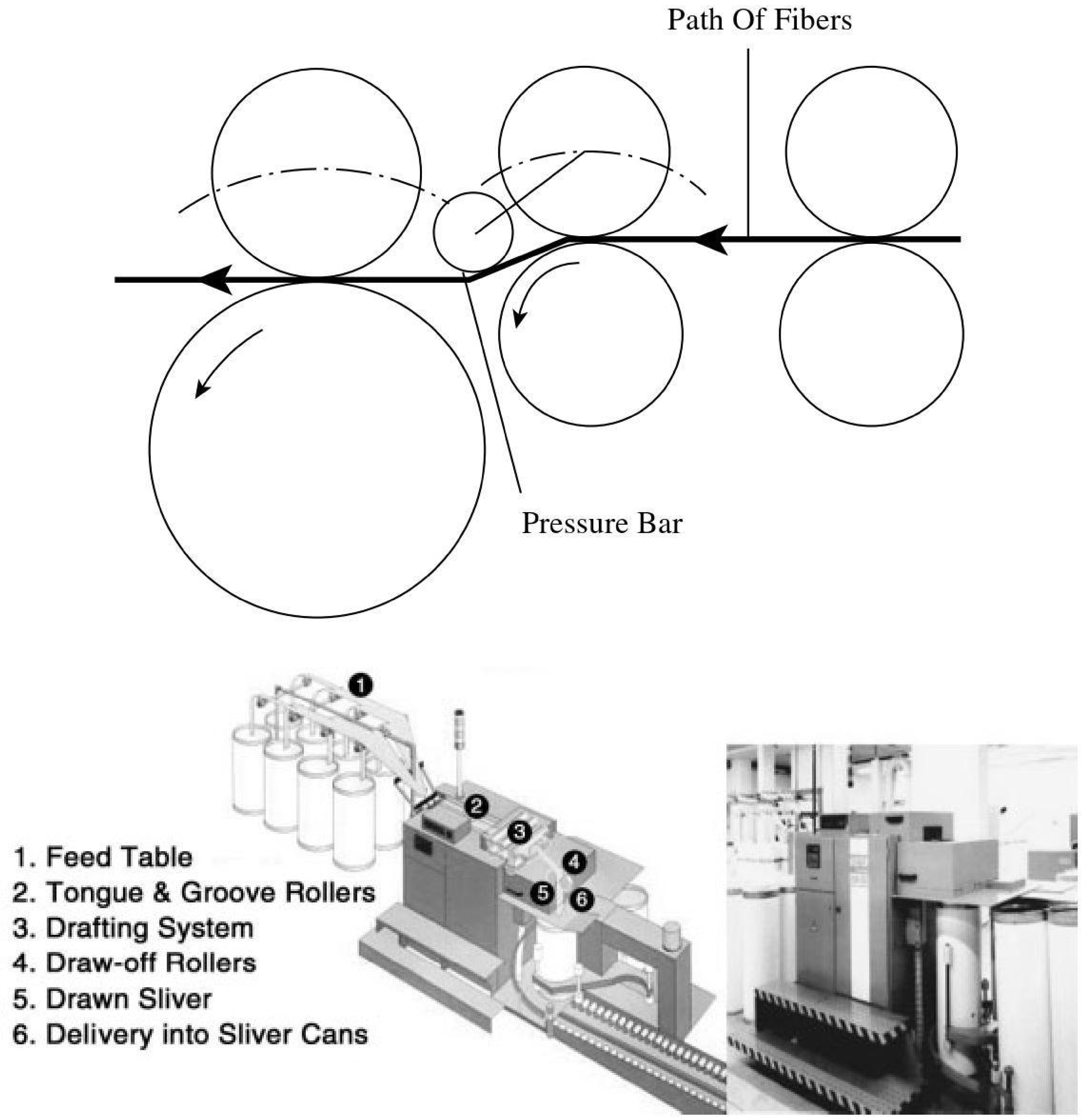


FIGURE 5.14 Main features of a drawframe. (Courtesy of Rieter Machine Works Ltd.)

drafting system should be capable of processing a variety of fiber types and staple lengths (typically, 22 to 80 mm) over a wide range of delivery speeds.

Generally, the back zone draft of all drafting systems is of the order of 1.25 to 2.0. This draft is termed the *break draft,* since it assists in minimizing the negative effect of sliver extension in the subsequent higher draft zone(s). The drafting force was shown to peak at such low drafts. Therefore, the *roller weighting* of the second top roller is of critical importance to avoid roller slip. As Figure 5.14 shows, a pressure bar is fitted in the front drafting zone. This deflects the fibers from a straight-line path, and the resulting tension reduces the effect of the material extension and assists in restraining the pulling forward of what would be floating fibers. However, it is essential that fibers enter the nip line of the front rollers directly from the pressure bar; otherwise, their path will be disturbed by the surface of the bottom front roller, and this will increase the irregularity caused by the drafting wave.

In the processing of cotton, the drawframe acts as a further cleaning point. Figure 3.7 (see Chapter 3) shows that dust particles, by Coulombic forces, can cling to fiber surfaces. As these fibers slide past one another during drafting, the fiber-to-fiber friction liberates the dust and any coarse trash caught between the fibers. These separated particles can then be removed with applied suction.

Open-loop autoleveling control is the most widely used on drawframes. A tongue-and-groove sensor, similar to the card system, is used to determine the variation of the combined silver feed. The sensor is sited prior to the inlet rollers of the drafting system. The measured values are stored until the measured portion of the combined sliver feed is within the drafting system, and the size of draft is then adjusted to correct for deviations. An important advantage of the open loop is that, because the combined sliver feed moves at a sixth or an eighth the speed of the output sliver, the sensor can respond more accurately to the material variations as compared with closed-loop positioning of the sensor.

We have seen in Chapter 3 that autolevelers are also fitted to revolving-flats cards. Usually, these give longer-term correction (i.e., variations between cans of slivers) and are referred to as *long-term autolevelers.* Drawframe autolevelers give correction to the sliver lengths within cans and may be considered medium-term devices. Short-term autolevelers also can be fitted to both machine types. The question, therefore, is which to use and when. The key factor to consider is the consistency of the count of the spun yarn. The expectation is that a yarn count should have a CV% of approximately 2, based on about 20 measurements (yarn package to yarn package) of 100-m samples. Yarn counts having a CV% = 3 have resulted in unacceptable visible faults in woven fabrics.[55] A CV% of 1.2 to 1.4 can be achieved with autoleveling at the drawframe. Generally, when two drawframe passages are used, and therefore a doubling of 36 or 64, long-term autoleveling at the card or medium-term autoleveling at only the first passage drawframe will give similar results. When one drawframe passage is required, the choice of which machine stage should have autolevelers fitted may come down to one of economics. The spinning of coarse count yarns by certain spinning methods (see Chapter 6) often only requires either the direct feed of a card sliver or a single passage drawframe sliver, in which case a short-term autoleveler should be used on the respective machines according to sliver type.[58]

5.1.4.2 The Gill Box

Whereas a drawframe is used in the straightening and parallelizing of cotton and other short fibers, a gill box is used for processing wool and other longer fibers. Instead of employing a multiple-zone, roller-drafting system with pressure rollers to minimize the effects of sliver extension and the floating-fiber drafting wave, gill boxes are commonly single-zone, or 2-over-2, roller systems in which pins are used to control the effects of material characteristics on the drafting. Figure 5.15 illustrates the main components of the drafting system of an intersecting gill box.

The *fallers* are metal bars with steel pins projecting from their working surfaces and equally spaced along the length of the bars. The pins may be round or flat; round pins are more robust, but flat pins give better fiber control since, for the same number per unit length, they have a larger free space within which a greater number of fibers can be held.[59] The faller lengths are parallel to the nip line of the roller pairs, and, when in contact with the sliver, the pins penetrate vertically, slightly beyond the line of the sliver axis.

The length of the drafting zone is often called the total *ratchet*. The shortest distance of a line of pins from the back nip line is therefore called the *back ratchet,*

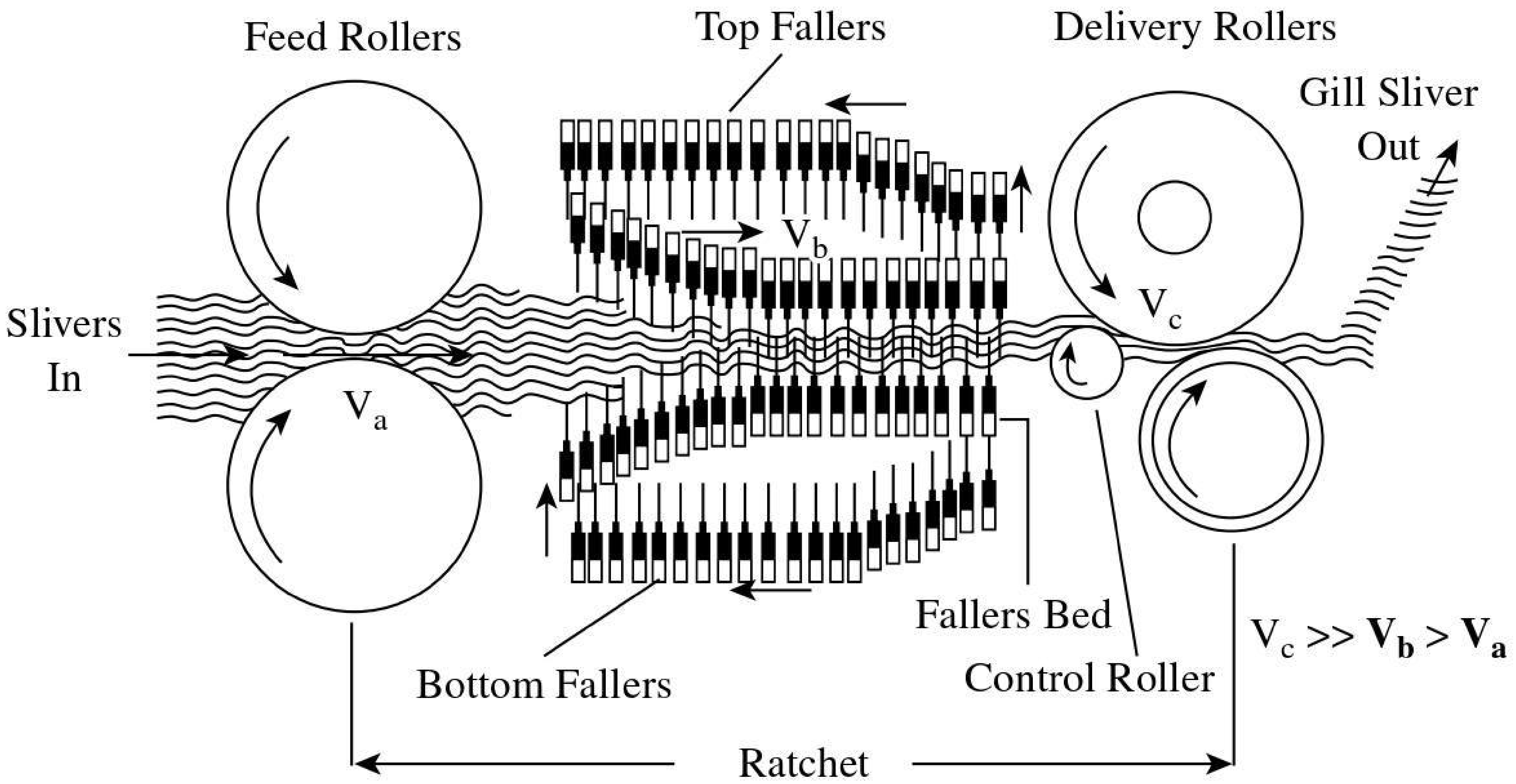


FIGURE 5.15 Features of intersecting gill box.

and the *front ratchet* is the closest distance of approach of a line of pins to the front nip line. The back roller pair is usually adjusted so that the back ratchet is smaller than the lengths of the short fibers. The group of fallers penetrating the sliver between the back and front rollers may be referred to as a *bed of fallers*. The total ratchet is set so that the longest fiber in the back beard does not extend beyond half the distance of the faller bed.

During the drafting action, each faller moves from the back to the front rollers at a speed 5% faster than the back-roller surface speed. Consequently, the pins gently comb through the back beard, and this assists in minimizing the effects of sliver extension, the removal of hooks leading into the faller bed, and in the general straightening and aligning of the fibers. Studies[60] have shown that the combing action of the fallers gives a small amount of straightening, but mainly of longer fibers. Fibers released by the back rollers are transported by the fallers to the front nip line where, once nipped, the material is fully drafted. The significant difference between the front-roller speed and the faller speed is very effective in the straightening and removal of fiber hooks that are trailing rather than leading within the front beard. Pulling fibers from between the pins gives far more straightening than does combing the fibers with pins.

Although the back-ratchet draft gives only a small amount of straightening, it is nevertheless of importance. If it is too high, the combing action of the faller pins may result in fiber breakage, and irregularities occur because of the uncontrolled motion of the short lengths of broken fibers. Too low a value, and fibers may not be suitably extended to remove their natural crimp. The drafting force in the front-ratchet zone then reaches a level to break fibers, owing to the greater friction resistance caused by the retained crimp.

On reaching the closest distance to the front roller, each faller then drops from the faller bed and is returned to repeat the fiber control part of the cycle. The fallers have their ends supported on metal saddles, and they may be chain driven (*chain-driven intersectors*). Alternatively, rotating screw threads may be used to propel them during their forward and return paths, with cams lifting them in and out of the faller bed (*screw-driven intersectors*). As with the drawframe, an autoleveler may be employed to ensure sliver count consistency.

With pin-control, fibers that are released by the back rollers are compressed between lines of adjacent pins and thereby become constrained to move at the faller speed until nipped and accelerated by the front rollers. However, as fallers move within reach of the front rollers, the presence of the front ratchet reduces pin control, and the front beard is then able to pull some unnipped fibers forward. Furthermore, as the front most faller is removed from the faller bed, it may disturb the motion of fiber ends and may cause a periodic fault known as *faller-bar marks* in the drafted output sliver. Two explanations have been given for the formation of faller-bar marks. Taylor[11] attributes them to the tendency of the dropping fallers to cause an intermittent pulling of the sliver out of the steady flow path to the front-roller nip. This periodically alters the number of fiber ends being nipped and thereby results in thick places occurring at the locations in the sliver corresponding to the withdrawal of the fallers. Grossberg and Yang,[61,62] having found that the forces involved were too small to produce significant periodic pulling, gave the alternative explanation that, in close proximity to the front rollers, the interfiber pressure on the fiber mass held between adjacent pins decreases suddenly to a minimum as the faller drops from the bed. The associated decrease in the drafting force enables elastic recovery to take place in the front ratchet zone, and some fibers therefore retract from the nip, initially causing a thin place, followed by a thick place, to be formed. It is possible that a combination of the two mechanisms actually occurs.

The wavelength of the periodic irregularity present in the sliver equals the product of the draft and distance between successive lines of faller pins (the *pitch of the fallers*). The amplitude of faller-bar markings increases with short fiber content, the front ratchet size, and, particularly, the level of draft. Taylor[63] has shown experimentally that at a draft of 5, faller-bar marks were scarcely detectable but became very conspicuous, even to the eye, when a draft of 12 was applied. The effect of faller-bar markings on yarn quality is diminished when a repeat drafting passage is used (i.e., two gillings), the associated reverse feed of the processed sliver length being beneficial.

It should be evident from the above that the fiber-pin interaction strongly influences the quality of the drafted sliver. As a general rule, the distribution of the fiber mass between the pins must be as uniform as possible, maintaining consistent friction and drafting forces. The cleanliness and the irregularity of the input sliver are therefore important factors. Impurities and thick and thin places in the feed sliver will alter the fiber packing densities between pins, which, if too high, can cause fiber breakage and, if too low, a pronounced drafting wave. Finer fibers should be processed with narrower pin spacing, which prevents the entry of impurities. The optimal input count of the doubled slivers is directly related to fiber fineness, i.e., fineness in microns = count in ktex, 19 μm = 19 ktex.[64]

5.1.5 PRODUCTION EQUATION

The production rate, P_R (kg/h), is given by

$$P_R = V_d \times T_t \times 60 \times E \times 10^{-2} \times N \quad (5.10)$$

where V_d = delivery of sliver (m/min)
T_t = sliver count (ktex)
E = machine efficiency (%)
N = number of deliveries per machine

5.2 COMBING

We have learned from the basic principles of drafting that, assuming the drafting system is appropriately set, drafting waves are attributable to the short fibers in the input material and that the amplitude and wavelength of the drafting wave increases with draft. In drawing, we have seen the use of two means of controlling the short fibers when moderate drafts are applied. At high drafts, control of all fiber lengths is important and, when the drafted material is to be of a fine count, the drafting wave amplitude can be suitably minimized if very short fibers are removed from the input material. Worsted yarns generally, and cotton yarns that are produced within the finer count range (i.e., 25 to 5 tex) on spinning systems that employ roller drafting, require very short fibers to be removed during the material preparation. It is important also that the quantity of neps and remnant fragments of impurity are minimized, as they can severely degrade the quality of such yarns. The process used to remove the short fiber and remnant impurities is called *combing*.

Definition: Combing is a process by which the quantity of short fibers and remnant fragments of impurities present in a carded or drawn sliver are minimized to give a clean sliver, having more of a rectangular staple diagram, with the vast majority of the constituent fibers in a straightened and parallel state.

Combing, therefore, makes possible the spinning of yarns of fine counts with low irregularities and a cleaner appearance. As we will be explained in Chapter 6, combing also results in stronger, smoother, and more lustrous yarns.

5.2.1 THE PRINCIPLES OF RECTILINEAR COMBING

Historically, a number of combing methods date back to around the mid nineteenth century, but the rectilinear method has become the most widely utilized. The principle was devised in 1846 by Josué Heilmann, of Alsace, France, to be used for the combing of cottons. It was also found to be effective for wools. For cotton processing, the method was developed by Nasmith, an Englishman, in 1902 to 1903, into the system on which modern cotton combing machines are based, known as the Nasmith comber (or comb). The machines developed for wool have become known by the alternative names of French or Schlumberger combs.

Essentially, rectilinear combing involves a sequence of five steps, termed the *combing cycle,* which is repeated continuously while the machine is operating. The steps are as follows:

1. Feeding a fringe of several slivers to a rotating cylinder or drum covered with pins.
2. Removing, with the pins on the rotating cylinder, the impurities and fibers not held within a nip line.
3. Releasing the remaining fibers in the nip and simultaneously inserting a row of pins across the width of fringe.
4. Pulling the longer fibers through the row of pins and piecing them to the previously detached group to form a new length of combed sliver.
5. Removing the impurities and extracted fibers from the rotating cylinder, making it ready for the next cycle.

Although both the Nasmith and the French comb use the same operating principles, there are important differences between components of the systems that make it appropriate to give separate descriptions of each in relation to the combing cycle.

5.2.1.1 Nasmith Comb

Figure 5.16 depicts a sideways view of the main components of a Nasmith comb and their related actions during a combing cycle.

The Cylinder Comb

This is a driven cylinder, with its length positioned across the width of the machine. The section of circumferential surface that does the combing is called the *half-lap*

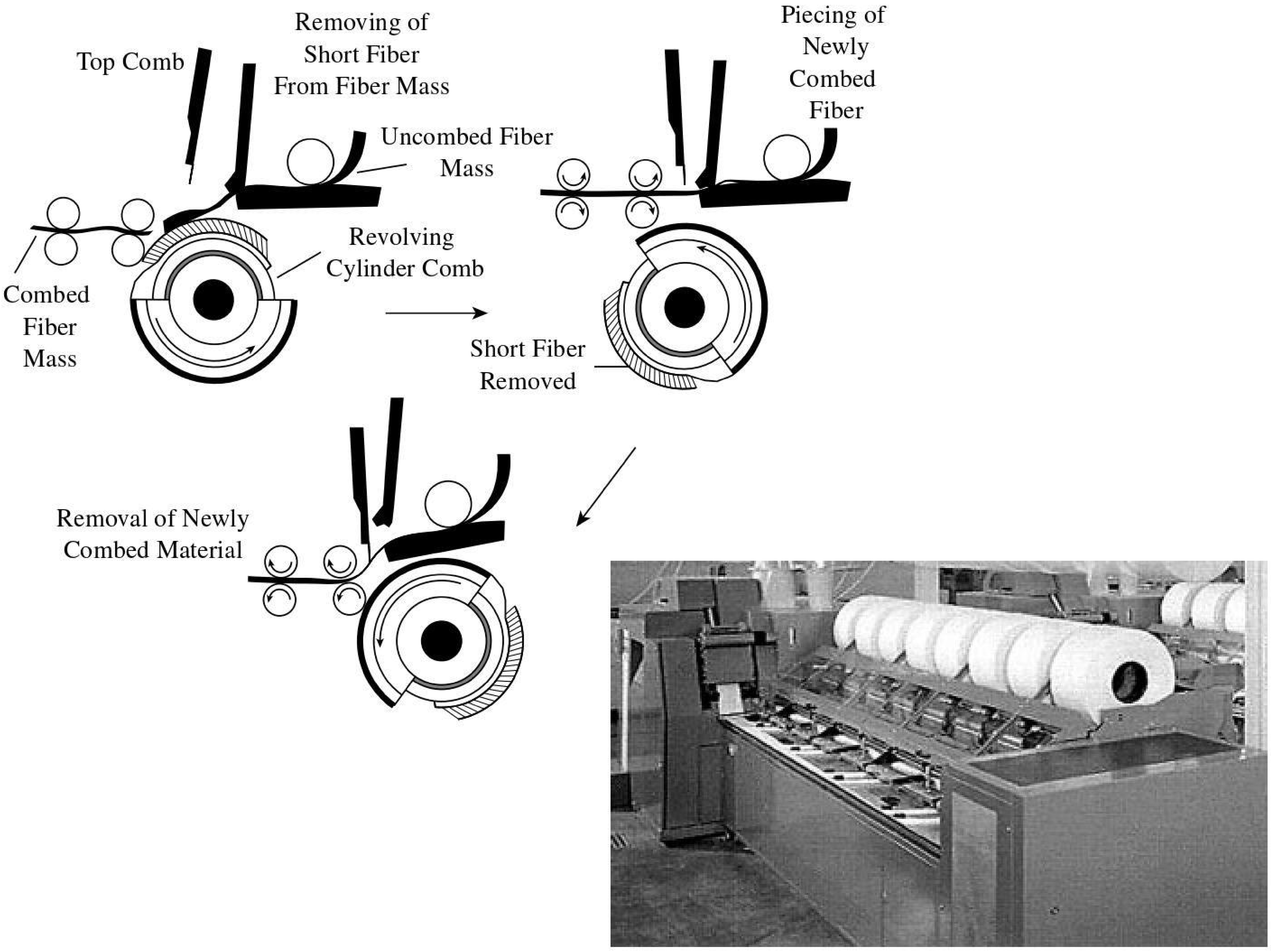


FIGURE 5.16 Main features of the Nasmith comb.

and consists of about 17 rows of pins, with their points projecting from the cylinder surface. The cylinder comb rotates independently of all other parts, and its main function is to remove the unnipped fibers, neps, and impurities from a fringe of slivers while straightening out any hooked or curled fibers in the fringe, with the fiber trailing ends being held at a nip line. The collection of fiber, dirt, and trash removed is called *noil* or *comber waste*. The half-lap is arranged so that the fringe is combed first by a row of widely spaced coarse pins and then by progressively more narrowly spaced and finer rows. Up to 28 slivers, each having had one passage of drawing, are preassembled in the form of a lap — a sliver lap[65] — in which the slivers lie parallel to each other with their ends making the sliver fringe that spans across the width of the machine. The reason why a drawn sliver rather than a card sliver feed is used will be explained later.

The Feed Roller/Top and Bottom Nipper Plates/Top Comb

The feed roller is made to supply, intermittently, a preset length of fringe ready for combing. The nipper plates separate and then come together (*open* and *close*) so as to give passage to the feeding forward of the fringe and then to nip the fringe ready for combing. The top comb is a single bar having fixed across the length of one edge equally spaced pins with their point projecting down toward to the sliver fringe. The top comb has an up-and-down vertical movement.

All four components have their lengths across the machine width, and they move as a unit, initially away from and then toward the detaching rollers.

Detaching Rollers and Delivery Rollers

Similar to other roller-set arrangements for gripping fibers, the bottom rollers are driven, fluted metal rollers, and the top are synthetic rubber-covered rollers. The roller pairs initially rotate counterclockwise so that a previously combed length forms an overlap onto which the next group of fibers to be detached will be pieced. They then rotate clockwise to remove the newly combed group of longer fibers from the fringe. To make this overlap and remove fibers from the fringe, the nip line of the detaching rollers has to move toward the fringe. To do so, the top-detaching roller is made to shift to a foremost position ready for detaching; this action is referred to as the *top roller rocking over the bottom roller.* When the top roller is in its detaching position, the nipper plates are at their closest distance to the detaching rollers. It is this preset distance (the detachment setting) that governs the fiber lengths removed from the fringe. Detachment occurs when the rollers rotate clockwise while, simultaneously, the top-detaching roller rocks back to its original position.

The Combing Cycle

The combing cycle begins with the nipper plates in their backmost position (farthest position from the detaching rollers) and closed so as to nip the sliver fringe. As shown in the figure, the feed roller is stationary, and the top comb is in the up position, clear of the fringe. During the early stages of the cycle, the pins projecting from the cylinder comb enter the sliver fringe and subsequently remove impurities and fibers not held by the nipper plates. As the pins leave the fringe, the nipper-plate unit begins moving toward the detaching rollers. The nipper plates start opening, the top comb drops into the fringe just in front of the nipper plates and, as the latter becomes fully opened, the feed roller pushes forward a short length of fringe. By the time the nipper plates reach the detachment setting, the detaching rollers will have formed an overlap and begun their clockwise rotation. The leading ends of fibers spanning the detachment setting will then be caught, and these fibers are pulled through the interspaces of the top comb. The top comb prevents neps, impurities, and fibers not spanning the preset distance from being dragged out of the sliver fringe by those being detached. It effectively combs and straightens the trailing ends of fibers being detached. In the following cycle, the cylinder removes, along with any neps and impurities, fibers retained in the sliver fringe that are not held by the nipper plates.

Once detachment has taken place, the nipper-plate unit returns to its backmost position and, in so doing, the newly formed length of fringe is nipped and ready for combing. The top comb will have returned to its up position. The combing cycle is then repeated. Since, in each cycle, the nipper plates have to be closed for the cylinder to extract the noil, a cycle may be referred to as a *nip*. The combing frequency is therefore the number of nips per minute, which is normally stated as the combing speed.

The detachment and piecing of fibers from the sliver fringe results in a thin web of straight and parallel fibers being issued from the delivery rollers. The combed web is then consolidated to make a sliver, which is pulled along a table alongside slivers from other combing heads on the same machines (usually six or eight heads), and the set of doubled slivers are drawn to form a single sliver, termed a *combed sliver,* by a drafting system at end of the machine. The sliver is then wound into a sliver can, ready for the next process. Figure 5.16 shows a modern cotton combing machine with the sliver-lap feed and the feed table to the drafting system with the slivers from each combing head. The combing process is very effective in removing very short fibers, and, as an example of this, Figure 5.17 compares the staple diagrams for the sliver lap feed, the combed sliver, and the extracted noil. It can be seen that, by reducing the short fiber content from 28 to 9%, the staple diagram becomes more rectangular.

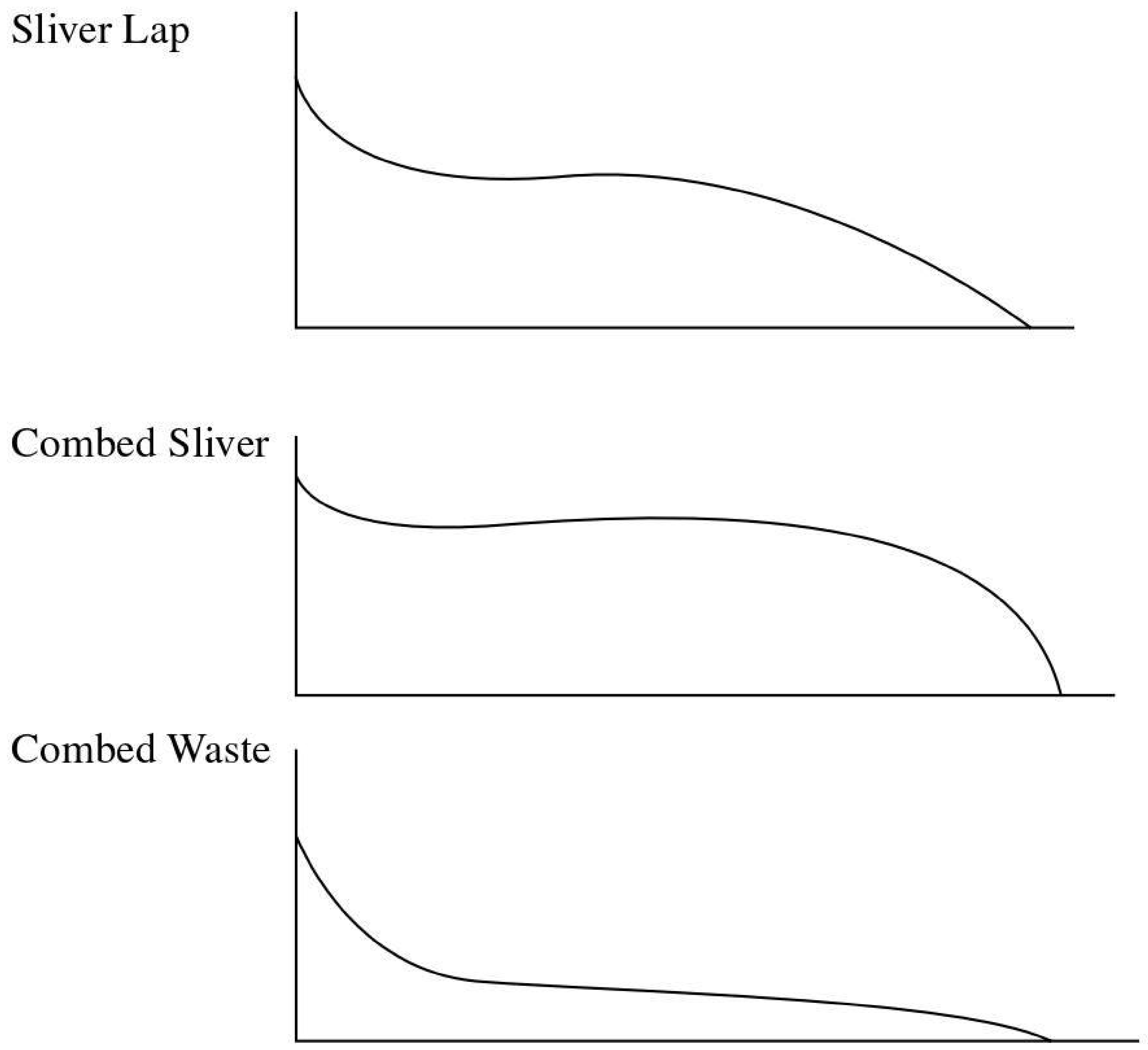
It should be clear to the reader that overlap piecings will produce a periodic fault in the sliver from each combing head. The doubling and drafting at the machine will assist in reducing the amplitude of the periodic wave. However, a further drawframe passage is usually required after combing.

Blends of combed cotton with man-made fibers are widely used for the production of fine-count yarns. A common practice is to carry out such blending after combing, in which case two drawframe passages are employed, the man-made sliver having had one drawing prior to blending.

5.2.1.2 French Comb

Figure 5.18 is a typical side elevation diagram of the main working parts of a French comb. The main points of difference between this and the Nasmith comb are

- *The sliver feed.* A feed gill is used to control 24 to 32 gilled, wool slivers (at least one passage of gilling). This is composed of three metal plates that move as a unit forward and backward, toward and away from the



Fiber Parameter	Sliver Lap	Combed Sliver	Waste (17% Extraction)
Effective Length (mm)	37	38	23
% Short Fiber	28	9	66

FIGURE 5.17 Staple diagram for combed Sudan cotton.

detaching rollers. The slivers lay juxtaposed on the bottom, grooved plate with a slotted plate placed on top of them. Eight rows of pins attached to the top plate project through the slotted plate, penetrate the slivers, and enter the groove of the bottom plate, thereby firmly holding the slivers. When the nipper plates open, the feed gill moves forward to supply a preset length of sliver fringe through the nipper plates. When the nipper plates are closed, the top plate of the feed gill withdraws the pins from the sliver, and the feed gill unit returns to its initial position, ready to repeat the feed. The nipped sliver fringe is then combed by the 17 or 18 rows of pins on the cylinder comb.

- *Detaching unit.* This consists of a spirally fluted roller and an endless apron. When the pins leave the sliver fringe, the detaching unit moves forward and grips the fiber ends. Simultaneously, the pins of the top comb penetrate the fringe so that only fibers of lengths greater than the detaching distance are extracted.

Figure 5.18 shows that the French comb is a single-head machine. The slivers are supplied to the machine in balls rather than cans so as to reduce floor space and provide ease of handling. Table 5.2 gives a general comparison of specifications for the two types of combing machine.

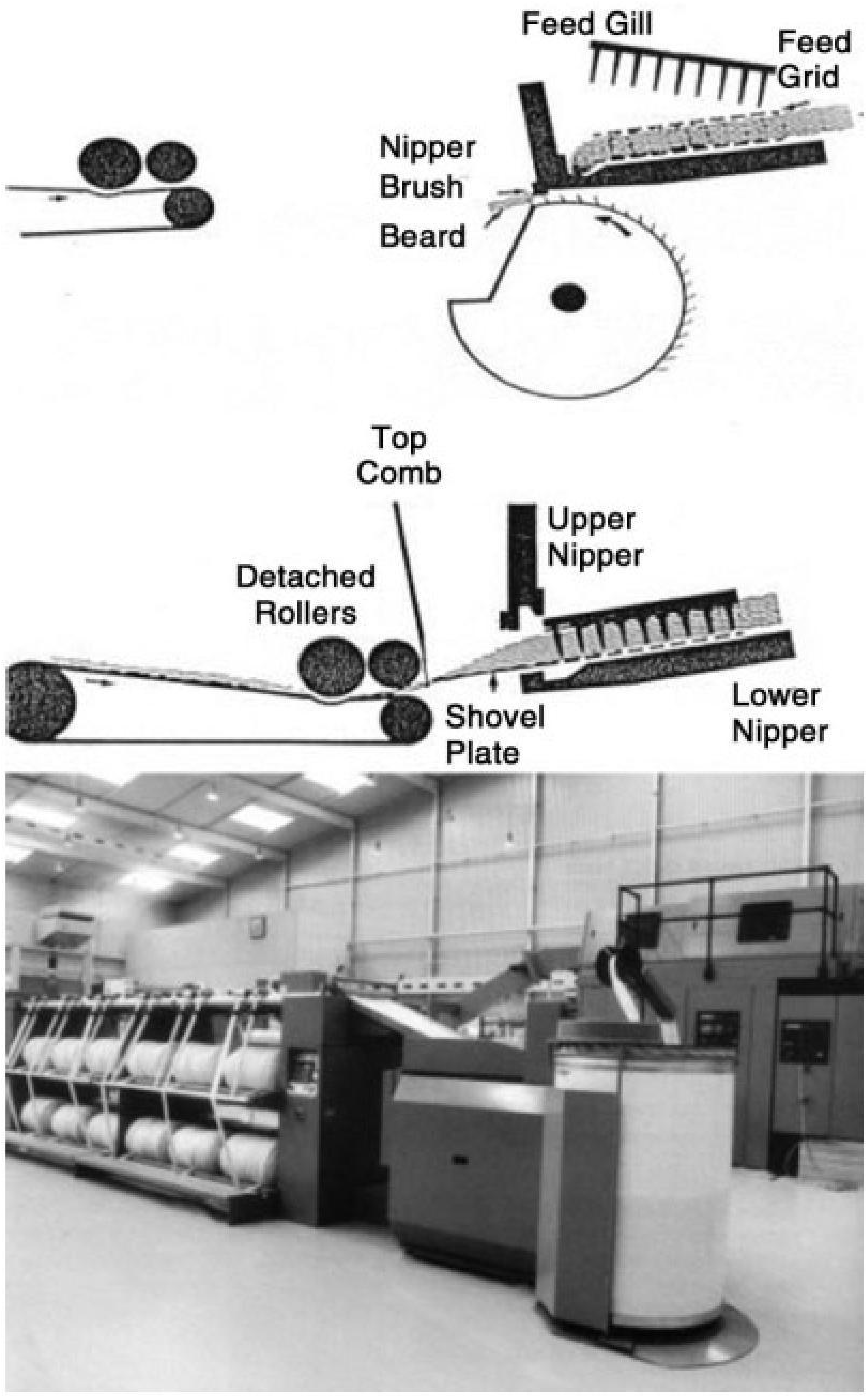


FIGURE 5.18 Operation of a French comb.

TABLE 5.2
Typical Performance Data

Parameter	Nasmith (cotton) comb	French comb
Nips/min	Up to 350	200–230
Number of heads	Commonly 8	Commonly 1
Feed count (ktex)	Up to 80	Up to 600

Similar to cotton combing, the combed wool slivers, called *combed top,* are passed through a drawing (i.e., gilling) operation. They normally undergo two passages of gilling, which are referred to as *top finishing*. The first gilling involves autoleveling, and the number of doublings may be up to 30 but with no greater than 10 of a draft. The second gilling would utilize a doubling of four or five and a similar draft, without autoleveling.

In contrast to the short-staple sector, it is common in the worsted industry to have the process steps of scouring through top finishing as one manufacturing operation, separate from the spinning mill. The sliver in top finishing is usually of 20 to 25 ktex and is packaged in approximately 20- to 25-kg lots for easy handling and transportation.

5.2.2 Production Equation

The production rate of a comber depends on the following:

• The total sliver feed mass per unit length	L, grams
• Combing speed	n, nips per minute
• Feed rate	f, mm per nip
• Noil	$W\%$
• Running efficiency	$E\%$
• Number of heads	N_H

The production rate P_R (kg/h) is then given by

$$P_R = (100 - W)\, L\, n\, f\, E\, N_H\, 60 \times 10^{-10} \tag{5.11}$$

5.2.3 Degrees of Combing

The percentage waste extraction during combing depends on the short-fiber content of the raw material, the final end use of the yarn, and the economics with respect to the effect of material cost on yarn cost. There are, particularly for cotton, four degrees of combing.

- *Scratch combing,* where up to 5% noil is removed. This gives no great improvement in average yarn properties but has the benefit or reducing end breakage rates in spinning and winding.
- *Half-combing,* which involves around 9% waste, resulting in reduced yarn irregularity and improved spinning performance.
- *Ordinary combing,* involving between 10 to 18% noil, which is necessary for spinning yarns in the finer end of the count range.
- *Full combing,* resulting in greater than 18% noil. This often means double combing to obtain the highest quality yarns — 18% removed in the first combing and 7% in the second.

For short-staple spinning, cottons greater than about 27 mm staple length are commonly combed; those greater than 30 mm are used for finer counts, and generally all are combed. Usually, 13 to 5% is considered sufficient to meet high-quality requirements. In worsted processing, the ratio of top and noil is called the *tear* and is often used as a measure of the degree of combing. With 60s quality wool, the tear is within 8 to 11, and for 64s/70s quality, it is around 8. With 64s quality wool, the noil extract can be around 4 to 8%. When tops are dyed,[66] they are either gilled or gilled and recombed, followed by two additional gillings.

5.2.4 FACTORS AFFECTING NOIL EXTRACTION

5.2.4.1 Comber Settings

In the first place, the machine settings should give control of the percentage of waste extracted. From the descriptions of the machine operations, it should be clear that the detachment setting is a main factor. However, if the detachment setting is to be based on the short-fiber content of a staple diagram, then the effect of the difference between number-length and weight-length distributions on the estimated noil percentage should be considered.[67] As Figure 5.19[67] illustrates, a number length distribution gives a more accurate estimate of the short fiber content in the material to be combed.

The position of the top comb relative to the nipper plates will influence the amount of waste extracted. If the top comb is set well in advance of the nipper plates, it will more effectively prevent the fibers being pulled by the detaching rollers from dragging through any impurities and short fibers, and the waste extraction will be high. Setting the top comb close to the nippers will reduce the amount of extracted waste, but this means higher levels of neps, impurities, and short-fibers in output sliver. Inefficient penetration of the top comb may also result in this.

5.2.4.2 Preparation of Input Sliver

The objective here is to ensure that the configurations of fibers longer than the detachment settings do not result in these fibers becoming part of the noil. This could happen either because of fiber breakage during combing or because the fiber extents fall short of the detachment setting. Figure 5.20 illustrates the latter point. Several fibers of differing lengths, with trailing hook configuration, are shown to be held at the nip line N. The distance FN is equivalent to the length of sliver ribbon moved forward by the feed mechanism, when the nipper plates are fully opened. Therefore, FD equals the detachment setting. Consequently, when the nipper plates

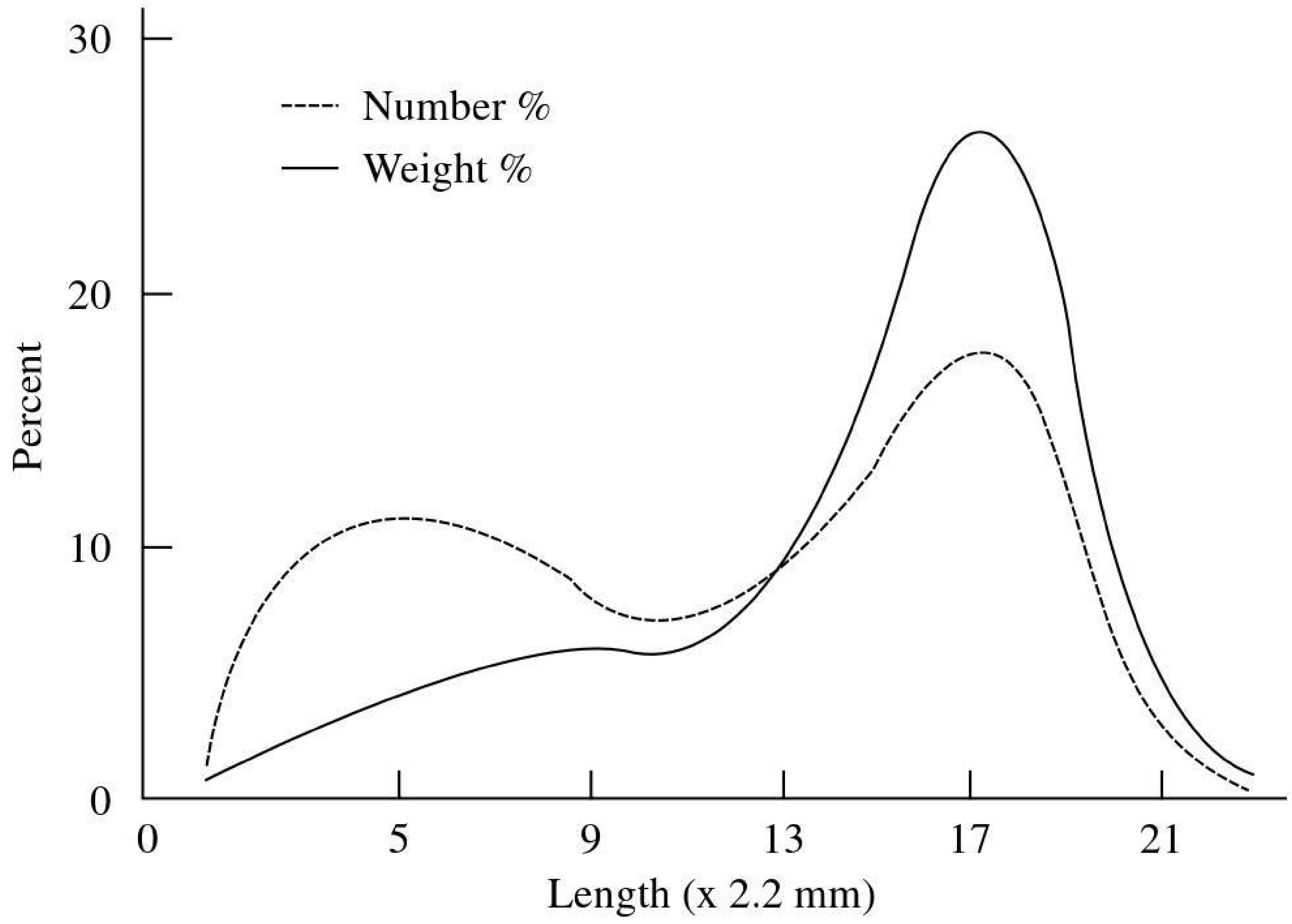


FIGURE 5.19 Number- and weight-based fiber length distributions.

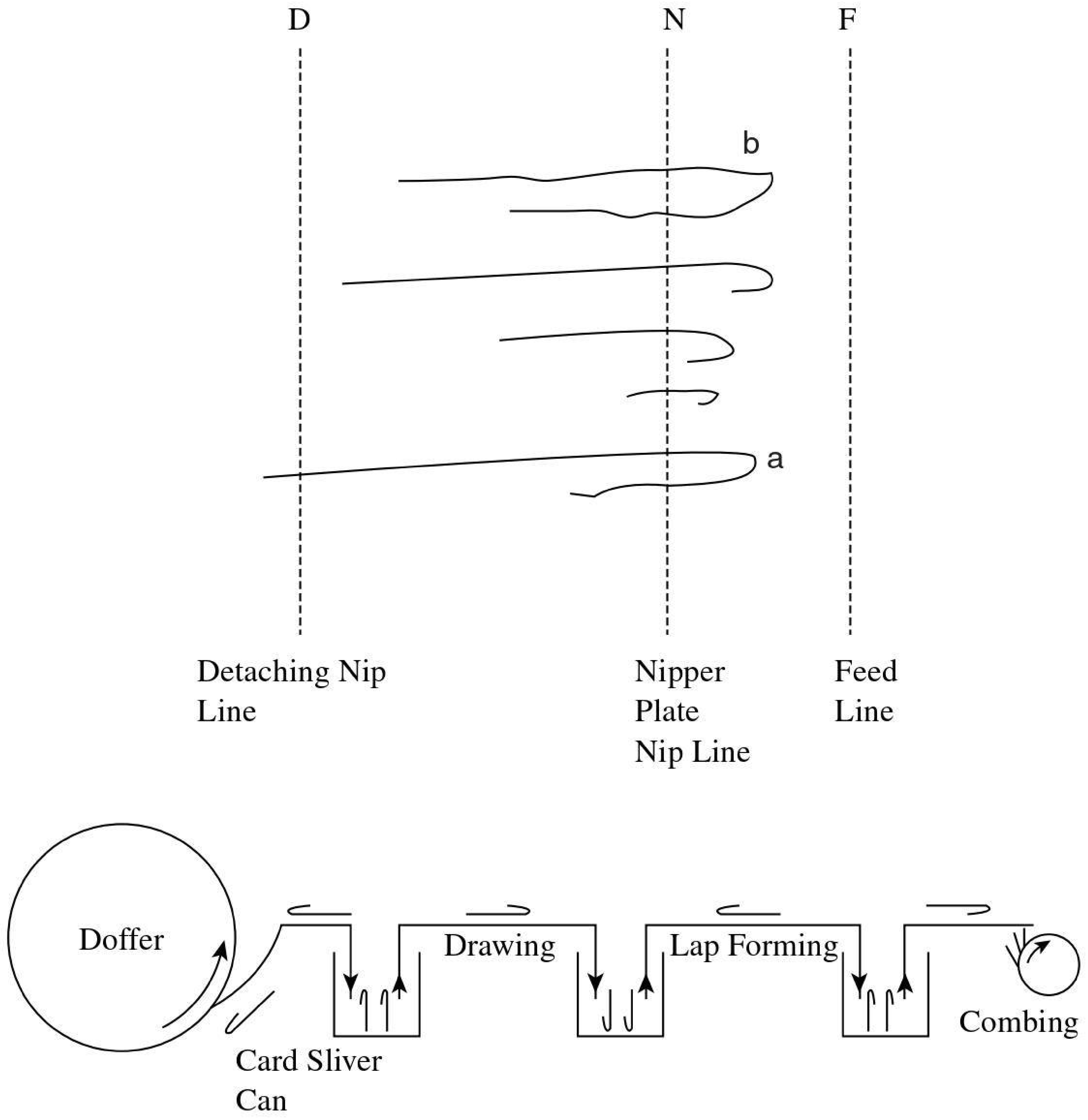


FIGURE 5.20 Fiber configuration in relation to detachment.

reach their foremost position only fiber *a* will be detached. The other fibers will be retained in the ribbon fringe by the top comb. During the next cycle, the cylinder comb will remove them as part of the noil. It can be easily reasoned that, if these fibers had their hooks leading rather than trailing, the cylinder comb would have straightened them prior to the detaching action, and the longer ones would have formed part of the combed sliver. Drawn or gilled slivers should comprise mostly straightened fibers, but remaining hooked fibers must enter combing with their hooked ends leading. The majority of hooks in the output sliver from a card are tailing (see Chapters 3 and 4). Therefore, to reposition these to be leading when presented to the cylinder comb, there should be an even number of reversing processes between the card and the comb, as depicted in Figure 5.20.[68–71]

Consider the configuration of fiber *b* in the figure. If the looped end became leading, it is likely that the actual fiber ends would be held by the nipper plates during the combing action of the cylinder comb, and if a projecting pin moved through the loop, the fiber would break. Similar breakages may occur to fibers with other unfavorable configurations in the sliver feed, in particular to fibers interlaced with neighboring ones. Fiber breakage in combing is strongly related to the degree of fiber parallelism in a sliver fringe. Therefore, it is important that appropriate drawing or gilling be used in the preparation of the sliver input to combing. For cotton fibers, the use of fixed flats in carding, followed by drawing, was found to have a significant effect on comber waste. Mill trials[72] have shown that, for the same machine settings, the percentage comber waste was reduced from 16.4 to 14.2%, and the resulting yarn properties were improved.

The fiber-pin interaction in combing has been studied by a number of researchers,[73,74] and various techniques have been used to obtain an indication of likely pin forces present during combing. It was found that, generally, when a pin enters a sliver fringe, the force required for the pin to move through the fringe rises to a peak value and then decays to zero as the pin passes through the fringe.[74] This is an indication of the resistance to pin movement. If the lengths of the nipped fibers in the fringe lie parallel to the motion of the pin, then the initial resistance to pin movement is largely the friction force arising from the sliding contacts with the fibers. On meeting impurities, neps, and short fibers to be removed, the resistance increases, as the pin then has to push these obstructions along its path until they are dislodged from the fringe. If these obstructions are not firmly held by other fibers, the increase in force will be negligible, and the peak pin force will be small. If, however, fringe fibers are not parallel, and interlaced fibers or doubled fibers are held at the nip-line (as would be expected in a card sliver fringe), then the peak pin-force reaches a high level at which these fibers will either have disentangled or been extended to reach their breaking strain, resulting in increased noil. The reported findings showed that peak pin force increased with (a) fringe density, because of increased interfiber friction; (b) fringe length, owing to the presence of more impurities, neps, and short fibers to dislodge from the fringe; and (c) a reduced number of drawing passages.

The top comb pin force has also been studied during detachment and found to be greater than forces associated with the front ratchet zone in gilling. It is a contributing factor to fiber breakage. Increasing the number of gilling passages, however, reduces the size of the top comb pin force. Belin and Taylor[75] found that the back-ratchet draft in gilling has a significant effect on the quantity of noil removed in combing. A moderate draft should not cause breakage in gilling but can reduce the size of the pin force at the cylinder and top combs developed during combing.

Although lubricants [combing oils of 106 centistokes (cS) viscosity] are added after scouring to reduce breakage, a small amount of residual grease on wool fibers does assist in keeping noil levels to a minimum. Sinclair and Wood[76] relate increased noil in wool combing to an *entanglement* factor, which is a complex function indirectly involving the residual grease content. They found that noil increases with residual grease content above 1%. Belin[83] reports 0.8% (measured by Soxhlet ether extraction) to be the optimal level of residual grease. At higher levels, the tendency is for fibers to stick together, and lubrication is impaired at lower levels.

5.3 CONVERSION OF TOW TO SLIVER

A tow is a collection of approximately 300,000 continuous man-made fiber filaments kept in a parallel, untwisted form. To convert tows into a sliver, the individual filaments must be cut or broken collectively into staple fibers of a specified length. Conventionally, the tow is chopped to the required staple length and baled ready for opening, blending, carding, and drawing/gilling so as to be made into a sliver by any of the particular process routes for material preparation. A much shorter process route, called *tow-to-top,* is to cut or break the filaments while retaining them in their straight, parallel state, thereby producing a linear assembly of staple fibers that is comparable to a drawn/gilled sliver. Besides the commercial advantages, there are technical benefits, since the fibers avoid impact forces of, in particular, opening and carding that cause neps and the unwanted very short fibers. In converting the tow, the ends of the resulting staple fibers obviously must not coincide so that sliver cohesion is obtained, and longer staples will give better cohesion for handing of the sliver. Tow-to-top conversion is therefore mainly utilized in worsted/semi-worsted yarn production, and then largely for viscose, polyester, and acrylic fibers. Two types of machine are used; cutting converters and stretch-breaking converters.

5.3.1 CUTTING CONVERTERS

A cutter converter basically comprises a feed creel, a cutting unit, a sliver-forming section, a crimping unit, and a sliver can delivery. As supplied by the fiber manufacturer, the tows are within the range of 10 to 60 ktex, depending on fiber type, and are packaged in plaited form into boxes. In the feed creel, the tows are tensioned over a series of bars, which straightens and spreads the filaments evenly across the width of the input to the cutter. The input count to the machine may be up to 200 ktex. Figure 5.21 shows the basic cutting technique. A helical-blade cutting roller is pressured onto the tows as they pass over a hard, smooth, stainless steel roller. The helical shape provides overlapping of the cut lengths for cohesion, and the pitch of the helix provides the staple length. The gaps between cutting edges of the helical blade have a rubber-covered surface that prevents filament misalignment, which could result in undersized lengths caused by double cutting of filaments.[77] The cut lengths are then consolidated and gilled to form the sliver. To impart crimp to the fibers for improved cohesion, the sliver is passed through a stuffer box before being coiled into a sliver can. Dull cutters can result in partially cut lengths or cause fusing of cut ends. The slivers from converters, therefore, usually undergo two further gilling passages, which separate individual fiber lengths possibly fused together at one of their cut ends.

5.3.2 STRETCH-BREAKING CONVERTERS

These converters use the idea of extending, in a controlled manner, synthetic filaments to their breaking strain, polyester and acrylic tow being the principal raw materials. When heat treated, the broken lengths of stretched filaments can be made to readily shrink to produce a highly bulked yarn. The process has therefore become popularly used in the material preparation for the production of high-bulk acrylic yarns.

The main features of a stretch-breaking converter are shown in Figure 5.21 and comprise four stretching zones: an initial tensioning zone, followed by a heated- and a cooling zone, and finally the filament breaking zone. The resulting silver is then stuffer-box crimped and further cooled before being coiled into a sliver can.

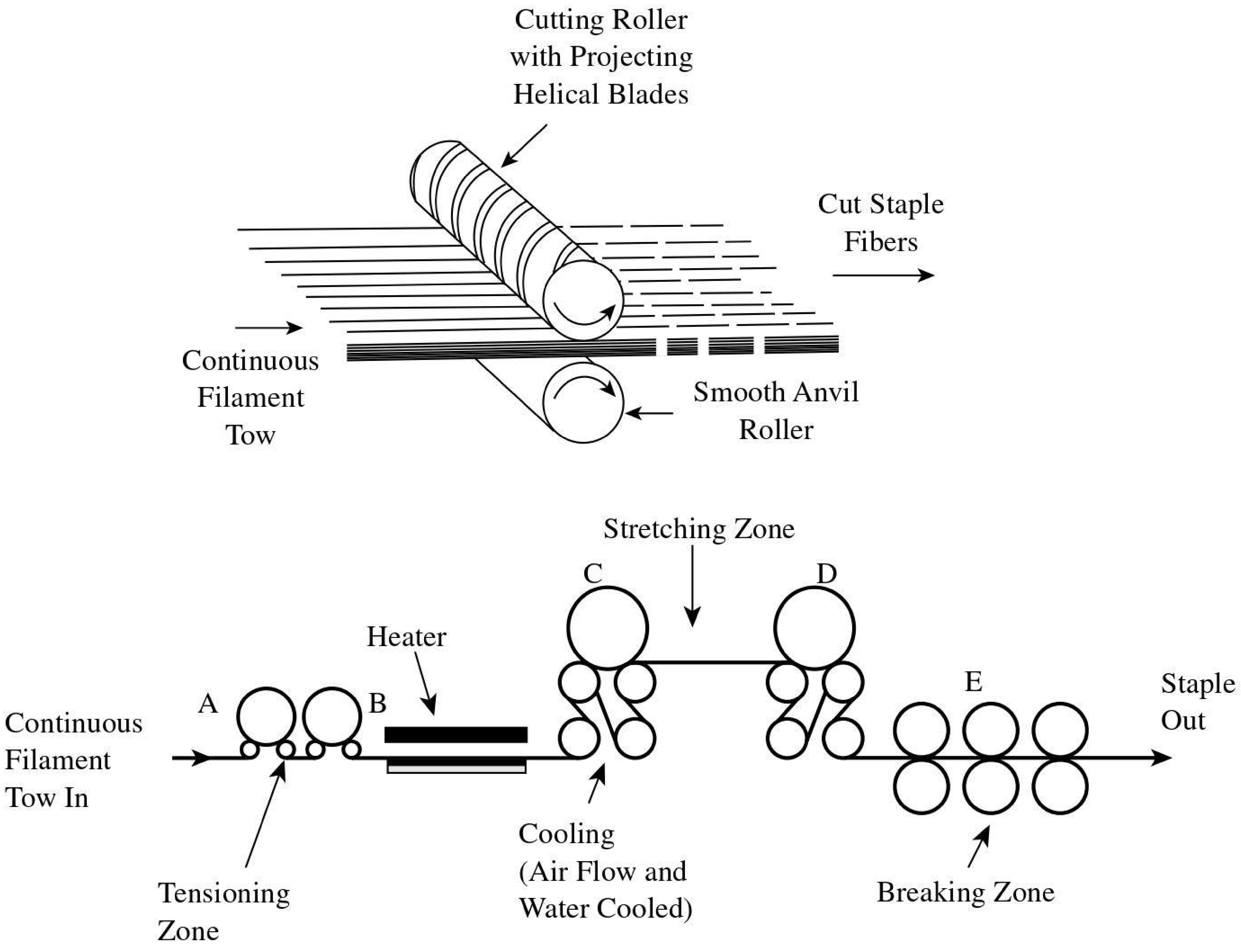


FIGURE 5.21 Tow-to-top converters.

Filament tows, making a total linear density of around 70 ktex for polyester or 120 ktex for acrylic, are fed to the stretch breaker via a creel spreader. The tows are initially tension between rollers (A) and (B). Rollers (B) and (C) stretch the tows with a draft (or draw ratio) of within 1.4 to 1.8, while they are heated to a temperature within the range of 120 to 170°C. At a set draw ratio, the filament tenacity increases, and its potential shrinkage decreases with temperature. Within a suitable operating range of draw ratios, when the heater temperature is constant, both tenacity and potential shrinkage increase with increased draw ratio. It is reported[78] that, in the stretch breaking of nylon 6.6 tows, depending on temperature and draw ratio, the tenacity of the broken filaments may be increased by 20 to 40%, extension 36 to 78%, and initial modulus 85 to 144%. The chosen settings will depend on the required shrinkage and the ease of breaking filaments. For the production of non-bulked, regular yarns, heating is unnecessary.

The filament must be well cooled before reaching the third stretching zone, which is between roller sets (C) and (D). To achieve this, air cooling and water-cooled rollers (C) are used. The final stretching of the tow to the breaking point of the constituent filaments is performed by the rollers (E), which are spaced to give the required mean fiber length. Ideally, a random distribution of filament breaks would be anticipated, resulting in a narrow distribution of fiber lengths. In practice, however, variations in filament alignment,[84] tensile properties, and fineness cause a wider distribution than the ideal.

5.3.3 PRODUCTION EQUATION

The production rate, P_R (kg/h), is given by:

$$P_R = V_d \times T_t \times 60 \times E \times 10^{-2} \tag{5.12}$$

where V_d = delivery of sliver (m/min)
T_t = sliver count (ktex)
E = machine efficiency (%)

5.4 ROVING PRODUCTION

For certain spinning processes, the drawn sliver count must be reduced in two steps so that, ultimately, an acceptable yarn quality is achieved. Equation 5.5 shows that, with roller drafting, the output irregularity increases as the draft increases, owing to the more pronounced effect of the drafting wave. Therefore, one benefit of a two-stage drafting operation is that the reversal of the material length at the second stage provides, effectively, a reversal in the drafting direction of the fibers, and this tends to reduce the amount of bunching of short fibers to give a less pronounced drafting wave. If, for example, we wished to spin a yarn of 30 tex from 1.5-dtex fibers, and the drawn sliver count is 3 ktex, then the required draft of 100 would best be applied in two steps, typically 5 and 20. It is necessary for the first step draft to be low because then only a low twist is needed to hold the fibers together. There would be, on average, approximately 20,000 fibers in the 3-ktex sliver cross section. The draft of 5 would reduce this to 4000 fibers in the cross section, and a small amount twist would be needed to give the attenuated length sufficient cohesion for suitable handling. Increasing the draft would require increasing the twist. However, the inserted twist must not cause problems in the second drafting step by developing a high drafting force. Since the drafted material of the second stage is to be substantial twisted to form a yarn, the greater draft should be applied in that spinning stage.

The first drafting step forms the final part of the sequence for preparing fibers for spinning. The intermediate product is called a *roving* and is made either on twist inserting machines, known as *roving-frames, speed-frames,* or *flyer-frames,* or on machines, called *rub-rovers,* that employ a rubbing action instead of twist insertion to consolidate the attenuated fiber mass. This latter system is suitable only for fiber lengths applicable to the worsted process, since sufficient cohesion is required for handling.

Definition: A roving is a continuous fibrous strand drafted from a sliver and given cohesion by either inserting a small amount of twist or compacting the fibers with an oscillating apron. It is drafted and twisted to be spun into a yarn.

In the production of a roving, a 3-over-3 roller drafting system is commonly used to attenuate the sliver. Unlike the drawing operation, the slivers are drafted separately and, since there are now fewer fibers in the cross section, alternative means to a pressure bar or pins are used for control of floating fibers.[79–81] The most commonly used is the double apron drafting method, illustrated in Figure 5.22. As shown, this is a two-zone drafting arrangement in which a pair of endless aprons is positioned in the high-draft front zone and made to move at the surface speed of the middle-roller pair. As fibers enter the high-draft front zone, the aprons will hold them and assist in keeping them moving at the surface speed of the middle rollers, while preventing the short-fibers being dragged forward by those fibers nipped and accelerated by the front rollers. By comparing the speed profiles of the floating fibers, it can be seen that the distance over which the motion of the short-fibers is uncontrolled has been reduced, thereby minimizing the prominence of the drafting wave.[9]

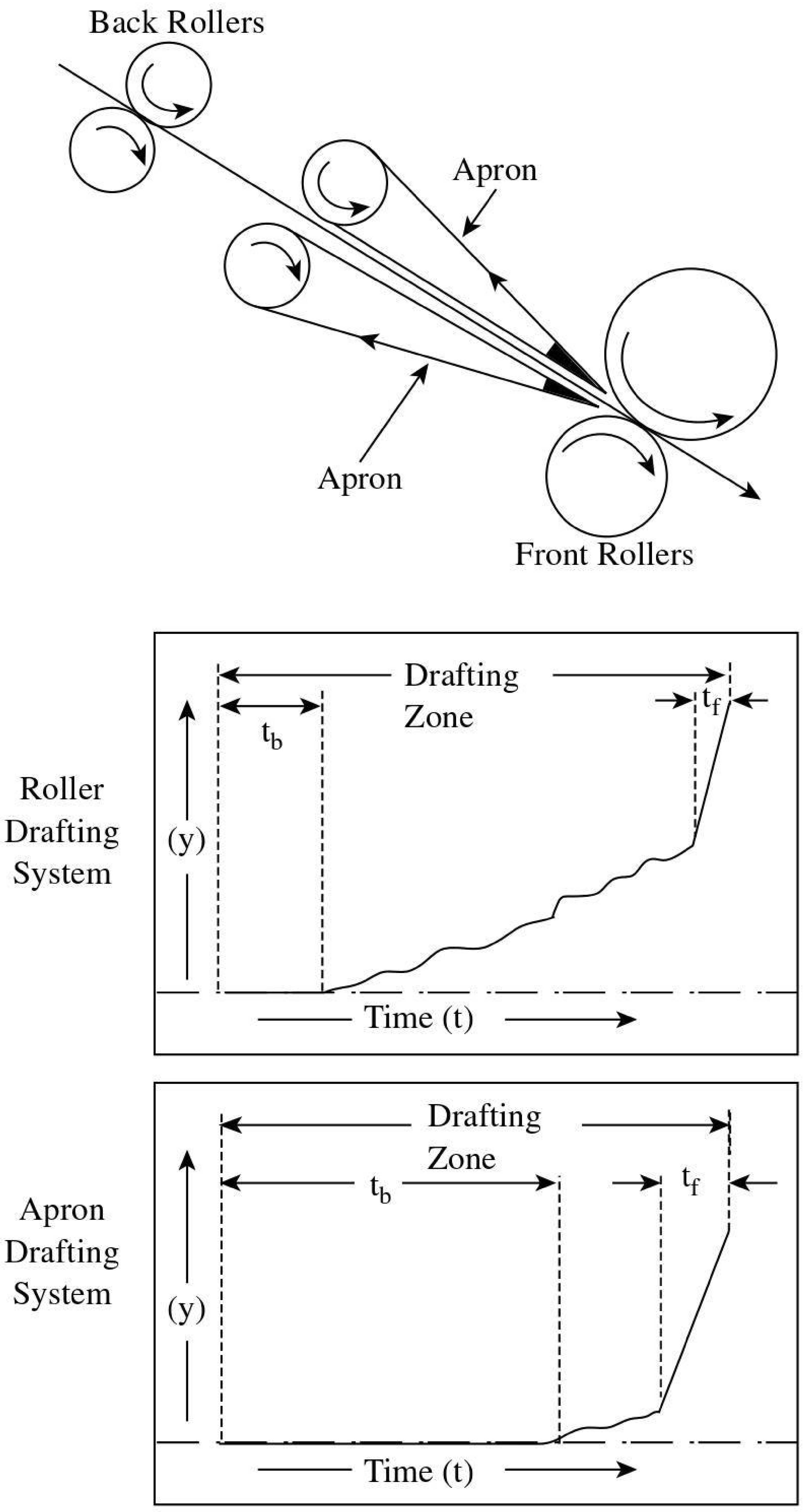


FIGURE 5.22 Apron drafting control of floating fibers.

5.4.1 THE SPEED-FRAME (TWISTED ROVINGS)

Figure 5.23 shows a sideways illustration of a speed-frame, and Figure 5.24 shows an example of a commercial machine. The main operating features are a 3-over-3 apron drafting system and a combined twist insertion and bobbin build mechanism. The function of the apron drafting system has already been explained. The operation of the twist-and-bobbin build device can be described with reference to the figure. As shown, the device has a central spindle that passes through a second, but hollow, spindle. Both are driven independently and pass freely through the rail, which traverses up and down a set distance along the length of the hollow spindle. A bobbin tube, onto which the roving is wound, sheaths the hollow spindle and rests on a mount (bobbin mount) fitted to the rail. The motion of the rail moves the bobbin up and down the hollow spindle length. Mounted on the top end of the central spindle is a component known as the *flyer.* This has a hollow leg through which the roving travels to the bobbing. Located at the exit is a presser arm and paddle around which the roving slides along to the bobbin. The arm is attached to a support rod, and, during rotation of the flyer, this rod is moved outward by centrifugal forces and thereby swivels the presser arm inward to guide the roving onto the bobbin tube. The opposite leg of the flyer is solid and gives dynamic balance during spindle rotation.

As the flyer rotates with the centre spindle, twist is inserted into the drafted ribbon issuing from the front rollers of the drafting system, thereby forming the roving. The contact between the roving and the rim of the flyer inlet imparts an added false twist (see Chapter 1), which strengths the roving length between the flyer and front drafting rollers, permitting a low value of real twist to be used. The roving, which is threaded through the hollow of the fly and around the presser arm, is pulled and wound onto the bobbin by the rotation of the hollow spindle. To do so, the hollow spindle rotates at a higher speed than the center spindle, and the rail lifts and lowers the bobbin past the presser arm to build successive layers of roving coils and make a full bobbin. This is often referred to as winding-up by *bobbin lead.* If the bobbin rotates at speed N_b, and the spindle at N_s, then the speed, V_w, at which the roving would be wound onto the bobbin tube is given by

$$V_w = \pi\, D_b\, (N_b - N_s) \tag{5.13}$$

where D_b = the bobbin tube diameter (in meters) at the instant of winding

In the equation, N_b and N_s are in units of rpm, and V_w is in m/min.

Clearly, if the roving is not to break during winding, there must be a balance between the winding-up speed, V_w, and the delivery speed, V_d (m/min), at which the drafted ribbon leaves the front drafting rollers. Therefore, as D_b increases with the number of roving layers wound onto the bobbin, N_b must decrease, since N_s must be kept constant to ensure a constant twist level. Two or three wraps of the roving around the pressure arm increases the winding-on tension. This, in turn, contracts the roving diameter to enable more roving to be wound onto the bobbin.

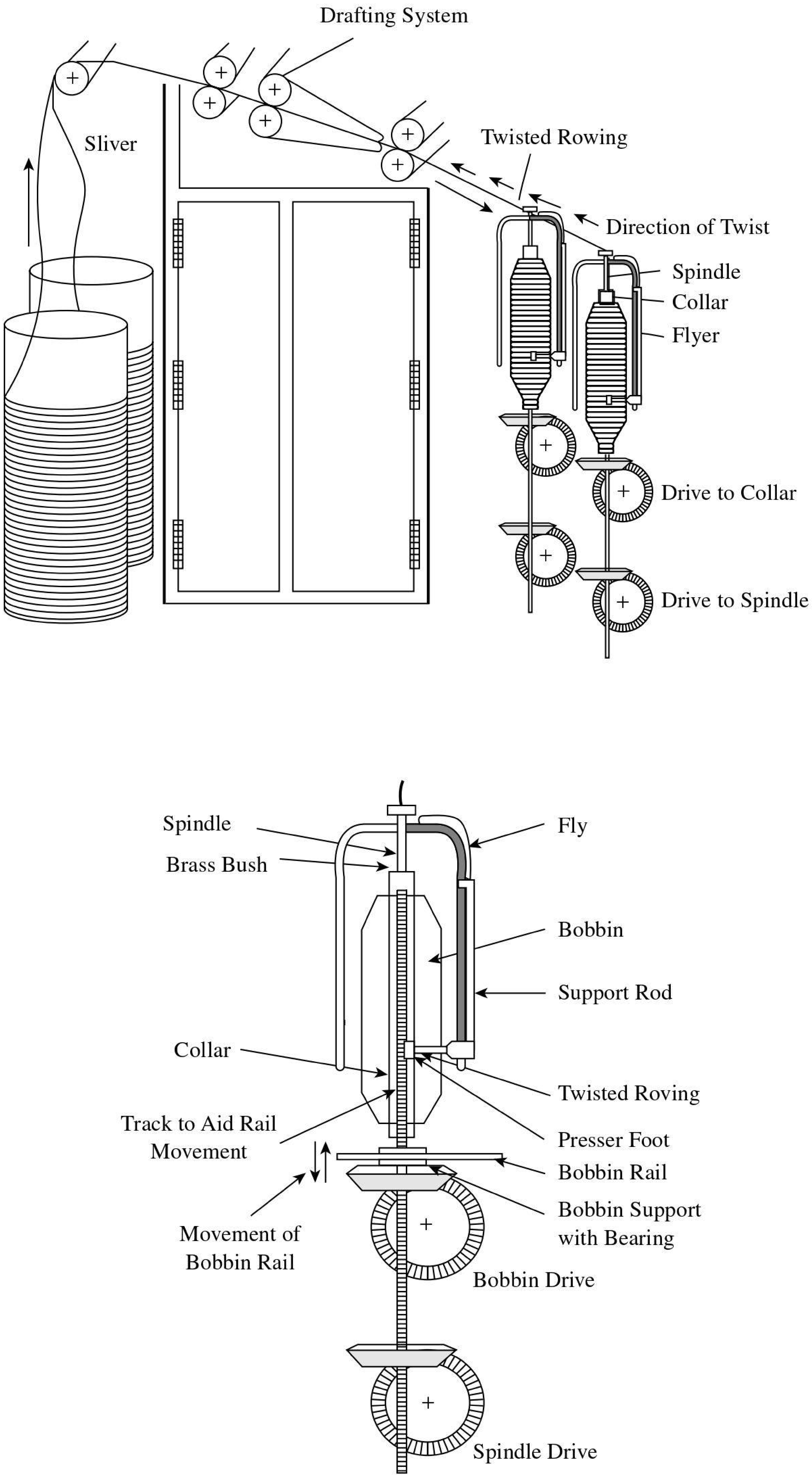


FIGURE 5.23 Basic features of a roving frame.

FIGURE 5.24 Basic roving frame.

It can be seen in Figures 5.23 and 5.24 that speed-frames are fitted with two rows of the flyer twisting device. The level of false twist inserted by the flyer inlet is dependent on the contact angle of the roving length between the flyer and the front drafting rollers; the smaller the angle, the higher the false twist. The back row of flyers is nearer the drafting rollers and therefore has the greater contact angle. The lower false twist does not give sufficient cohesion to the roving length to prevent induced tensions reducing the roving count slightly. In some cases, this difference can be significant and result in a difference in the yarn count produced from front and back rows of roving bobbins. To prevent this, modern speed-frames have the back row flyer fitted with a raised false-twister attachment (see Figure 5.25) bringing the contact angles of the two row to almost similar values.

5.4.1.1 Production Equation

The production rate of a speed-frame is dependent on the spindle speed of the fly, the number of spindles per machine, the production efficiency, the roving count, and the twist multiplier used. The following equation gives the calculated production rate.

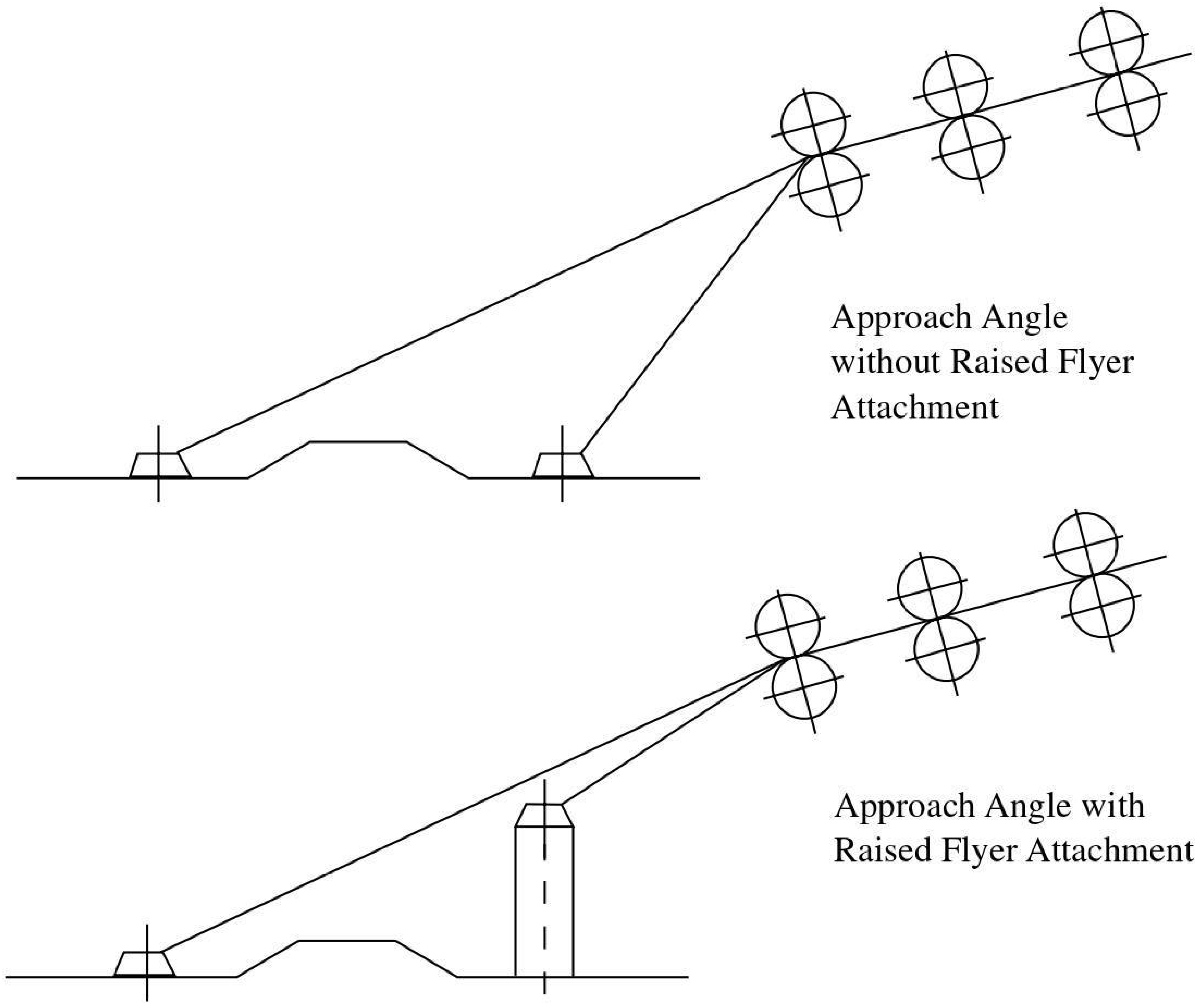


FIGURE 5.25 Flyer attachment to counter count differences. (Courtesy of Zinser Ltd.)

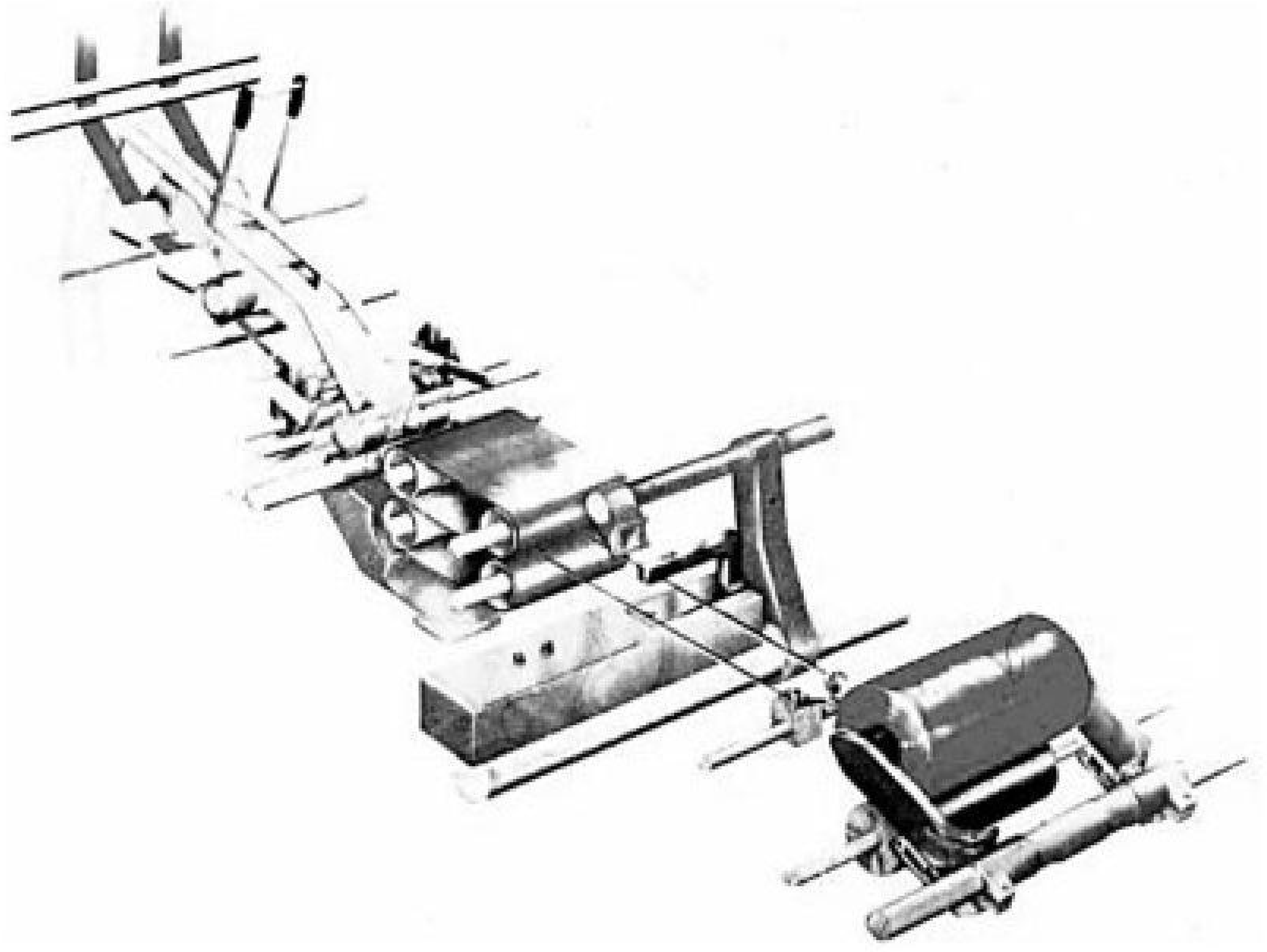


FIGURE 5.26 Basic features of twistless roving frame.

$$P_R = \frac{60 \times 10^{-9} \times E \times n \times N_s \sqrt{T^3_{t-r}}}{TM} \tag{5.14}$$

where P_R = production rate (kg/h)
TM = twist multiple (turn m/tex)
E = machine efficiency (%)
n = number of spindle per machine

N_s = spindle speed (rpm)
T_{t-r} = roving count (tex)

5.4.2 Rub Rovers (Twistless Rovings)

The principle used to produce twistless rovings is similar to the production of woolen slubbings (see Figure 5.26). The drafted ribbon of fibers issuing from the double-apron drafting system is threaded between a pair of oscillating aprons that roll and compress the ribbon of fibers into a round, consolidated, more cohesive, continuous length. The twistless rovings are then wound with minimum tension onto a tube. With the absence of twist the production rate becomes as shown below.

5.4.2.1 Production Equation

$$P_R = 60 \times 10^{-5} \times V_d \times n \times T_{t-r} \times E \qquad (5.15)$$

5.5 ENVIRONMENTAL PROCESSING CONDITIONS

Figure 1.8 (Chapter 1) gives a flowchart of process routes for the production of carded and combed ring-spun yarns, rotor yarns, worsted and semi-worsted yarns, and woolen yarns. Although some routes are relatively short, it is nevertheless true to say that fibers undergo a great amount of sliding contact between themselves and with machine surfaces. The associated friction generates static charges and, being basically nonconducting, fibers retain and accumulate the charges and tend to cling to nonmetallic parts of machines, resulting in processing difficulties and faults in the output material.[82] The heat developed during process operations will tend to reduce the moisture content of hygroscopic fibers, and, since moisture is an important means of conducting away static charges, the problem of static can increase with the number of processes. There is also the risk that fibers will become more susceptible to breakage.

To minimize static problems, it is necessary to maintain the environmental conditions, in terms of percent relative humidity (%RH) and temperature, at levels that will retain adequate moisture in hygroscopic fibers. Certain finishes are usually applied to man-made fibers as lubricants and to reduce the tendency for static charge buildup. Nevertheless, it is still found necessary to have controlled %RH and temperature. If, however, the humidity is kept too high, fibers may stick to metallic and nonmetallic surfaces. Table 5.3 gives quoted values of %RH according to fiber type and process stage.

Wool is more hygroscopic than other fibers, so higher levels of relative humidity are used. The moisture content is influenced by the condition of the wool (i.e., the presence of wool fats and oils, acids, and alkalies; the degree of compactness; and structural changes the fiber may undergo during processing, particularly scouring). However, within 70 to 80% RH and 21°C, the environment will keep the moisture in wool at between 15 and 18% regain, making it suitable for mechanical working. Cellulose fibers develop much less static that protein fibers, so lower %RH levels (45 to 55%) but higher temperatures (up to 27°C) are used, particularly in the

TABLE 5.3
Process Environmental Conditions for Fiber Types

Process	Cotton/regenerated cellulose		Synthetics		Protein fibers	
	°C	%RH	°C	%RH	°C	%RH
Opening	23	55	27	40	18–23	66–80
Carding	23	50–55	27	40	18–23	65–80
Combing	27	42	27	–	18–23	65–80
Drawing	25	48–50	27	45–65	18–23	70–80
Roving	25	48–50	27	40–45	18–23	50–60
Spinning	27	48–50	27	35–40	18–23	50–60

Courtesy of P. R. Lord, *Economics, Science & Technology,* 1981, 172.

preparatory process stages, as this also increases the elasticity of the fiber. For synthetics, 35 to 60% RH and temperatures up to 27°C cover most levels used, with nylons being at the lower end of the %RH range, acrylic around the middle, and polyester at the higher end.

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