7 The Principles of Package Winding

The principal objective of winding is to assemble many meters of yarn into package form suitable for use in subsequent operations such as weaving and knitting. A suitable package is one that can be easily unwound at high speed. Faults like very thick and very thin places in the yarn length should be removed, but the number of joint ends (i.e., piecings) must be kept to a minimum and, when required, a lubricant (wax) should be applied to the yarn surface. The yarn on packages for high-speed weft knitting is usually waxed. The removal of faults from the yarn is known as *clearing* and, in practice, *clearing and waxing* are important aspects of winding.

In the case of most unconventional spinning systems, the yarn is cleared, waxed, and wound into a suitable package during spinning. As an example, Figure 7.1 illustrates the situation for rotor spinning. With ring-spinning systems, there is

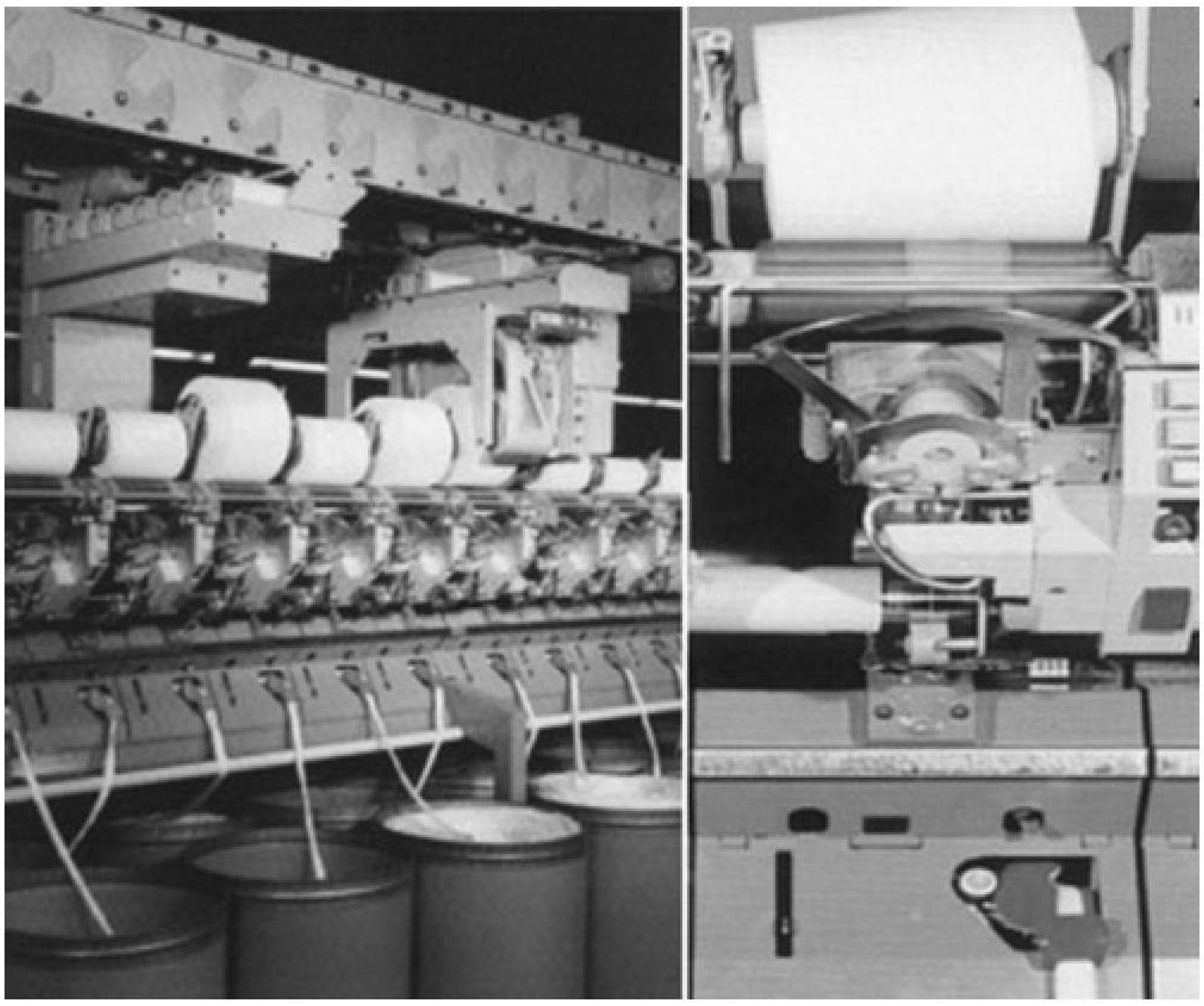

FIGURE 7.1 **(See color insert following page 266.)** Typical integrated spinning, yarn clearing, and winding on rotor machines. (Courtesy of W. Schlafhorst AG & Co.)

insufficient yarn length on the ring-spinning package. The yarn is therefore removed from a number of such packages and rewound into a suitable one. Figure 7.2 depicts the typical arrangement for the rewinding of ring-spun yarns. As the yarn is removed from the ring bobbin,* it will balloon (see Chapter 8), which can increase the yarn hairiness. The yarn therefore passes through a balloon controller, then via several tension control devices, followed by the yarn clearer, which cuts sizeable faults from the yarn. A piecing device joins the cut ends, and the yarn then travels via a waxing unit before being wound into a package.

The text of this chapter focuses mainly on the rewind of yarns from ring-spinning packages to larger-size packages. The basic underlying principles are, however, applicable to the unconventional systems. Therefore, where appropriate, comments and descriptions relating to unconventional systems are given. Five important aspects are considered: package formation, thread-line dynamics and tensioning, yarn clearing, the piecing of yarn ends, and waxing.

7.1 BASIC PRINCIPLES

In Chapter 1, it was stated that, in the winding process, the two commonly wound package types are the *parallel-sided cheese* and the *cone* shown in Figure 7.3 alongside a ring-spinning package. Two basic actions are required when producing either package type (see Figure 7.4). A bobbin forming the core of the package must be rotated so that the yarn, while under tension, can be wrapped around the bobbin circumference. Simultaneously, the point at which the yarn is wound must be traversed along the bobbin length. Control of the yarn position can therefore be achieved by regulation of the traverse in relation to the package rotation. In this way, concentric yarn layers can be made to build up to form the package.

Bobbins may be made of card or plastic, the latter being perforated if the yarn is to be package dyed. Parallel-sided cheeses have tubular bobbins. For cones, the bobbin is of a conical form, i.e., a truncated cone; the angle of taper — the semi-vertical angle — depends on the end use for the resulting package. Table 7.1 lists four common tapers. The wound cone package may have a fixed taper, which gives it flat ends, in which case the package is referred to as *straight-ended.* Cones may also have an accelerated taper, where the taper of the package is greater than the bobbin, resulting in a concave end at the top (the nose) and a convex end at the bottom (the base) of the package. These are called *dished ends.*

7.1.1 WINDING PARAMETERS

The bobbin length over which yarn is wound is termed the *traverse length.* The number of wraps (or coils) of yarn wound within a traverse length is called the *wind,* and the traverse ratio (TR) equals twice the wind, which is equal to the number of bobbin rotations in one traverse cycle. For the sake of simplicity, we will first consider parallel wound packages and discuss cones later on.

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* The ring bobbin is a slightly tapered cylindrical tube onto which a yarn is wound during ring spinning. It also may be called a ring tube, yarn bobbin, or spinning bobbin.

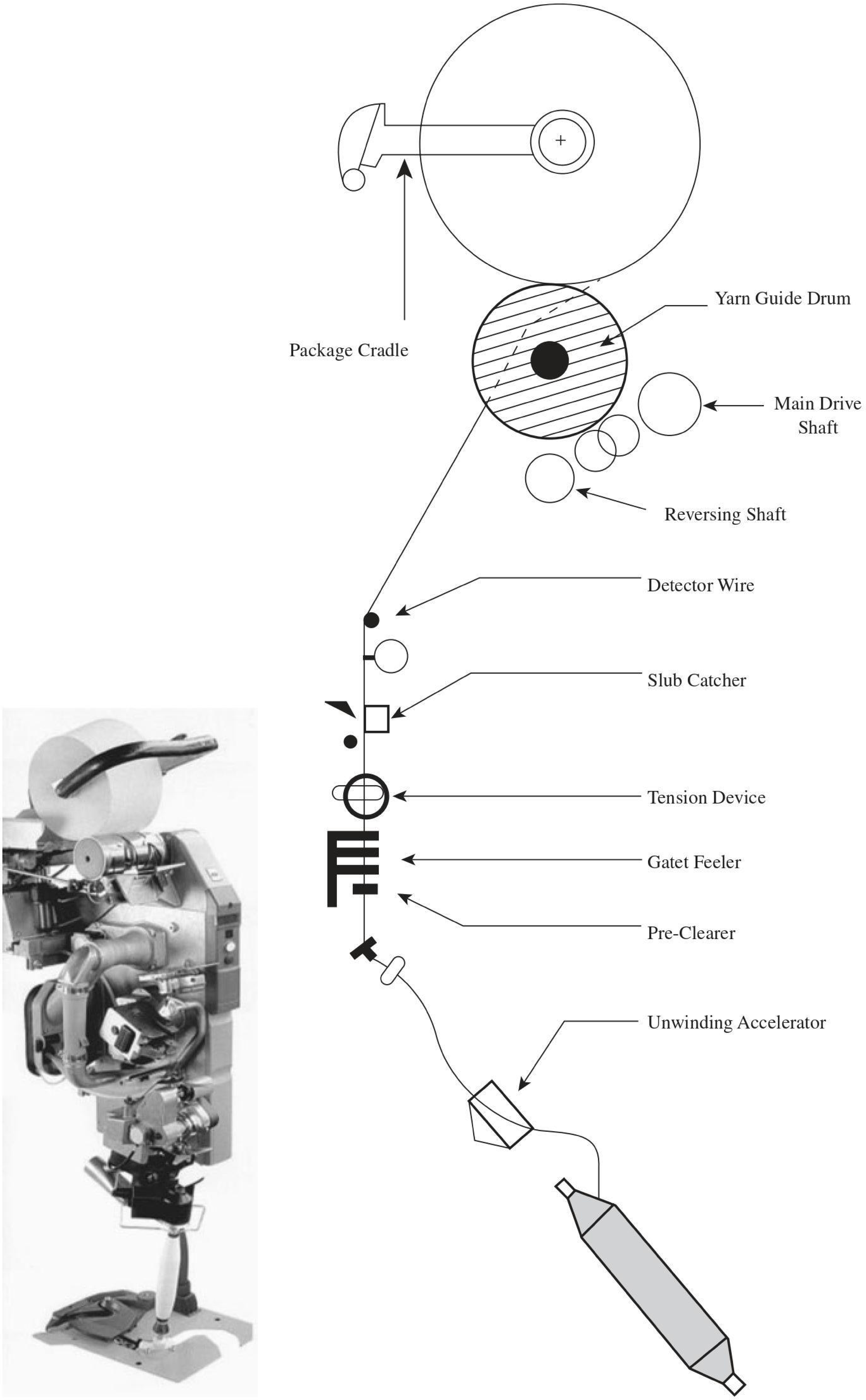

FIGURE 7.2 Typical arrangement of winding unit. (Courtesy of W. Schlafhorst AG & Co.)

meters of running yarn are viewed as indicating a poor-quality yarn. The tensile strength (cN/tex), variation in strength [CV% (strength)], the breaking strain (ε%) are the important properties in weaving; less strength is required for weft (9 to 12 cN/tex) than for warp (12 to 16cN/tex), and the minimum extension should be around 6.5 to 8.0%.

The weaving performance of a yarn is judged in terms of weaving costs, particularly as a result of downtime. On average, 20 to 30% of stoppages in cotton weaving result from yarn breaks, 30 to 40% are due to faults during warping sizing, and 30 to 40% are loom related.[202] With short-staple yarns, the processing behavior of the sized warp yarns is critically dependent on the properties of the sizing agent and the degree of sizing. However, the yarn structure is also a key factor, and loom types have specific requirements regarding the characteristic profile of warp yarns.

Over the years, weaving rates (picks per minute or meters per minute) have significantly increased with continuous improvement in shuttle-less looms. The efficiency in weaving is now highly dependent on downtimes for beam changes and tying in new warps, repair time delays, and, importantly, downtimes caused by short stops caused by warp or weft breaks. The short stops constitute a very important quality factor since, in many instances, greater than two per 100 km of yarn would be seen as below average.

The number of warp stoppages is highly dependent on the abrasion resistance of the warp yarn and a low level of hairiness, since hairs can cause adjacent yarns in a warp to cling together (snag) and hinder the passage of the weft yarn through the shed. Warps for air-jet looms generally need to have high abrasion resistance. A low degree of hairiness is particularly important in air-jet weaving. For projectile and rapier looms, warp yarns are subject to less abrasion during weaving, but the important requirement is a reduced snagging tendency (i.e., a low force needed to separate the threads during shedding). In rapier looms, hairy weft yarns can prevent the efficient transfer of a yarn between grippers. Generally, ring-spun yarns have higher snagging tendency and lower abrasion than rotor yarns.

There is a direct relationship between yarn tension during weaving and weft insertion rates. Hence, for weft insertion rates above 1200 m/min, the CV% of yarn strength is an important quality factor. Particularly important for a weaving yarn is the number of “weak places.” These are the short lengths usually identified by the Uster Classimat system and are of the order of 50 cm with breaking strengths less than 30% of the mean yarn strength. When these weak places are placed under peak tension in the warp or weft, they break.

6.3.1.3 Fabric Quality

The count variation or $CV\%_{100m}$ affects fabric appearance. For woven fabric, depending on weave structure, variations in count within and between weft packages can cause stripiness that is discernible to the human eye. With knitted fabrics, the quality characteristics that are particularly important in the evaluation of yarns are elongation at break, Classimat values, and the Uster CV. As seen in Figure 6.95, a high Uster CV% will give knitted fabrics a patchy appearance.

The ideal yarn has been defined as “being the one that is spun from the finest fiber with the least twist, the fullest volume, the best evenness, and the most consistent strength.”[203] Although the perfect yarn will always be the quest of textile technologists, agreements have to be reached between the yarn manufacturer and customer on quality criteria, and these are best based on “as good as necessary” quality specifications rather than “as good as possible.” Whatever the agreed specifications, the yarn manufacturer has to take steps to ensure that every wound package delivered to the customer conforms to the specified requirements, i.e., quality must be assured.

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7 The Principles of Package Winding

The principal objective of winding is to assemble many meters of yarn into package form suitable for use in subsequent operations such as weaving and knitting. A suitable package is one that can be easily unwound at high speed. Faults like very thick and very thin places in the yarn length should be removed, but the number of joint ends (i.e., piecings) must be kept to a minimum and, when required, a lubricant (wax) should be applied to the yarn surface. The yarn on packages for high-speed weft knitting is usually waxed. The removal of faults from the yarn is known as *clearing* and, in practice, *clearing and waxing* are important aspects of winding.

In the case of most unconventional spinning systems, the yarn is cleared, waxed, and wound into a suitable package during spinning. As an example, Figure 7.1 illustrates the situation for rotor spinning. With ring-spinning systems, there is

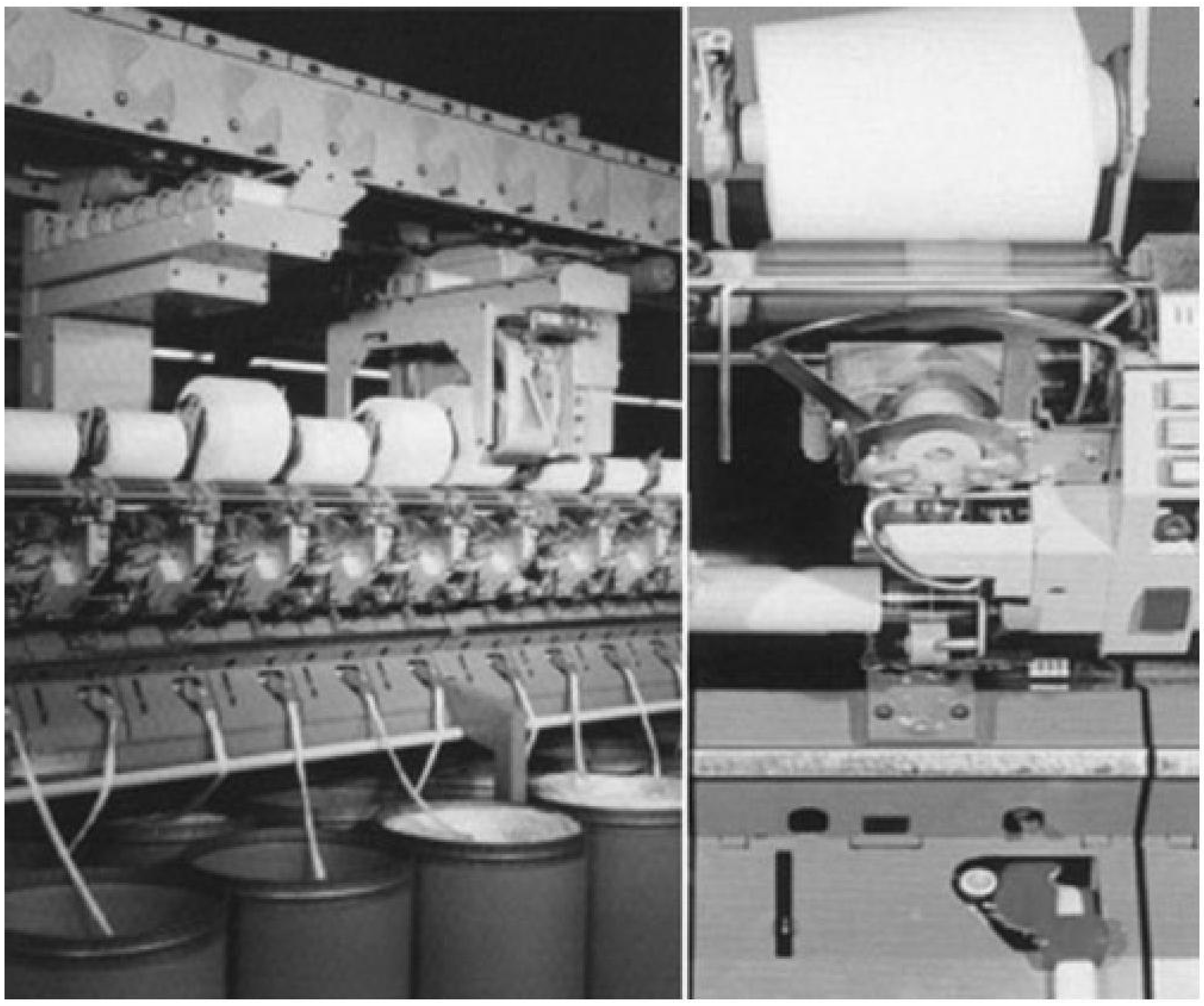

FIGURE 7.1 **(See color insert following page 266.)** Typical integrated spinning, yarn clearing, and winding on rotor machines. (Courtesy of W. Schlafhorst AG & Co.)

insufficient yarn length on the ring-spinning package. The yarn is therefore removed from a number of such packages and rewound into a suitable one. Figure 7.2 depicts the typical arrangement for the rewinding of ring-spun yarns. As the yarn is removed from the ring bobbin,* it will balloon (see Chapter 8), which can increase the yarn hairiness. The yarn therefore passes through a balloon controller, then via several tension control devices, followed by the yarn clearer, which cuts sizeable faults from the yarn. A piecing device joins the cut ends, and the yarn then travels via a waxing unit before being wound into a package.

The text of this chapter focuses mainly on the rewind of yarns from ring-spinning packages to larger-size packages. The basic underlying principles are, however, applicable to the unconventional systems. Therefore, where appropriate, comments and descriptions relating to unconventional systems are given. Five important aspects are considered: package formation, thread-line dynamics and tensioning, yarn clearing, the piecing of yarn ends, and waxing.

7.1 BASIC PRINCIPLES

In Chapter 1, it was stated that, in the winding process, the two commonly wound package types are the *parallel-sided cheese* and the *cone* shown in Figure 7.3 alongside a ring-spinning package. Two basic actions are required when producing either package type (see Figure 7.4). A bobbin forming the core of the package must be rotated so that the yarn, while under tension, can be wrapped around the bobbin circumference. Simultaneously, the point at which the yarn is wound must be traversed along the bobbin length. Control of the yarn position can therefore be achieved by regulation of the traverse in relation to the package rotation. In this way, concentric yarn layers can be made to build up to form the package.

Bobbins may be made of card or plastic, the latter being perforated if the yarn is to be package dyed. Parallel-sided cheeses have tubular bobbins. For cones, the bobbin is of a conical form, i.e., a truncated cone; the angle of taper — the semi-vertical angle — depends on the end use for the resulting package. Table 7.1 lists four common tapers. The wound cone package may have a fixed taper, which gives it flat ends, in which case the package is referred to as *straight-ended.* Cones may also have an accelerated taper, where the taper of the package is greater than the bobbin, resulting in a concave end at the top (the nose) and a convex end at the bottom (the base) of the package. These are called *dished ends.*

7.1.1 WINDING PARAMETERS

The bobbin length over which yarn is wound is termed the *traverse length.* The number of wraps (or coils) of yarn wound within a traverse length is called the *wind,* and the traverse ratio (TR) equals twice the wind, which is equal to the number of bobbin rotations in one traverse cycle. For the sake of simplicity, we will first consider parallel wound packages and discuss cones later on.

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* The ring bobbin is a slightly tapered cylindrical tube onto which a yarn is wound during ring spinning. It also may be called a ring tube, yarn bobbin, or spinning bobbin.

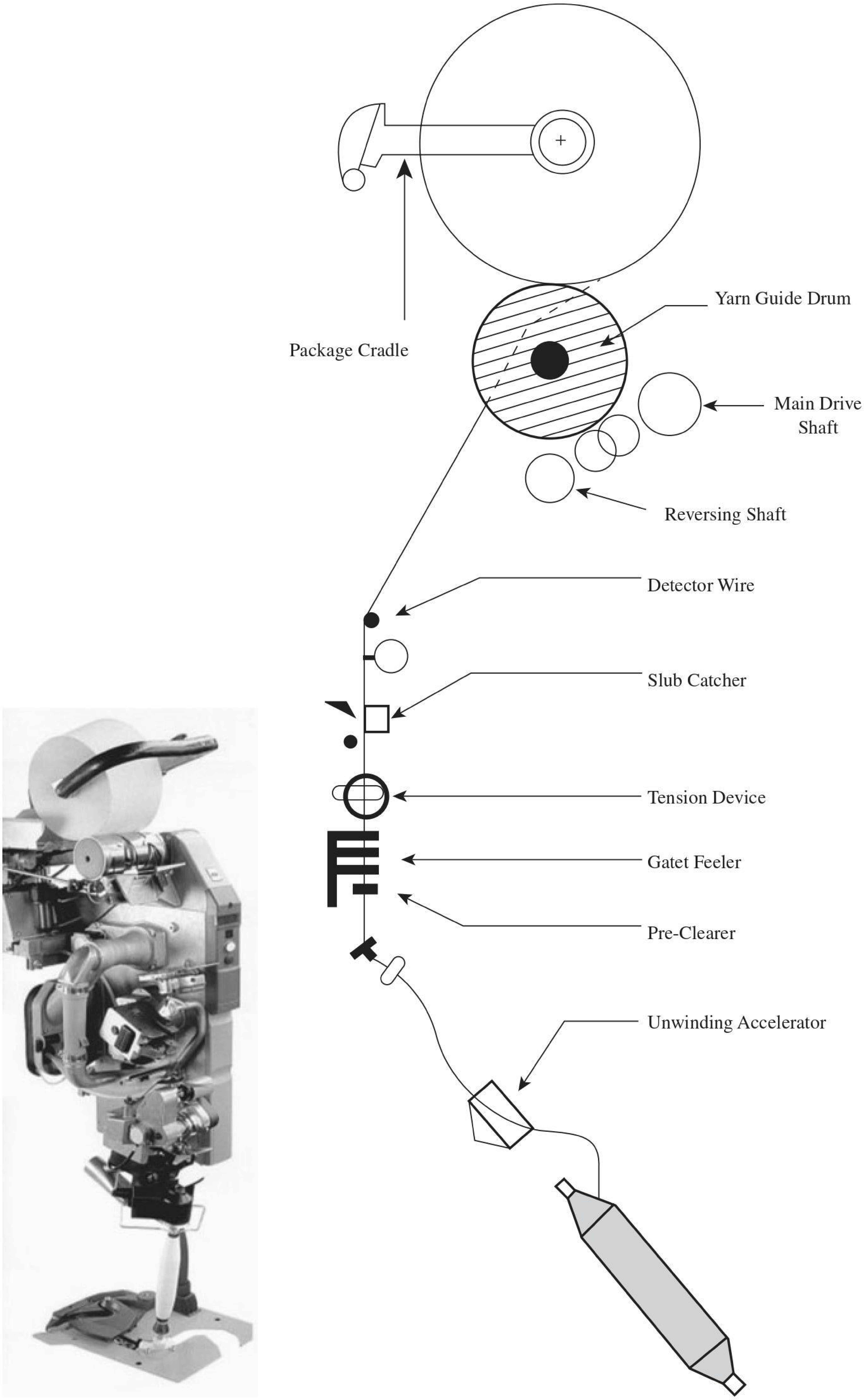


FIGURE 7.2 Typical arrangement of winding unit. (Courtesy of W. Schlafhorst AG & Co.)

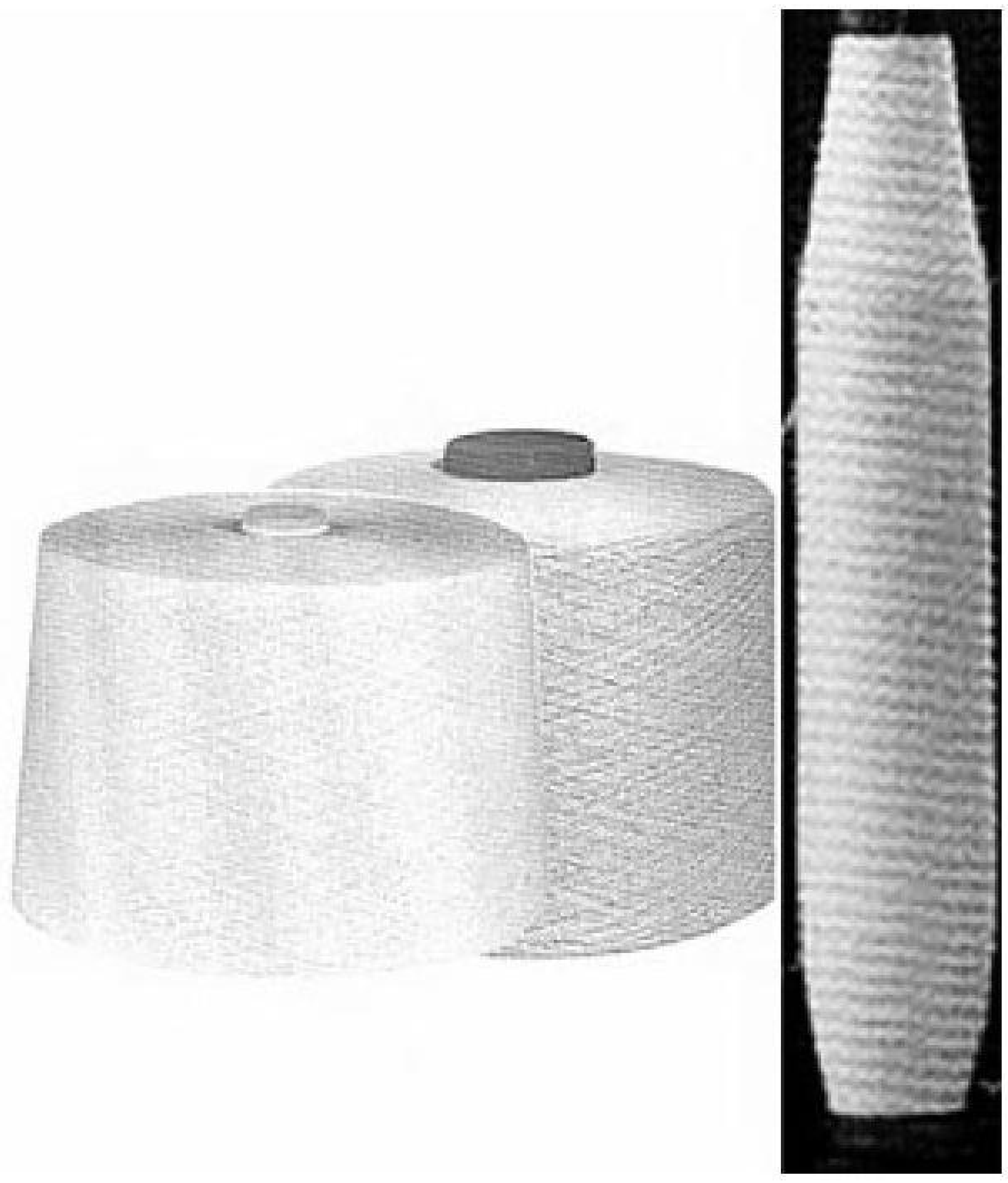


FIGURE 7.3 Ring-spinning package and rewound yarns of cheese and cone packages.

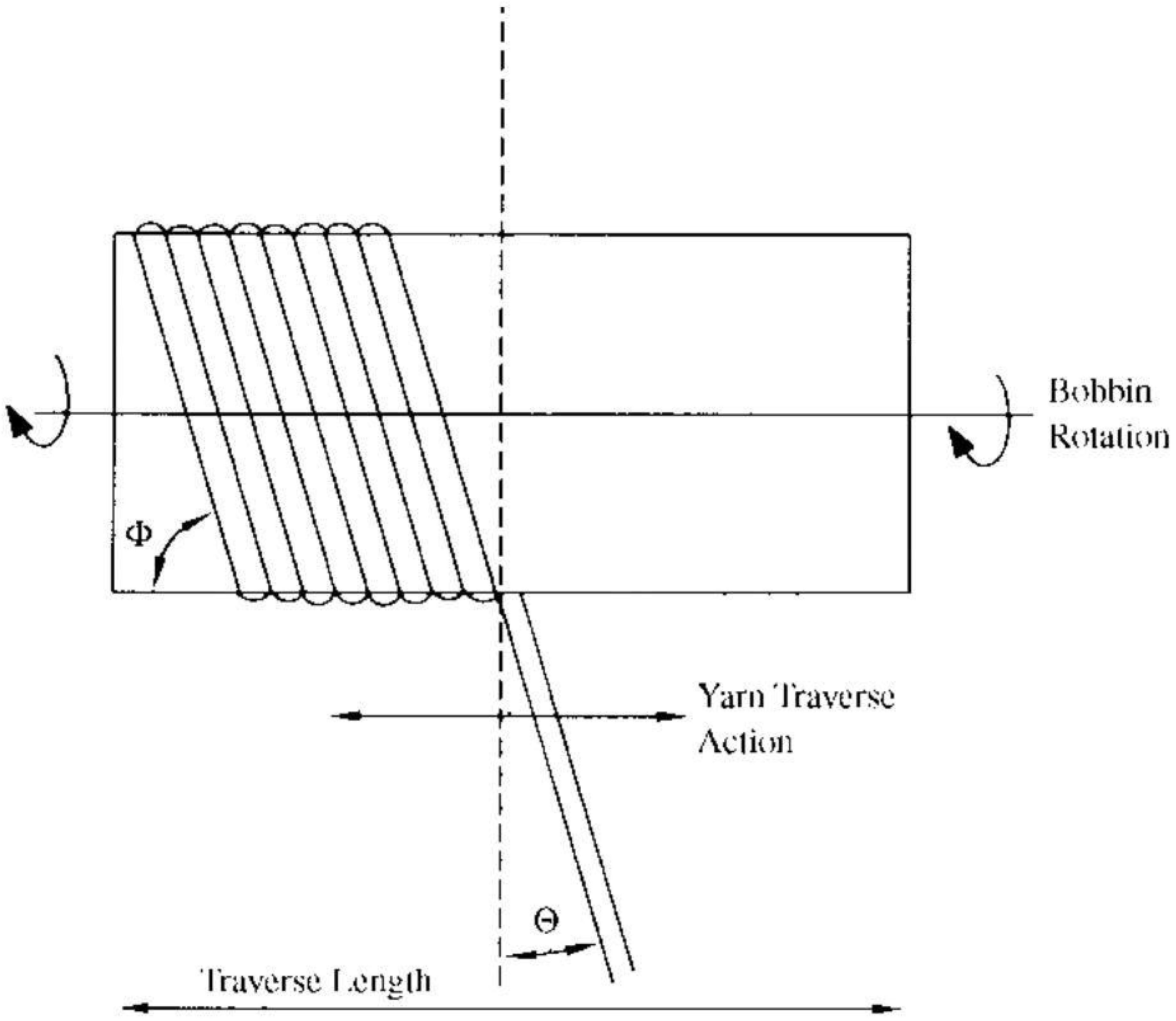


FIGURE 7.4 Basic winding actions.

TABLE 7.1
Common Tapers for Random-Wound Cones

Cone taper (semivertical angle)	End uses
3°30'	General purposes
4°2'	Wet processing (e.g., dyeing)
5°5'	Weft knitting: at final diameter taper may increase to 10°
9°1'	Weft knitting: at final diameter taper may be 14° to 18°

The angle θ between the inclined yarn (the yarn lay) on the package and a plane perpendicular to the bobbin axis is called the *wind angle* and can be calculated according to

$$\tan\theta = V_{ts}/2\pi r N_b \tag{7.1}$$

where V_{ts} = the traverse speed (m/min), assumed to be constant even at the points of reversal
r = radius (m) of the layer being wound
N_b = bobbin rotational speed (rpm)

It is often found that the greater the wind angle, the more stable the package. The maximum limit to the wind angle is the value that, if exceeded, allows the yarn, on reaching the end of a layer during traverse reversals, to slip over the end of the layer beneath.

The coil angle, ϕ, is the angle between the direction of the yarn on the package and the direction of the traverse length. Therefore, $\phi + \theta = 90°$. Throughout the remaining sections, the coil angle will be used in preference to the wind angle.

The winding speed of the yarn is the resultant speed of the bobbin surface and traverse speeds. It can be calculated from

$$V_{wy} = \sqrt{V_{bs}^2 + V_{ts}^2} \tag{7.2}$$

where V_{bs} and V_{ts} = the bobbin surface and traverse speeds, given by

$$V_{bs} = 2\pi\ r\ N_b \tag{7.3}$$

$$V_{ts} = 2LN_t \tag{7.4}$$

where L = traverse length
N_t = traverse frequency

The winding speed is also given by

$$V_{wy} = V_{bs}\ \mathrm{cosec}\,\phi \tag{7.5}$$

Yarn reversal at the traverse ends cannot occur instantaneously. Therefore, unless steps are taken, more coils occur in the region of the package ends than in the rest of the traverse length. The package density is then higher at the ends, forming what is termed *hard package ends.* This is considered to give poor package formation and would be unacceptable for package dyeing of yarns. As explained later, a uniform package density can be obtained by slightly displacing the traverse of each layer laterally in one direction and then the other by 3 to 5 mm.

7.2 TYPES OF WINDING MACHINES

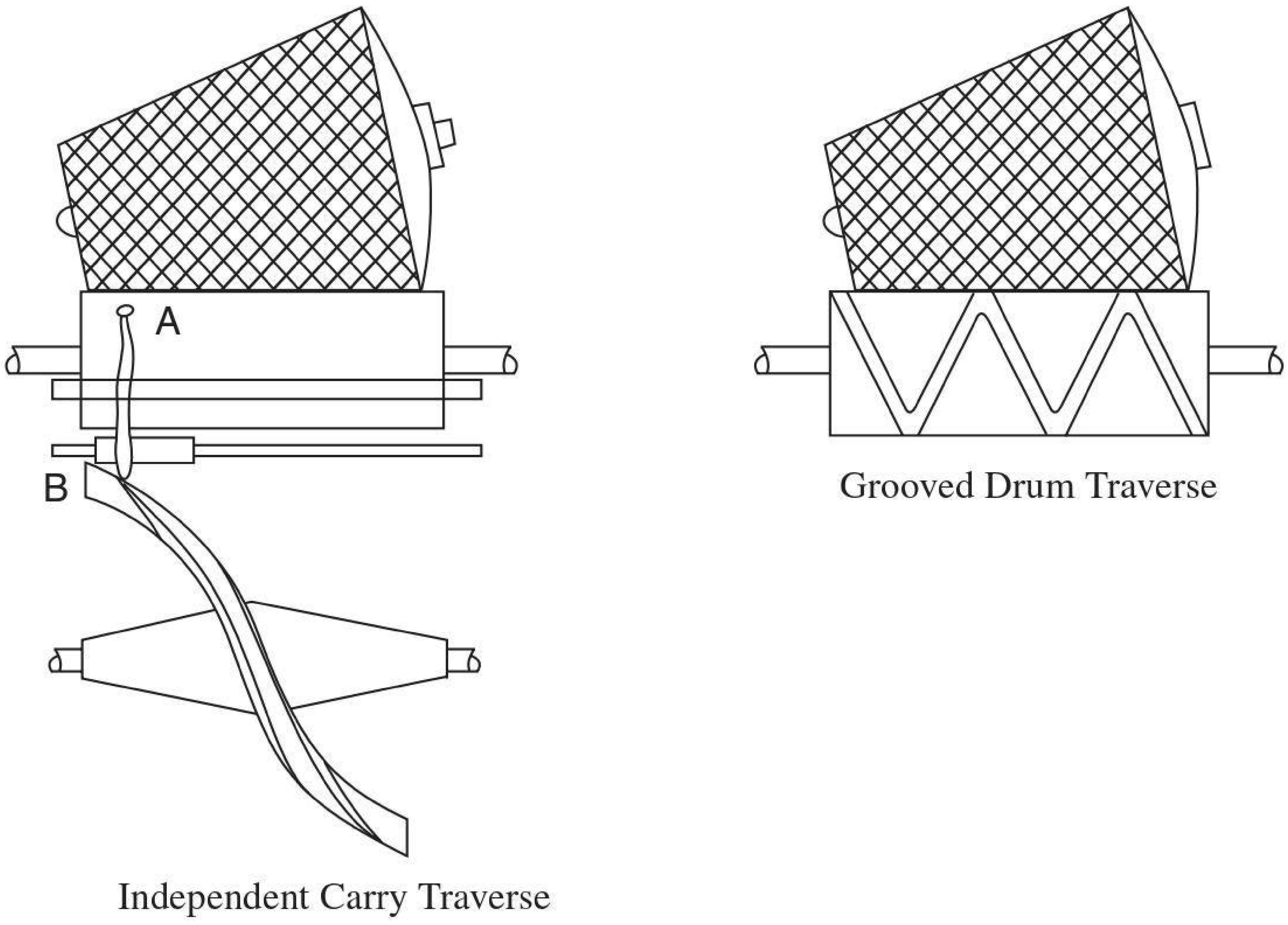
There are two widely used types of winding machine: drum winders (used to wind staple-spun yarns into random-wound packages) and precision winders (for winding filament yarns into precision-wound packages). Throughout this book, we are concerned only with staple spun yarns, but it is useful to have a basic understanding of the differences between the two types of winding, so both are discussed in this chapter.

7.2.1 DRUM-WINDING MACHINES

Drum-winding machines rotate the forming package through surface contact with a cylindrical drum, and the yarn is traversed either by an independent traverse, typically a wing cam, or by grooves in the drum. Figure 7.5 illustrates the two types of traverse systems.

7.2.1.1 Wing Cam

There are several different independent traverse systems, but the simplicity of the wing cam makes it a useful example to describe. As shown, the end, A, of a yarn guide bar moves the yarn while the other, B, is made to move around the periphery of the cam, traveling one circuit of the periphery per revolution of the camshaft. As B makes one circuit of the cam, A reciprocates, moving the yarn through a return traverse (i.e., double traverse) along the length of the bobbin. The reciprocating yarn guide limits the winding speed because of the inertia on reversals. A very high rate of traverse is impeded by the mechanics of the guide system, since forces of 16 to 64 times the weight of the yarn guide can be present during the reciprocating action. The reciprocating guide can be replaced by a spirally grooved traverse roller, which



Independent Carry Traverse

Grooved Drum Traverse

FIGURE 7.5 Winding traverse motion.

moves the yarn along the traverse length. In this case, only the yarn undergoes reversal as it is held in the traversing groove of the rotating roller, and speeds in excess of 1500 m/min can be achieved. A further advantage of the grooved traverse roller is that, as a result of tension, the yarn being wound enters the groove without the need for threading up as is required with the independent traverse system.

7.2.1.2 Grooved Drum

With the grooved drum system, the surface speed of the drum, and the traverse speed are kept constant. A continuous helical groove (i.e., interconnected clockwise and counterclockwise helical grooves) around the drum circumference guides the yarn along the traverse length as the yarn is wound onto the bobbin**.** A continuous helix has points of crossover of the clockwise and counterclockwise helices. To retain the yarn in the correct groove during its traverse, particularly at the intersections, one groove is made deeper than the other, and the shallower groove is slightly angled.

For both types of traverse, we can refer to a drum constant, *k*, as the number of turns corresponding to a double traverse of the yarn on the bobbin. This is similar to the wind.

$$k = \frac{N_d}{N_t} \tag{7.6}$$

where N_d = the drum rotational speed

A wing cam traverse provides one double traverse (i.e., a traverse cycle) for every turn of the camshaft. There are therefore N_t traverse cycles per minute (i.e., the traverse frequency). The constant *k* is purely a ratio that can be, but usually is not, a whole number. With groove drums, the continuous spiral is such that *k* is always a whole number. The *k* value of a groove drum is easily found by inspection. It is twice the number of crossings of the spirals, e.g., a 2.5 crossing drum has $k = 5$. However, a drum with $k = 1$ is called a *split drum*, not a 1/2-crossing drum.

From Equations 7.4 and 7.6,

$$V_{ts} = 2L\,\frac{N_d}{k} \tag{7.7}$$

And the transverse ratio, *TR*, is

$$TR = k\,\frac{D_d}{D_b} \tag{7.8}$$

where D_d and D_b = respective diameters of the drum and bobbin

The reader should note that the above equation for TR is applicable only to cylindrical packages. As we shall see later, with cone-shaped packages, it is convenient to refer to the mean diameter, d_m. Thus, for cones, $TR = k\,D_d/d_m$.

As the package diameter increases, its rotational speed decreases, and so does the wind and the transverse ratio, but the coil angle, ϕ, remains unchanged. To make stable packages in which the coils retain their position and do not drift toward the middle or the ends of the package, ϕ should be within the range of 68° to 81°.

The decrease in the traverse ratio with increasing package diameter presents a problem in the winding process.

7.2.1.3 Patterning/Ribboning

As the traverse ratio decreases, it passes through a series of integer values. How long it remains at any particular integer value depends on the rate of change of the package diameter as winding proceeds. At small diameters, the rate of increase of D_b is too high for patterning to persist. However, when the transverse ratio corresponds to a whole number, the yarn coils of successive traverse will follow exactly the same path of wind. The coils of successive winds are therefore formed on top of each other, producing a raised honeycomb pattern on the bobbin surface.

As the package builds up, we can see from Equation 7.8 that, with D_b increasing, TR decreases and ceases to become an integer. The action of patterning is then disrupted. Nevertheless, a number of patterning zones can exist in a package, because patterning can also occur when TR has certain nonintegral values that result in the yarn returning to its starting point after a small number of double traverses (e.g., TR = interger + 1/2, or 1/3, 2/3, 1/4, 3/4, 1/5, 2/5, 3/5, 4/5). Patterning is an objectionable fault, as it causes an uneven package density. If package dyeing is carried out, this may result in uneven dyeing of the yarn.

7.2.1.4 Sloughing-Off

As coils in a patterning zone lie exactly on top of each other, two or three such overlaying coils can be inadvertently pulled off together during the unwinding of the yarn from the bobbin. This leads to an entanglement of the coils, which then has to be cut away. This is a fault known as *sloughing-off.* Clearly, sloughing-off causes machine stoppages in warping and in weaving where the package is used as a weft supply. In weft knitting, the effect can be more severe, causing needle breakage. Beside sloughing-off, the coils in the patterning zone can cause snagging and thereby high-tension variations.

7.2.1.5 Anti-patterning Devices

Patterning must be avoided, and drum-winding machines are equipped with anti-patterning devices. They can be one of four types, as described below.

Variation of Traverse Frequency, N_t

For cam-operated traverse machines, a small sinusoidal variation is made to the normal running speed of the camshaft. The lay of yarn coils is therefore not constant but varies slightly from one double traverse to another (see Equation 7.1), and there is also a slight variation in TR (see Equations 7.6 and 7.8). Thus, the start of each double traverse will sometimes be before, and sometimes behind, the previous one. This approach to pattern breaking is a very effective one.

Variation of Drum Speed, N_d

For rotary traverse machines (grooved drums), small reductions and increases are made automatically to the speed of the drum 20 to 30 times per minute. The changes in speed slow and then speed up the package but, as the drum accelerates, there is a small slippage between the package and the drum until frictional contact between the two brings the package up to the increased drum speed. The slipping of the package causes a change in the lay of the coils being wound-on at the time and in *TR*; patterning is thereby prevented.

Lifting of Bobbin to Reduce N_b

An alternative way of introducing slip is to rapidly raise (1 mm) and then lower the forming package off and onto the drum 20 to 30 times per minute.

Rock-and-Roll Method

This method is confined to cone winding, which will be discussed later. It involves intermittently tilting the package from the drum so that the base of the cone-shaped package being formed remains in contact with the drum while the nose rises a millimeter or so. This occurs several times per minute.

7.2.2 PRECISION WINDING MACHINES

We can see from the above description that drum-winding systems involve significant frictional contact between the yarn and the package-forming device. Yarns that can be easily damaged by friction, in particular filament yarns, are wound into packages using precision winders.

With precision winders, the package is mounted onto a drive spindle, and a reciprocating yarn guide, driven by a cylindrical cam coupled to the spindle drive, is used to move the yarn along the traverse length. The reciprocating yarn guide limits the winding speed because of the inertia on reversals.

The term *precision* refers to the control of positioning each layer of yarn as it is wound onto the bobbin. There is a precise ratio of spindle to traverse speed. Therefore, as the package diameter increases, the wind and *TR* are kept constant. Thus, for precision winders, Equation 7.8 becomes

$$TR = \frac{N_b}{N_t} \tag{7.9}$$

The coil angle is given by

$$\tan\phi = \frac{\pi D_b N_b}{V_{ts}} = \frac{\pi D_b N_b}{2LN_t} = \frac{\pi D_b TR}{2L} \tag{7.10}$$

Hence, as D_b increases the coil angle, ϕ, increases, and the angle of wind, θ, decreases. Continuous filament yarns are prone to slip at reversal points; therefore, in contrast to the drum winding of spun yarns, the precision winding of filament yarns requires ϕ to be within the range of 70° to 80°. Importantly, the package diameter should not allow ϕ to exceed 80°, which can mean a small package size when using a constant spindle speed. But note that, although precision winding is essentially for continuous filament yarns, it can be used for very fine spun yarns.

Provided that the machine is arranged such that *TR* is not an integer or a multiple of 0.5, patterning will not occur with precision winding, so no pattern-breaking devices are needed. With N_b constant, the surface speed of the forming package increases with D_b, as does the yarn tension. Increasing yarn tension can cause increased package density in the outer layers. All yarns have a limiting speed at which they can be wound into packages economically so, once the package surface speed equals the limiting speed for the yarn, the package will have reached maximum diameter. The limiting speed is governed by the situation in which the mean tension and the variation about the mean are at such a level that peak tension values reach the yarn breaking load. Then, an excessive number of yarn breaks occur during winding, resulting in a low production efficiency, a low production rate, and poor-quality packages with a high number of piecings.

Precision winders may have a constant or variable spindle speed, constant or variable surface speed, or a combination of these. A constant spindle speed requires minimal tension fluctuations. A variable spindle speed provides a constant mean winding tension; a device (a tension-compensator) is used to monitor any change in the mean tension, and it slows or increases the spindle speed to maintain a constant tension. For constant surface speed, the spindle speed has to decrease as the package diameter builds up. When a combination approach is used, the spindle speed first increases to give the required production rate, after which surface speed is kept constant.

The advantage of a combination system, as compared with constant spindle speed, can be illustrated by the following numerical example of building a parallel-sided cheese package. Knowing the traverse length, *L*, and traverse ratio, *TR*, the optimal bobbin diameter, or package core diameter, $D_{b(min)}$, and the maximum package diameter, $D_{b(max)}$, can be calculated by applying the coil angle restrictions. Thus, from Equation 7.10,

$$D_b = \frac{2L\tan\phi}{\pi TR} \tag{7.11}$$

Let $L = 20$ cm and $TR = 5$. Then, for $\phi = 70°$ and $80°$, respectively, $D_{b\,(min)} = 7$ cm, and $D_{b(max)} = 14.44$ cm.

If the limiting winding speed for the yarn is 600 m/min, then, for the constant spindle speed system, the actual spindle speed will be the value that enables the surface speed of the package to reach the limiting winding speed at a package diameter that equals $D_{b(max)}$. This will require a traverse frequency or cam speed of

$$600 = \frac{\pi D_{b(max)} N_b}{100} = \frac{\pi D_{b(max)} TR N_t}{100} \tag{7.12}$$

and $N_t = 264.5$ cycles per minute (or revolutions per minute of the wing cam shaft), which must not exceed the maximum available on the machine, say 350 rpm.

The surface speed of the bobbin or package core will be

$$\frac{\pi D_{b(min)} TRN_t}{100} = 290.8 \text{ m/min} \tag{7.13}$$

For combination systems, winding during the earlier stage of package build can occur at the fastest possible spindle speed until the package surface speed equals the limiting speed for the yarn. Then, the spindle speed is controlled to maintain this surface speed as the package diameter increases. Thus, the change of winding mode would occur when the bobbin diameter reaches a value given by

$$\frac{\pi D_b TR350}{100} = 600 \text{ m/min} \tag{7.14}$$

so D_b = 10.91 cm and, at this diameter, the coil angle is 76.9° (see Equation 7.10).

In the second stage of winding, the package builds up at 600 m/min until the diameter reaches 14.44 cm ($\phi = 80$). Based on these calculations, Figure 7.6 shows a graph comparing the two modes, and it is evident that the combination mode will always give a higher production rate than can be obtained with a constant spindle speed.

It should also be clear that, if a constant surface speed system were used to build the package at the limiting speed of 600 m/min so as to obtain an even higher

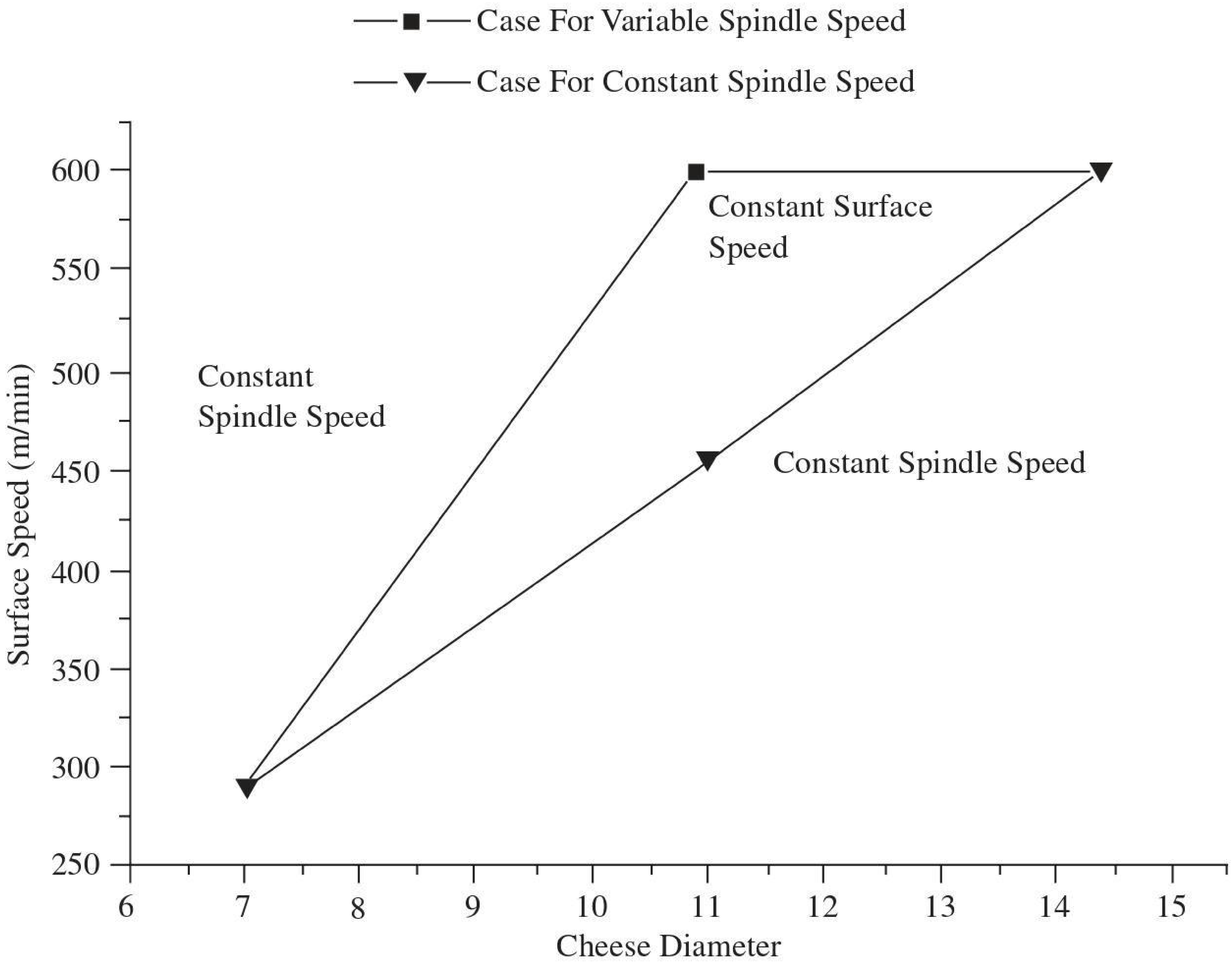


FIGURE 7.6 Package building at constant and variable spindle speed modes.

production rate, the disadvantage would be less yarn length wound on the package. This is because the bobbin diameter, $D_{b(min)}$, would need to be 10.91 cm rather than 7 cm as used for the combined and constant spindle speed systems.

7.2.3 ADVANTAGES AND DISADVANTAGES OF THE TWO METHODS OF WINDING

Advantages and disadvantages of the two winding methods are shown below.

Advantages and Disadvantages of the Two Methods of Winding

Characteristics		Precision winding		Random winding
Patterning	+	No patterning	–	Inherent patterning, anti-patterning device necessary to prevent pattern zones
Package density	–	Not constant	+	Constant
Density of wind	+	High package density	–	Low package density
Geometry of yarn lays	+	Precise yarn laying	–	Irregular yarn laying form layer to layer
Unwinding performance	+	Good winding performance	–	Problem of pattern zones
Technical system	–	Complex systems, expensive machines	+	Simple system, lower-cost machines

+ = advantages, – = disadvantages

Courtesy of Durur, G., *Cross Winding of Yarn Packages,* Ph.D. Thesis, University of Leeds, July, 2000.

7.2.4 COMBINATIONAL METHODS FOR PATTERN-FREE WINDING

With the application of microprocessor control techniques, winding machines have been developed with the objective of combining the positive features of the two basic winding methods. These newer methods are known as *stepped precision winding,* which produces a wound package referred to as *digicone,* and *ribbon free random winding.*

7.2.4.1 Stepped Precision Winding (Digicone)

The aim is to combine the advantage of the constant wind angle of random winding and the advantage of the constant traverse ratio, TR, of precision winding to produce a pattern-free package with a near-constant coil angle, ϕ. Figure 7.7 illustrates the arrangement used. The drum is driven to give a constant winding speed, and the motor also drives a variable ratio-drive unit, V, which controls the traverse drum speed.

Figure 7.7a shows a plot of winding ratio and coil angle, ϕ, during package build. Precision winding is characterized by the horizontal line, P, because of its constant TR, whereas random winding is represented by a hyperbolic curve for a constant ϕ. With precision winding, there is a precisely constant TR, but with random winding, ϕ is not precisely constant. This is because of the required anti-patterning

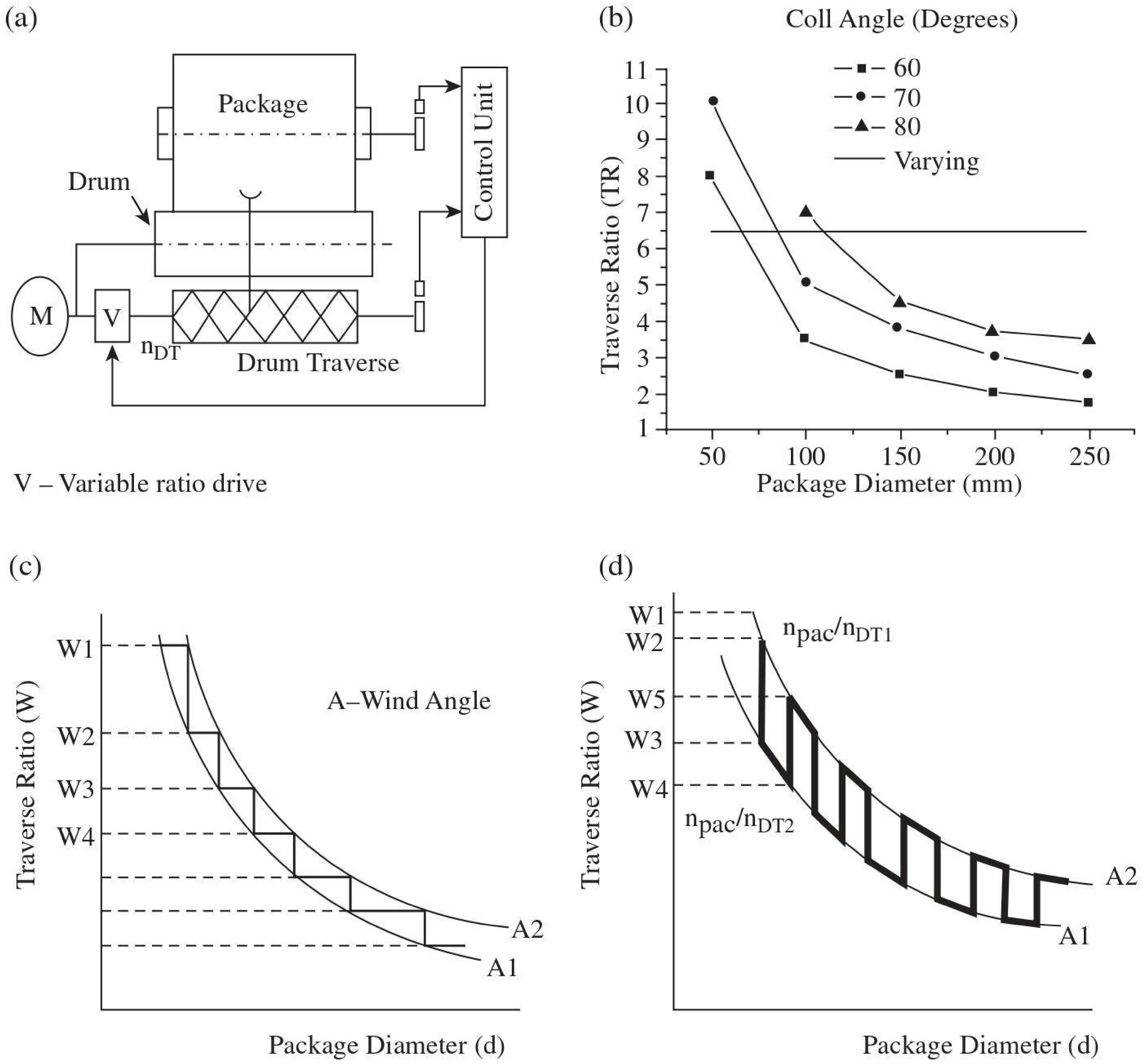


FIGURE 7.7 Stepped precision and ribbon free random windings. (Courtesy of Durur, G., *Cross Winding of Yarn Packages,* Ph.D. Thesis, University of Leeds, July, 2000.)

action. Random winding therefore involves a very narrow range of ϕ values. It is within this range that stepped precision winding simulates the basic principles of precision winding.

At the start of winding (See Figure 7.7c), the TR is set at a high value (W1) that provides the required gain, and ϕ = A1. As winding proceeds, TR remains at (W1), but ϕ increases to A2, the maximum allowable value. This point is determined from shaft encoders connected to the spindles, and the ratio of the coupling is altered to a lower TR of (W2) so as to reset ϕ to A1 and retain the gain but to avoid an integer value. The procedure is repeated throughout the build of the package. Each resulting yarn layer will be wound with a different TR, but ϕ will be nearly constant.

7.2.4.2 Ribbon Free Random Winding

This method is similar to the basic random winding method, but steps are taken to ensure that the TR does not reach integer values. The control system is arranged in a similar way to the digicone process, but the difference is in the variable drive control (V) of the traverse cam speed. Instead of varying the speed to achieve step-constant TRs, the speed is varied to obtain step-constant ϕs.

Figure 7.7d shows that two traverse cam speeds are involved, n_{DT1} and n_{DT2}; thus there are two set ϕ values relating to the ratio of the package speed, n_{pac}, and the cam speed (see Equations 7.9 and 7.10). Winding begins with ϕ set at A2 and, as the package diameter increases, TR nears the critical value W2, at which stage the yarn traverse speed is changed by the control unit to reduce TR to W3 and ϕ to A1. The package now continues to build in diameter until TR nears W4, when the yarn traverse speed changes again to increase TR to W5 and ϕ back to A2. This reversal of ϕ at critical values of TR proceeds to the full package size. In contrast to digicone, the ribbon free random-wound package has layers that are wound at two very distinct ϕ values.

7.3 RANDOM-WOUND CONES

The above discussion was largely about the winding of parallel-sided cheese-type packages. Although the underlying principles apply to the winding of conical packages, there are important differences in producing random wound cones, as in this case the forming package is surface driven. These differences are therefore not applicable to the precision winding of cones.

7.3.1 PACKAGE SURFACE SPEED

The principal difference between cheese winding and cone winding on drum-driven systems is concerned with the package surface speed. A cone in contact with a rotating cylindrical drum may have a rotational speed of N_b, but the surface speed will vary along the traverse length, the lowest value being at the nose and increasing to the highest value at the base. In contrast, a parallel-sided cheese has the same surface speed at all points along its traverse length. With a cone, there can be only one point on the traverse length that has a surface speed equal to that of the rotating drum, and this is therefore the point of drive of the cone by the drum (see Figure 7.8). Since, at every other point along the traverse length, there is a difference between the surface speeds of the cone and the drum, slippage will occur at all surface-contact points except the point of drive.

The distance along the traverse from the cone base to the point of drive is called the *drive length,* indicated as “y” in the diagram, which remains constant during winding of the package. There is initially some variation in y when the cone is small, but this is negligible. Thus, for a fixed drive length, Figure 7.8 also illustrates, in relation to the drum surface speed, the changes in the cone surface speed at points along the traverse length as the cone builds up. N_1–B_1 represents the surface speed of the cone from nose to base at the start of winding. It can be seen that the nose speed is much smaller than the point of drive speed, but the base speed exceeds the point of drive speed. As the nose and base diameters increase, the cone rotational speed decreases. Therefore, the surface speed of the nose increases while the base speed decreases, both moving toward but never achieving the drum speed, as indicated by lines N_2–B_2 and N_3–B_3.

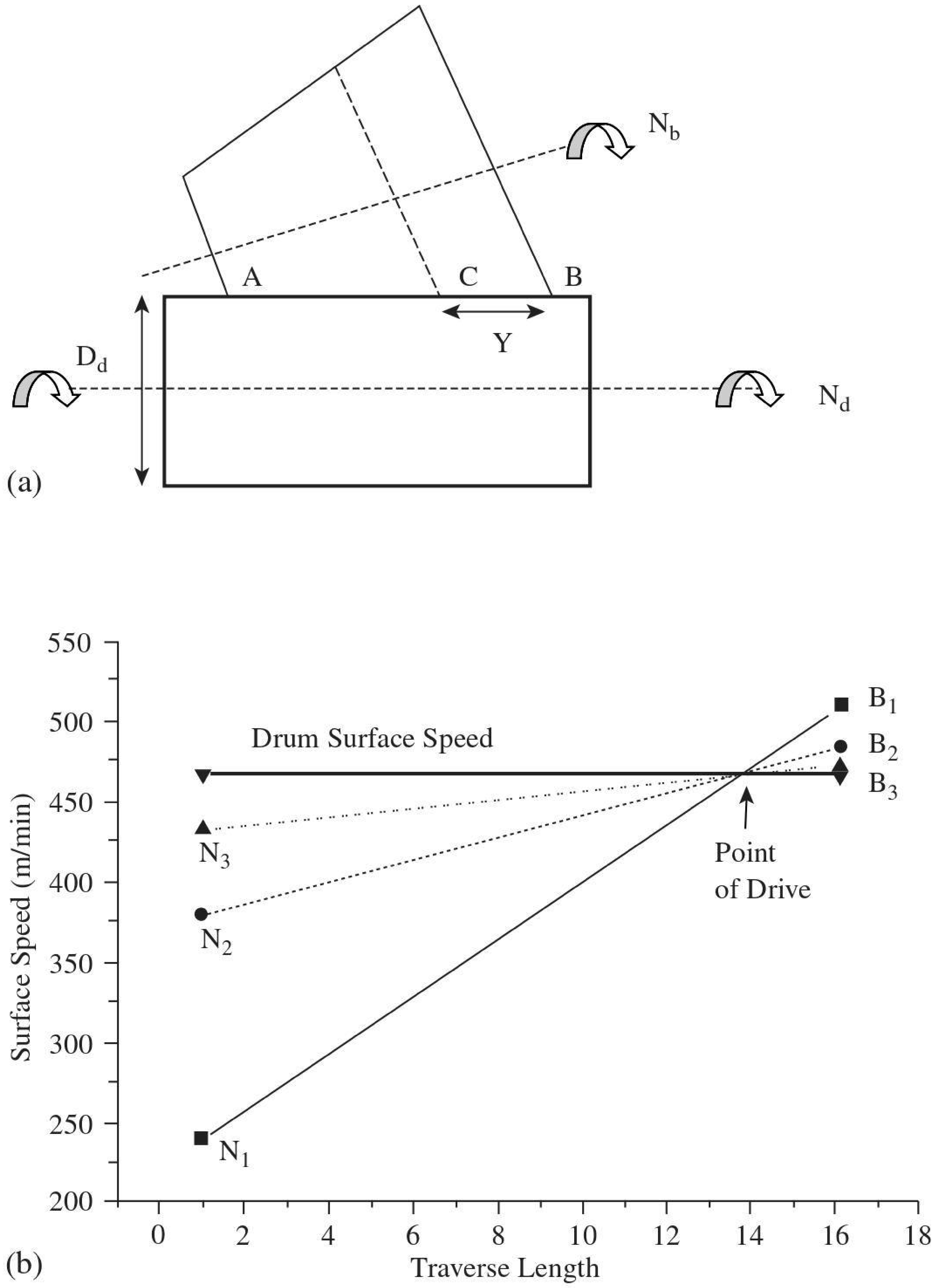


FIGURE 7.8 Random-wound cones.

The production speed of winding is the mean surface speed and not the speed at the point of drive. The mean surface speed can be calculated from the drum diameter, D_d, and the drum surface speed, N_d. Thus, the rotational speed of the cone, N_b is given by

$$N_b = \frac{N_d D_d}{d_d} \tag{7.15}$$

where d_d = the diameter at the drive point of the cone, a distance y from the cone base

If α = the cone angle and d_d = cone base diameter, then,

$$d_d = d_b - 2y \sin \alpha$$

The mean surface speed, $V_{m,}$ of the cone then becomes

$$V_m = \frac{N_b \pi (d_b + d_n)}{2}$$

$$= \frac{\pi N_d D_d (d_b + d_n)}{2[d_b - 2y \sin\alpha]} \tag{7.16}$$

Figure 7.9 illustrates how V_m increases asymptotically toward the drum surface speed as the mean cone diameter increases. It is clearly beneficial to use as large as possible a mean core diameter, but doing so must enable adequate yarn length to be wound into a cone package with the required taper.

7.3.2 Abrasion at the Nose of Cones

The difference in surface speed that occurs between the nose region of the cone and drum can result in yarn abrasion, and yarns sensitive to friction can be affected adversely by the heat produced. For example, polyester/cotton blend can show localized fusion of the polyester. To alleviate such effects, cam-operated traverse systems have what is termed *split drums.* One part of the drum is solid and drives the bobbin, while a second, shorter part (a *loose shell*) is free to rotate and supports the rotating nose of the cone. With drum traverse systems, the cylindrical drum is replaced by a slightly tapered one, thereby reducing the speed difference between the nose of the cone and the drum.

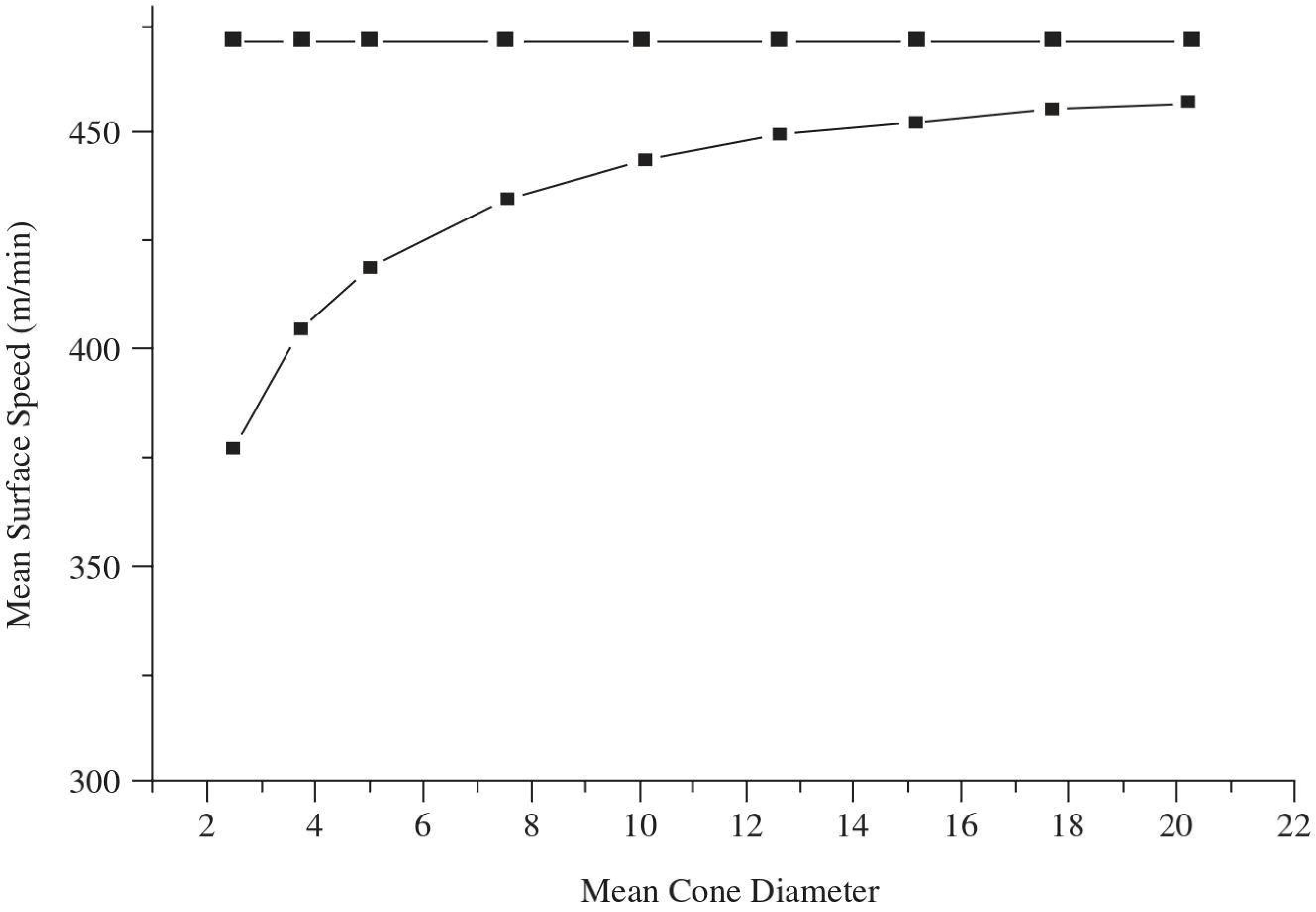


FIGURE 7.9 Mean surface speed with package build.

7.3.3 TRAVERSE MOTIONS

It should be evident to the reader that, with a cone package, the surface area is greater at the base of the cone and decreases toward the nose. Therefore, to build a package of uniform density, it is necessary to ensure that the yarn length wound per unit surface area is a constant value. More yarn then needs to be wound in the region of the base than in the region of the nose, and this is achieved by an accelerated traverse motion in contrast to a constant traverse motion used for cheeses. The yarn guide or winding point moves more rapidly across the traverse near the nose than it does near the base. In this manner, more coils per unit length are wound at the base region.

The accelerated traverse motion is obtained with a cam system by a change in cam profile, whereas, for drum traverse systems, the grooves are widely spaced in the nose region, and the spacing decreases rapidly toward the base region.

7.4 PRECISION OPEN-WOUND AND CLOSE-WOUND PACKAGES

Precision-wound packages may be either cheeses or small-taper cones. As shown in Figure 7.10, the packages can have straight ends or, by varying the traverse length, cone ends that give a pineapple shape to the package.

Pineapple packages reduce the chances of yarn coils slipping over the package ends and causing problems during unwinding in subsequent processes. With cones, it is not common practice to wind continuous filament yarn on to taper bobbins greater than 4°20'. Precision-wound cones of 4°20' are used for dyeing and, for this purpose, are open wound. In precision open-wound packages, the traverse rate is set to enable succeeding yarn lengths per traverse to be positioned with a regular advance or spacing along the package surface. The positionings of the yarn lengths are not very close, but a dense package is made, and this type of package is widely used in the winding of synthetic filament yarns and of yarns that are to be package dyed. In producing very dense packages for processes in which having the maximum amount of yarn in package form is a requirement, the packages are close wound.

In precision close winding, by appropriate selection of the traverse ratio or wind, each coil of yarn can be made to lie side by side with the preceding coil. Precision-

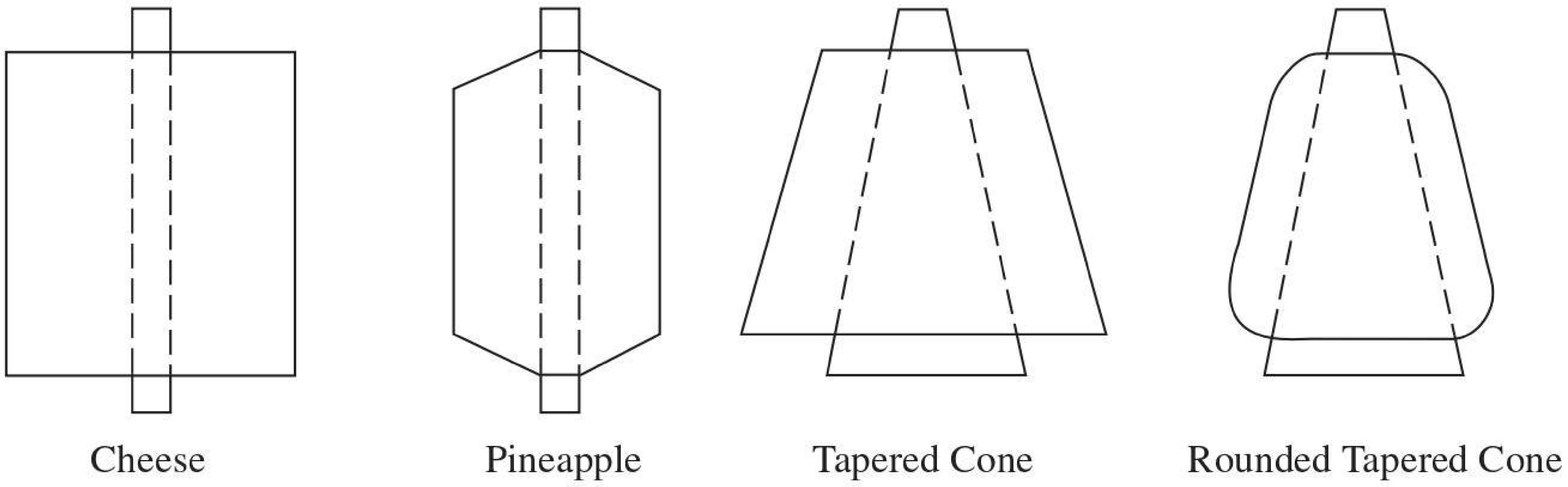


FIGURE 7.10 Precision close-wound and open-wound packages.

wound packages are consequently very firm; they will hold more yarn than any other package of the same size, are more resistant to handling, and will easily unwind.

7.4.1 THEORY OF CLOSE-WOUND PACKAGES

We saw earlier that, when the return of a double traverse ends at its starting point, the next double traverse will lay coils on top of the preceding coil, resulting in patterning. If the wind or TR is an integral number or an integer + 0.5 (i.e., a multiple of 0.5), then, at each double traverse, succeeding yarn layers will be laid on top of one another. If the is wind made to be slightly greater (or less) than an integer, then, as Figure 7.11 illustrates, yarn coils will lie in contact beside each other, producing a precision close-wound package.

We can see that the reversal points of the double traverses being laid precede one another in sequence 1, 2, 3, 4, …, *n* counterclockwise around the bobbin circumference, with *n* being the maximum number that can be contained in the circumference. The *n* + 1 reversal point starts the repeat of the sequence but, in comparison to the first sequence, because the bobbin diameter has increased, the number of reversal points in the second sequence will be greater than *n*. It should be noted from the figure that coils 2, 3, 4, and so forth, on the return traverse, cross over coil 1. The same occurs for each succeeding coil. Consequently, each cycle of the reversal point sequence gives a double layer of the yarn.

The amount by which a coil is displaced relative to the preceding one is termed the *gain*. Therefore, the concept of *yarn gain* is employed to produce close-wound packages. The traverse ratio, or the wind, is adjusted to a value slightly greater or less than a whole number to prevent yarn length in succeeding layers from lying along the same path on top of one another.

Consider two adjacent coils on the first double layer of a close-wound package. The circumferential displacement, u_c, subtends the angle β at the bobbin axis. Hence,

$$\beta \text{ (in radians)} = \frac{2u_c}{D_b} \tag{7.17}$$

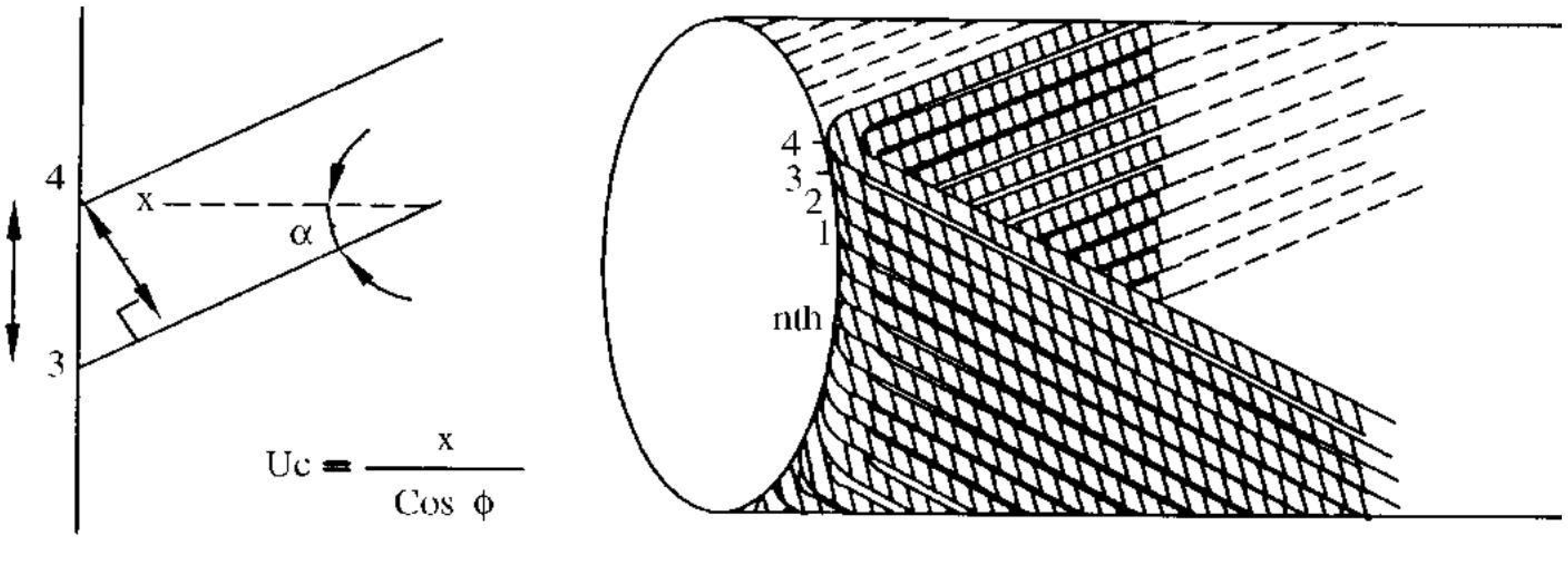


FIGURE 7.11 Close-wound layer.

From the approximate right-angled triangle shown,

$$x/u_c = \cos \varphi$$

Thus,

$$\beta = 2\frac{x}{D_b \cos \varphi} \tag{7.18}$$

And, dividing by 2π,

$$\beta = \frac{x}{\pi(D_b \cos \varphi)} \tag{7.19}$$

which is the angular displacement of the two coils per revolutions of the bobbin. This is the *yarn gain,* and it may be defined as angular displacement of the reversal points around the circumference of the package ends. It follows from our earlier discussion that, if $TR_{(nominal)}$ is the integer value or a multiple of 0.5, then a precision close-wound package would be obtained with $TR = TR_{(nominal)} + \beta$ or $TR_{(nominal)} + 0.5\beta$. Put in general terms, if patterning occurs for $TR_{(nominal)}$ = multiples of n, where $n \leq 1$, then anti-patterning is effective for $TR = TR_{(nominal)} + n\beta$. When $x = d_y$, the yarn diameter, and $\beta = d_y/\pi\ [D_b \cos \varphi]$, then the anti-patterning becomes precision close winding.

Usually, the gain is set by a gearing arrangement and does not alter as the package builds up. This means that, since β remains constant, u_c will increase, and with small-diameter bobbins having large yarn carry capacity, the reversal points will become more widely spaced as the diameter increases (as compared to larger-diameter bobbins having less yarn capacity).

A close-wound package, produced with appropriate "2gain," has a diamond pattern appearance at the package surface, and the winding is sometimes referred to as a *diamond wind.* An open-wound package has no characteristic surface pattern appearance. Many faults can be encountered in the winding, but the ones described below are the most important.

7.4.2 PATTERNING OR RIBBONING

This major fault can occur in improperly made random-wound packages. We have already discussed this fault in detail, along with measures taken to prevent its occurrence. Therefore, we will move on to consider other possible faults.

7.4.3 HARD EDGES

Generally, cross-wound packages tend to have hard edges, and these become a problem when yarn is to be wet processed (e.g., dyed or bleached) in package form. The cause of the problem is that the yarn traverse speed decreases to zero within the proximity of the reversal points for the change of direction and then accelerates to the set speed. Although this occurs in a fraction of a second, more yarn is laid on the forming package at the location of reversal points. As illustrated in Figure 7.12, rather than the ideal sharp reversal point, there is a curvature. The net effect is that the packing density along the traverse length varies, and this can cause uneven flow of, say, the dye liquor into the package layers. Softer edges and a more uniform package density can be obtained by a lateral oscillation of approximately 30 cycles per minute of the drum or of the forming package. This displaces the traverse length, enabling the reversals to be spread over a width of 3 to 5 mm (see Figure 7.12).

7.4.4 COBWEBBING (WEBBING OR STITCHING OR DROPPED ENDS)

Cobwebbing is a result of some coils slipping over the forming edge of the package during the action of reversal. In subsequent processing, unwinding of the package becomes problematic in that, when the fault is at the package base, the increased unwinding tension often breaks the yarn. The fault may occur because of several reasons such as insufficient tensioning, too large a coil angle, or (on independent traverse machines) an incorrect setting of the yarn guide from the package. The fault is usually corrected by adjustment of the machine settings.

7.4.5 TWIST DISPLACEMENT

Twist displacement can occur with rotary traverse drums. The large contact area of the grooves causes twist displacement, which if periodic can lead to fabric faults. Machines therefore are usually designed to have a ‘scrambling effect’ on the twist displacement to avoid periodicity. When winding low twist yarns the disturbance of the twist may often lead to excessive yarn breaks. The cam and guide arrangement does not cause any appreciable twist displacement and it is therefore preferable to wind low twist yarns on such machines.

7.5 YARN TENSIONING AND TENSION CONTROL

The over-end withdrawal during the unwinding of a yarn from a ring-spinning package causes ballooning, as described in detail in Chapter 8, and marked fluctuations occur in the yarn tension.[2] In unwinding the coils from the top to the bottom layer of the ring-spinning package, the mean tension and the fluctuation in tension about the mean increase with time as the layers are removed. The fluctuation in tension can be minimized or eliminated by tension devices applied to the tread line as indicated in Figure 7.2, but these will increase the mean tension, which eventually

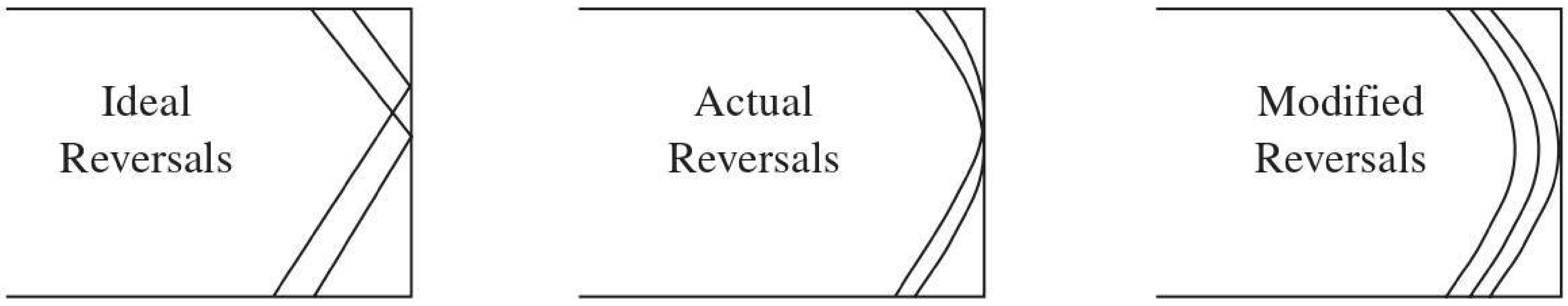


FIGURE 7.12 Hard and soft edges.

becomes the tension at which the yarn is wound into cheeses or cones, i.e., the winding tension. Thus, the greater the mean unwinding tension, the higher the mean winding tension.

When unwinding yarn from the ring-spinning package, little control of the mean winding tension is possible except by changing the winding (or unwinding) speed. Hence, the rise in tension during about the last fifth of a ring-spinning package can be a major factor in determining the take-up speed used throughout winding. The more advanced machines tend to accelerate to a higher unwinding speed while unwinding the first fifth of the package. They maintain this speed before reducing it over the last fifth of the package, thereby gaining a higher production rate. Even with this approach, it is desirable to control the mean tension and fluctuation in tension, as the wound cheese or cone would have a uniform density, and the yarn would subsequently then be easily unwound. Also, because a number of yarn properties are dependent of the stress history of the yarn, the yarn length on the cheese or cone is likely to have more consistent properties.

For example, controlling the tension within set limits permits very weak places in the running length to break and to be repaired more cost effectively than would be the case in subsequent processes. Tension on a yarn can enable fiber ends near the yarn surface to slip from the constraining frictional tact with other fibers and project from the yarn surface. Therefore, tension variation during winding can lead to variation in hairiness along the yarn.

In controlling the unwinding of yarns from the ring-spinning package, various means of applying tension are available, and it is therefore useful to consider the differing features of tension devices.

7.5.1 CHARACTERISTICS OF YARN TENSIONING DEVICES

7.5.1.1 The Dynamic Behavior of Yarns

As the running yarn from a ring-spinning package passes through a tensioning device, the increased tension further stretches the yarn. Assuming that the breaking extension is not reached, some permanent strain could occur, depending on the yarn elastic properties. Other yarn properties susceptible to the applied tension would be count, diameter, degree of twist, bulkiness, and hairiness, as indicated above. It is therefore desirable for the tension device to

1. Give output tensions between known limits
2. Avoid introducing tension fluctuations or magnifying those already present in the tread line
3. Avoid changing the yarn twist distribution

7.5.1.2 The Capstan Effect

Tension devices work by frictional contact between the yarn and solid surfaces. A common feature is that of the yarn passing around a curved or cylindrically shaped surface. To consider the general case of such a situation, it must first be pointed out[3] that Amonton's classical law of frictional contact between solid bodies is not applicable to fibers and yarns in its simple well known form of

$$F = \mu R \tag{7.20}$$

where μ is the coefficient of friction and R is the reaction to the normal force.

From a number of studies on the frictional behavior of textile materials,[4] it has become generally accepted that the relationship between F and R takes the form

$$F = a\, R^n \tag{7.21}$$

where a changes with the surface characteristics of the materials in contact and n changes with their elastic properties. The value of n approximates to 0.67 for two perfectly elastic solids and increases to 1.0 for two surfaces having an area determined by purely plastic conditions. Clearly, when $n = 1$, $a = \mu$, and Amontan's laws apply.

Equation 7.21 can therefore be used to determine theoretical behavior of yarn passing around a curved surface. Figure 7.13 shows such a situation and indicates the tension forces at the two ends of a small section, ds, of the yarn length in contact with the curved surface.

The angle subtended by ds is $d\theta$. Let R be the reaction (per unit length of the yarn) to the normal force caused by the yarn tension. Then, under static conditions, when $dT = 0$ and the yarn is stationary,

$$2T \sin (d\theta/2) = Rds$$

or, for $d\theta$ being very small

$$T\, d\theta = Rds \tag{7.22}$$

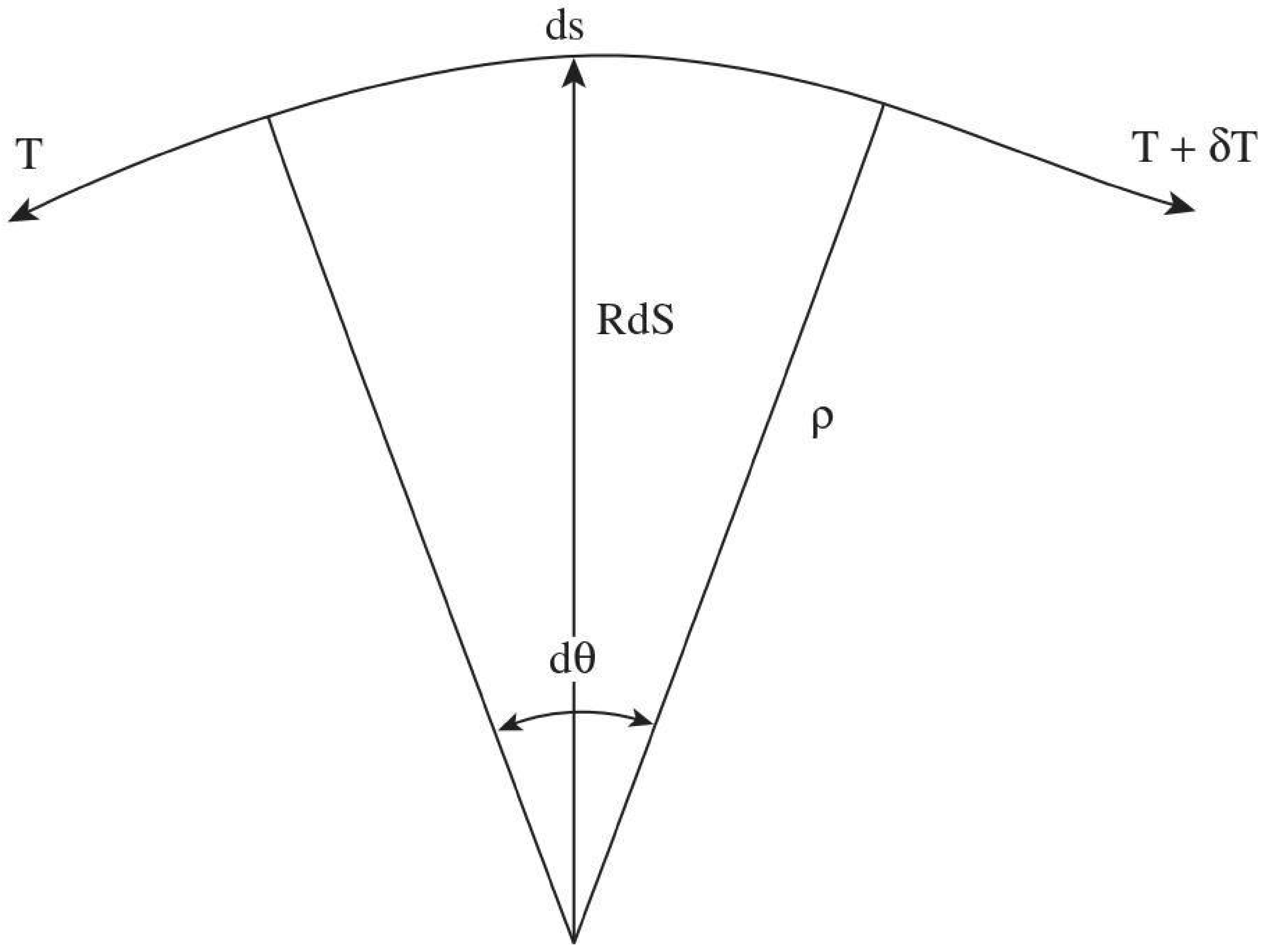


FIGURE 7.13 Tensions in yarn element around cylindrical radius.

Under dynamic conditions, when the yarn is running at a constant speed,

$$Fds = dT \tag{7.23}$$

where F is given by Equation 7.21.

Taking the ratio of Equations 7.23 and 7.22 and substituting for F,

$$dT/T = aR^{n-1}\,d\theta \tag{7.24}$$

If ρ is the radius of curvature, then from Equation 7.22, $T\,d\theta = R\rho d\theta$ or $T = R\rho$, and Equation 7.24 becomes

$$\frac{dT}{T} = \frac{aT^{n-1}d\theta}{\rho^{n-1}}$$

or

$$\frac{dT}{T^n} = a\rho^{1-n} \tag{7.25}$$

The integral of Equation 7.25 between the limits of input, T_i, and output, T_O, tensions, from $\theta = 0$ to ϕ, gives

$$\frac{T_O}{T_i} = (1+X)^k \tag{7.26}$$

where $X = B\phi/k$
$B = a(\rho/T_i)^k$
$k = 1/[1-n]$

The binomial expansion of $[1+X]^k$ has the form $e^{B\phi}$. Therefore, Equation 7.26 becomes

$$\frac{T_O}{T_i} = e^{B\phi} = \exp\left\{\left[a\left(\frac{\rho}{T_O}\right)^{1-n}\right]\phi\right\}$$

When $n \to 1$ $k \to \infty$, Amonton's law applies, so $a = \mu$. Thus, in the general case, the change in tension as a yarn passes around a curved surface can be represented by

$$\frac{T_O}{T_i} = e^{\mu\phi} \tag{7.27}$$

where $\mu = [a(\rho/T_O)^{1-n}]$

7.5.1.3 Multiplicative and Additive Effects

Tension devices can increase the yarn tension by multiples of the capstan effect, by an additional frictional factor, or by a combination of both. The multiplying action can be exploited in the capstan series shown in Figure 7.14a, where the tread line is deflected around a set of pins to establish the desired output tension, T_O.

$$T_O = T_i \, e^{\mu \Sigma \phi} \tag{7.28}$$

where $\Sigma\phi = \phi_1 + \phi_2 + \phi_3 \ldots + \phi_n$

As we saw earlier, the input tension fluctuates during unwinding, and capstan series devices increase the magnitude of these fluctuations. The friction coefficient, μ, is also subject to changes resulting from variations in twist and yarn speed varying the yarn and solid surface contact. The effects from the variations in μ will be magnified because of the exponential relationship. For these reasons, tensioning devices are rarely based on just the multiplicative principle.

Figure 7.14b illustrates a plate tensioner, which is an additive tensioning device, increasing the yarn tension according to

$$T_O = T_i + \mu R \tag{7.29}$$

The output tension now only varies linearly with μ rather than exponentially, allowing the output tension to be more easily adjusted to the required value.

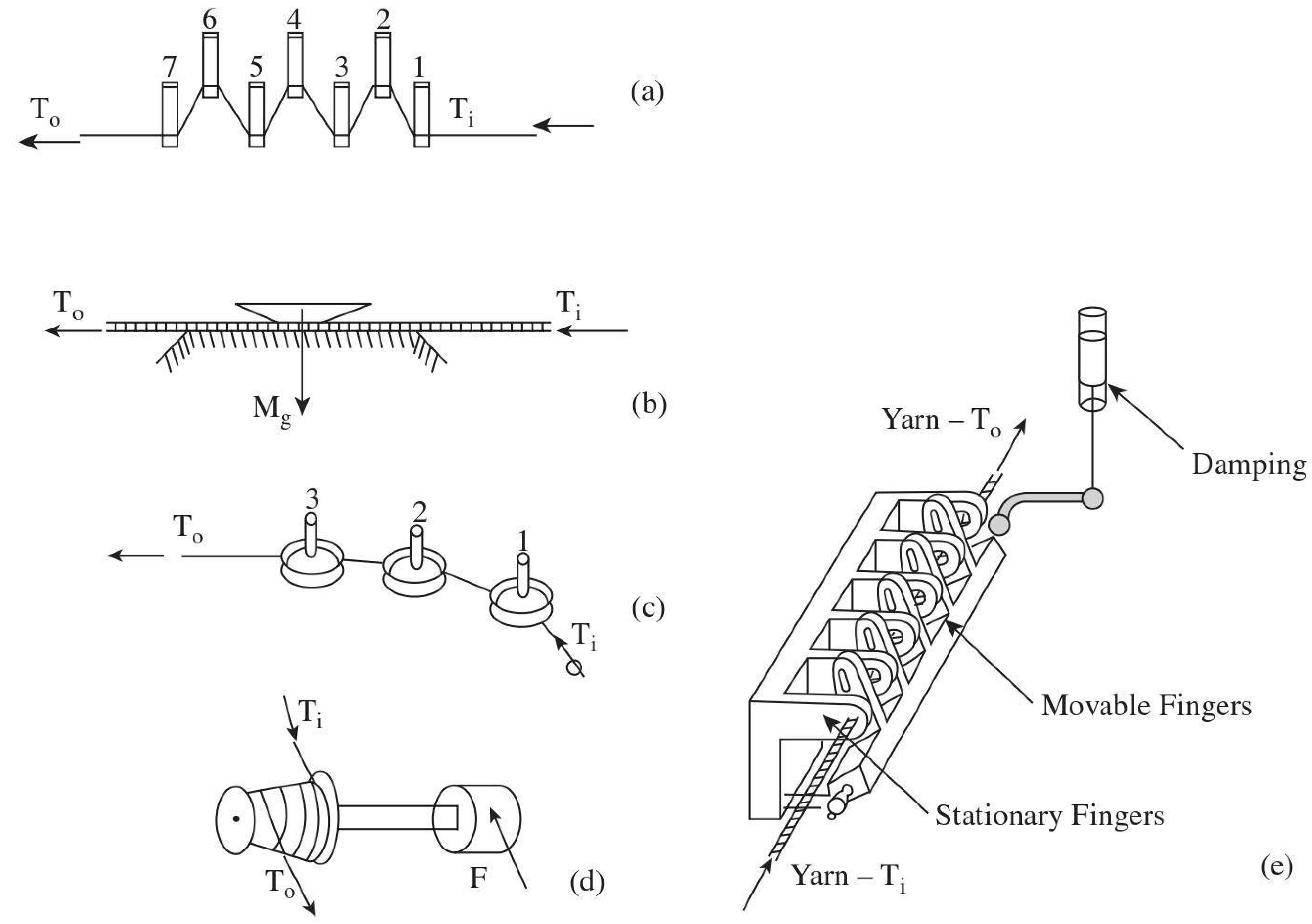


FIGURE 7.14 Tension devices.

7.5.1.4 Combination Tensioning Devices

The disc tensioner (see Figure 7.14c), which is widely used, combines multiplicative and additive effects. Thus, the output tension is

$$T_O = T_i\, e^{\mu 2\beta} + \mu_1 R(1 + e^{\mu 2\beta}) \tag{7.30}$$

where μ_1 and μ_2 are the respective friction coefficients of the disc surface and the curved surface. A purely additive effect can be obtained if the thread line is not deflected by the curved surface.

The pulley or whorl-type tensioner shown in Figure 7.14d also gives a combined effect. The yarn is wrapped around the pulley, which rotates against the resistance of magnetic breaking force, F. The additive component is therefore the force of the couple needed to overcome the magnetic resistance.

The above-described tensioners may provide the required output tension but do not reduce or damp tension fluctuation. The gate tensioner, illustrated in Figure 7.14e, can be used to smooth or eliminate such fluctuations. The yarn passes through a series of intersecting pins or posts that are arranged so that one set is weighted but free to move back and forth, thereby varying the contact angle with the yarn to compensate for fluctuations in the input tension. The output tension can be derived[5] as

$$T_O = \frac{W[1 - e^{2\mu\beta}]}{(1 - e^{2[n-1]\pi\beta})\sin\beta} \tag{7.31}$$

where n = number of posts
β = angle of wrap
W = the applied weight

The gate tension device has a low natural frequency that can amplify tension fluctuations of the same frequency. A damping dashpot, as shown in the figure, is used to eliminate this.

7.6 YARN CLEARING

Spun yarns often have “objectionable faults” such as very thick or very thin places. The thick places, called *slubs,* can be the result of a group of badly drafted fibers twisted together to form a relatively short length in the yarn, several times the yarn diameter. Poor piecing of yarn breaks during spinning, the twisting in of loose airborne fibers, and the defective operation of machinery can also result in slubs and thin places. Ineffective opening and cleaning and/or contamination of raw material can cause unsightly foreign matter in the yarn. Chapter 6 describes typical yarn faults that can arise during processing and that have degrading effects on fabric quality. In ring-spun yarn production, such faults are removed at the winding stage of the production sequence. In unconventional spinning systems, such as rotor and air-jet spinning, the clearing of faults occurs at the automated machines.

There are various types of clearing device, principally mechanical, dielectric (capacitance), and photoelectric (optical). The mechanical clearers are the most basic and essentially consist of an adjustable slot or conical tube through which the yarn passes. The slot or tube traps only thick places that are greater than the set constriction. The device incorporates a cutting edge that breaks the yarn at the fault. Mechanical clearers cannot remove thin places or unsightly impurities or even discriminate between the lengths of thick places. Slubs of elliptical cross section (torpedo-shaped) usually slip past. Because of such limitations, mechanical clearers are rarely used.

The capacitance and photoelectric scanning devices[6–8] are the widely used systems. The capacitance system monitors the mass per unit length and generates a voltage that is compared with a set reference value for the mean yarn thickness. When the voltage difference exceeds a given maximum value, the yarn is automatically cut and the fault removed, and the yarn ends are pieced together for winding to continue. With photoelectric scanning, a beam is projected from a light source laterally across the yarn, and a photocell measures the intensity of the light passing by the yarn. In this way, variations in the yarn thickness can be monitored. When the change in intensity is greater than a set level, the fault is removed and the yarn ends pieced. Yarn silhouette can be viewed with optical clearers, the electronic signals are generated from several angles so as to ensure that torpedo-shaped slubs are detected.

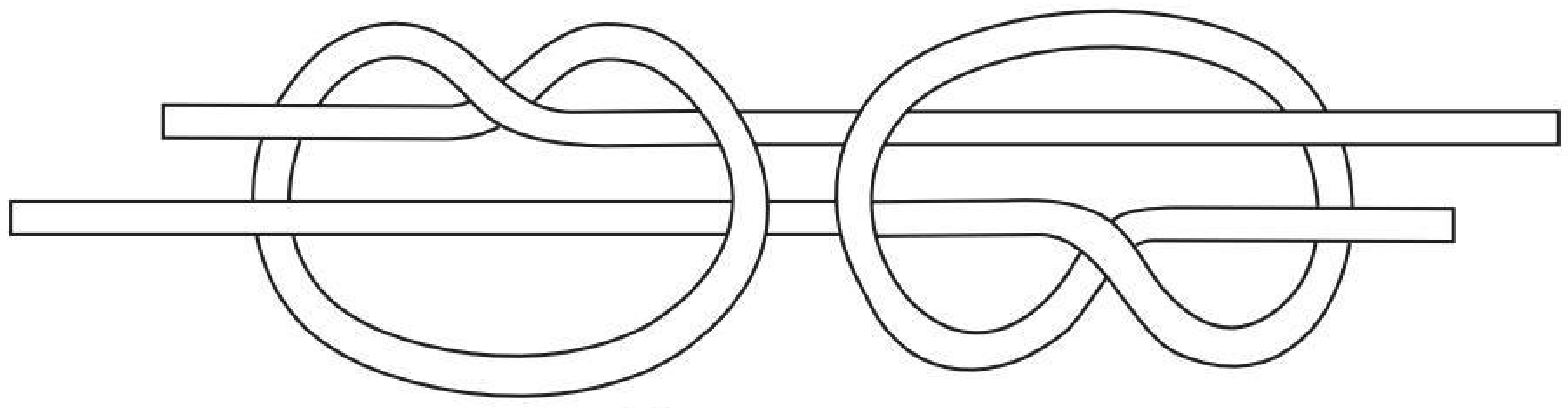
7.7 KNOTTING AND SPLICING

When a detected fault is cut from a yarn, the resulting yarn ends are pieced together, either by knotting or splicing them using an automatic piecing device.

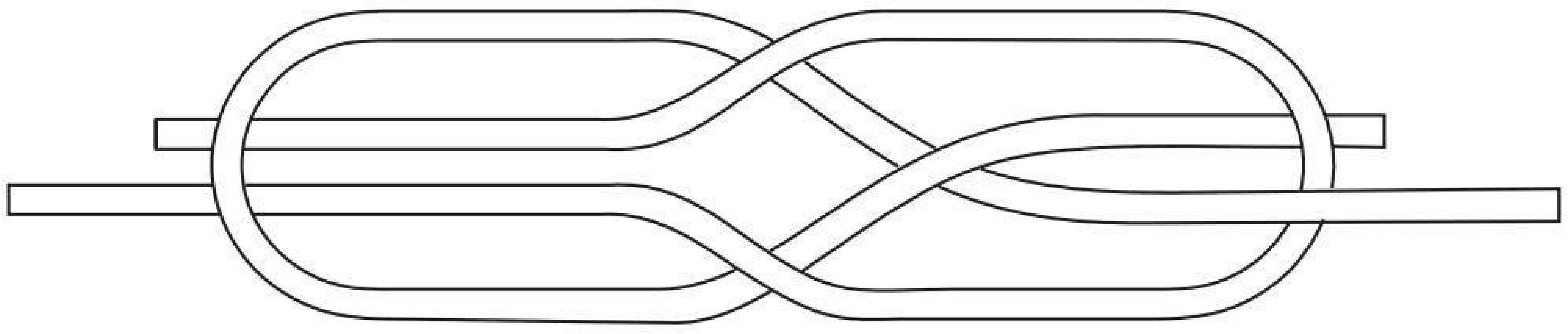
7.7.1 KNOTTING

Among the various types of knot, the weaver's knot and the fisherman's knot, illustrated in Figure 7.15, are the two types that may be used. The latter is suitable for most yarns. The weaver's knot is more appropriate for short-staple yarns, as it is a smaller knot, but it slips more easily when under tension.

The advantage of a knot is that its strength will be several times that of the yarn strength so, if properly tied, it gives reliability to the piecing. However, the knot has many disadvantages for the end user of the yarn and may be seen as "one fault replacing a worst fault." Its main drawback is size, i.e., its thickness and tails. The weaver's knot is two to three times the yarn thickness; the fisherman's knot is three to four times as large. Often, therefore, it may be preferable to accept a thick place in the yarn as a compromise on the final fabric quality, even if it is of comparable thickness, since no tail ends will be present and, as it is less firm than the knot, it could be less visible in the fabric. In processes subsequent to winding, knots can be problematic. When passing at high speed through a tension device (e.g., a disc tensioner), a knot can give rise to a sudden high peak tension, causing a yarn break. Although smaller and hence preferable for finer yarns, the weaver's knot is susceptible to untying when tensioned. In weaving, then, the alternating stresses on the



Fisherman's Knot



Weaver's Knot

FIGURE 7.15 Fisherman's and weaver's knots.

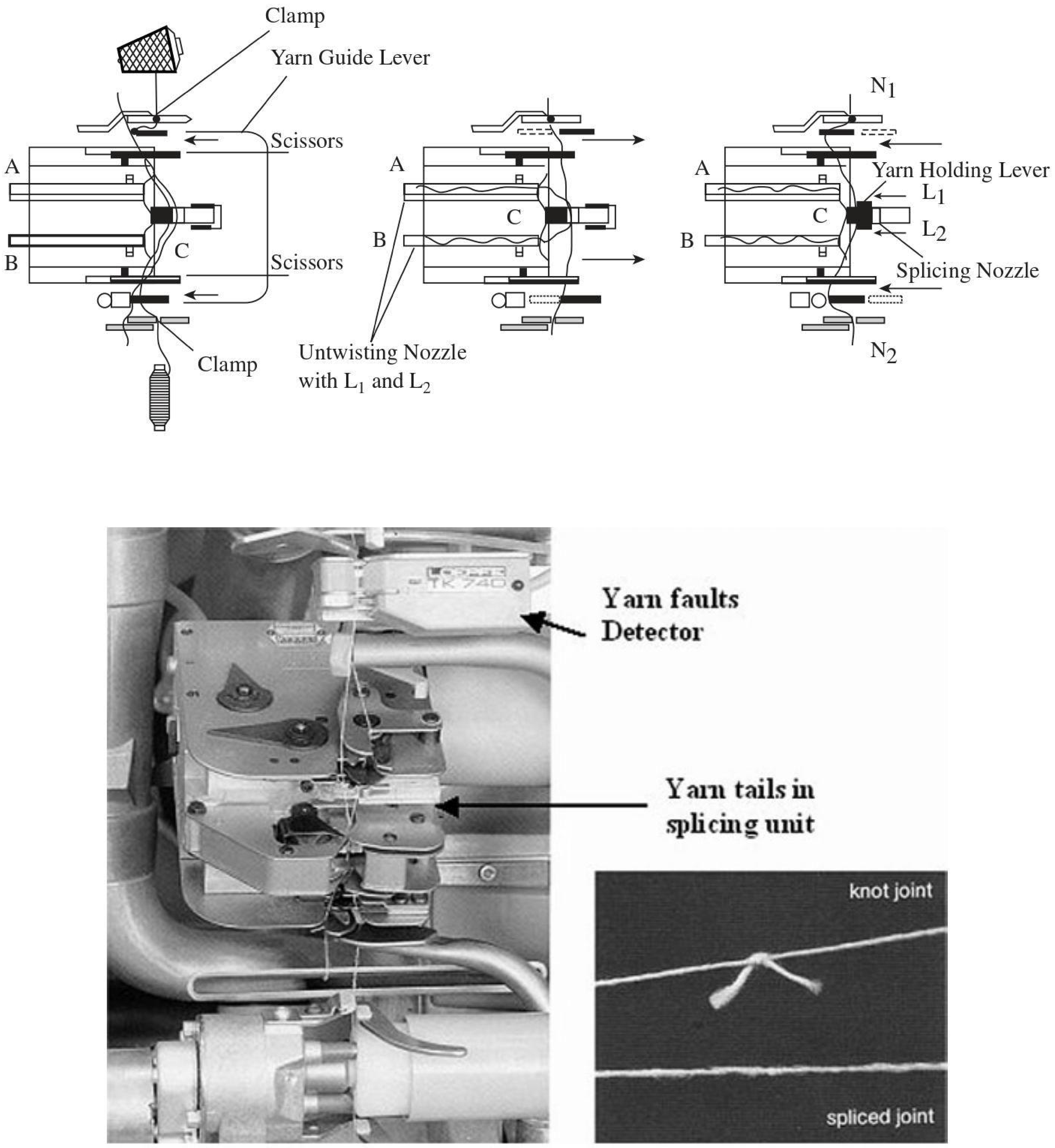
warp yarn can cause slipped knots, especially with plied yarns. With densely woven fabrics, knots and tails can rub neighboring warp ends, hampering shedding and causing yarn breaks. The size of the knot can disturb weft insertion on air-jet looms, leading to fabric faults, and, in knitting, difficulty in passing a knot through needles can cause holes in the fabric because of dropped stitches or needle breaks.

The development of the splice has made a major reduction in the size of pieced ends and has therefore eliminated many of the processing difficulties mentioned above and greatly improved fabric quality. Consequently, splicing is seen as the industry standard and, although not all spun yarns can be spliced, the great majority of winding machines are fitted with automatic splicers.

7.7.2 Splicing

There are various methods of producing a knot-free yarn joint (e.g., gluing, wrapping, and welding)[9] but, with spun yarn, only the splice has proved to be a suitable replacement for the knot. The principle for splicing two yarn ends is to untwist a short length at the ends and then intermingle and retwist together the fibers of the two ends. Electrostatic and mechanical techniques have been used for splicing but were unsuccessful because of the complexity of the devices, the time required to make the splice, and, importantly, the very low strength of the joint.

Commercial splicing devices currently employ air jets to untwist, intermingle, and retwist the fibers. Figure 7.16 illustrates the basic actions of the splicing process. The device has two untwisting tubes (A, B) and a twisting chamber (C). The two yarn lengths to be joined are held on opposite sides of the twisting chamber at N_1 and N_2, while their free ends L_1 and L_2 are placed respectively into the tubes B and A. The lengths lie parallel to each other within the respective twisting chambers. This is the arrangement for untwisting the yarn ends by the air vortices generated by a pulse of compressed air injected through nozzles into A and B. The lengths L_1 and L_2 are then drawn back until there is a certain length of overlap of the untwisted



Courtesy of Savio.

Courtesy of Schlafhorst.

FIGURE 7.16 Yarn splicing.

ends within the splicing chamber. A pulse of compressed air is then injected through other nozzles into the chamber, and the resulting vortex entangles and twists together the fibers of the overlapping ends to form a spliced piecing. Winding of the yarn then continues.

To obtain a suitable splice in terms of size, a compromise may need to be reached between splice strength and appearance. A well spliced joint has a diameter 20 to 30% greater than the yarn over a length of approximately 15 to 20 mm, and an average strength of around 80% of the yarn strength with a low CV% of strength.[9]

Some splicers are equipped to thin the thickness of the yarn ends during untwisting by removing an appropriate amount of fibers. However, in general, splicers have interchangeable splicing chambers of differing geometry as well as adjustable settings so as to optimize tail length overlap and the duration of the compressed-air pulses for untwisting and retwisting. A suitable choice of settings will depend on fiber type and the surface structure, count, and twist of the yarn.

Machine downtimes caused by yarn breaks are expensive, particularly if the entire machine has to be stopped to repair the break. Comparing the cost of repairing yarn breaks in winding with the costs for subsequent processes, we would find that the latter are many times greater: for example, 700× for warping, 2100× for sizing, and 490× for weaving. Steps therefore must be taken in winding to ensure a yarn package quality that will enable high efficiency in later processing. Table 7.2 outlines many of the claimed advantages of replacing the knot with a splice.

TABLE 7.2
Benefits of Knot-Free (Spliced) Yarns

Fabric Production	End Product	Benefits
Weaving	Denim (83-tex cotton yarns)	• 60% reduced yarn breaks • 2% increased efficiency • 15% reduced production cost • 40% reduction in second quality fabrics
	Poplin shirting	• 50–60% reduced yarn breaks • 10% reduced production cost (warping and weaving) • 40% reduction in second quality fabrics
	Bed sheeting (29-tex cotton yarns)	• 50% reduced yarn breaks • 10–12% reduced production cost • 40–50% reduction in second quality fabrics
	Worsted serge (29/2-tex polyester/wool, 55%/45%, yarns)	• Fewer stoppages in assembly winding, twisting and weaving • 60–70% reduction in burling and mending*
	Worsted cotele (23/2-tex wool yarns)	• 30% reduced yarn breaks • 50% reduction in burling and mending*
Knitting	Outerwear (28-tex worsted yarns)	• 30–40% reduced stoppages • 60–70% reduced number of holes • 50% reduction in second quality fabrics
	Underwear (17–20-tex cotton yarns)	• 40–60% reduced stoppages • 50–70% reduced number of holes, press-offs and dropped stitches • 70% reduction in second quality fabrics

*Manually removing faults from the back of a fabric; e.g., opening knots, cutting tails, etc.

Courtesy of W. Schlafhorst AG & Co.

7.8 YARN WAXING

It is common practice to wax staple-spun yarns for knitting applications, given the problems of friction associated with the many thread line deflection points of the thread guides and the knitting needles on knitting machines. For optimal running of yarns during knitting, there needs to be a uniform wax distribution along yarns and a minimum of wax rub-off.

The amount of wax deposited on the yarn has a marked influence on the dynamic frictional characteristics of the yarn. Figure 7.17a shows that, at a given running speed, the yarn coefficient of friction decreases to a minimum with increasing wax deposited and then increases with further yarn waxing. Of the three zones indicated, clearly, Zone II is the preferred range of deposition, usually 0.5 to 1.0 g/kg of yarn.

Wax grades vary according to melting point, oil content, microstructure, and hardness. Little has been published in the way of selecting a wax grade for optimal running performance. However, it would seem that selection depends on many factors such as fiber type; yarn structure, count, and moisture content; as well as room temperature and humidity in the winding area and during storage and shipment.

The preference with the commonly used wax disc is for a coarse microcrystalline structure, which allows small wax particles to be removed and held onto the yarn surface as shown in Figure 7.17b, as this should enable a uniform distribution of deposition. Steaming or high-humidity conditioning of wax yarns can result in an increased friction coefficient. Steaming will melt the wax particles and also give a partial penetration of wax into the yarn. If the yarn has to be relaxed in this way, then the deposition should be increased to offset the effect.

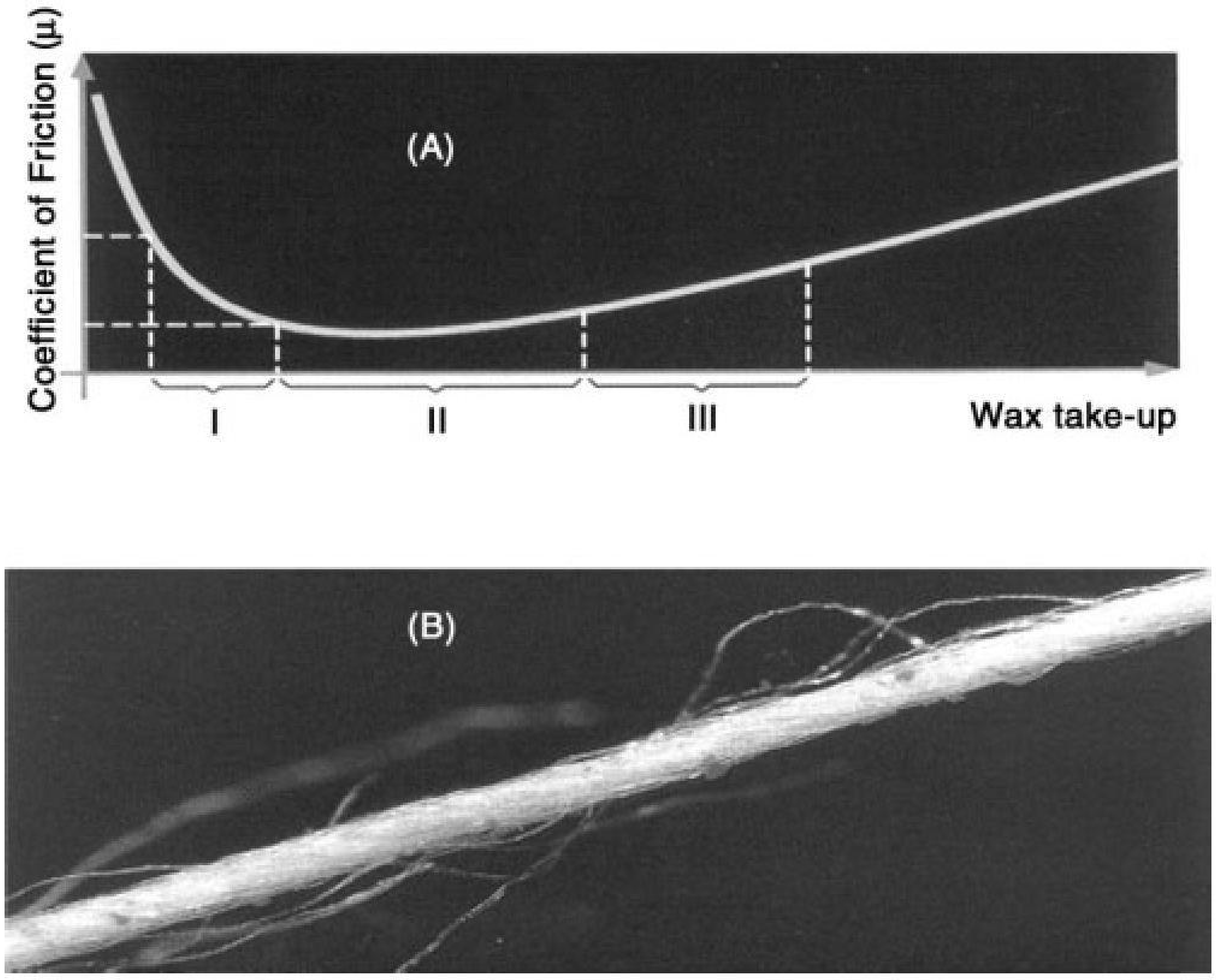


FIGURE 7.17 Yarn thread line friction with increased wax take-up. (Courtesy of W. Schlafhorst AG & Co.)

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