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Advances in yarn spinning technology

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Fundamental principles of ring spinning of yarns

R. S. RENGASAMY, IIT Delhi, India

Abstract: Ring spinning is one of a number of methods for assembling and twisting fibres to form a yarn. To fully explain the fundamentals of the ring spinning process, a review of the general principles of yarn formation is described. Various aspects of ring spinning such as principles of real twisting, roller drafting, inclination of drafting arrangement and offset of top rollers over bottom drafting rollers, spinning triangle and consolidation of fibres into yarn, rings and travellers, yarn tension and its fluctuations, balloon formation, mechanism of end breaks, package formation and application of ring spinning are discussed.

Key words: real twist, drafting rollers, offset, spinning triangle, ring, traveller, yarn tension, yarn balloon, end breaks, package formation.

2.1 Introduction

The human body has to be clothed for protection against the environment. Clothing needs to be flexible enough to allow the body to move easily. Clothes are three-dimensional structures made from joining two-dimensional structures called fabrics. Fabrics are usually woven or knitted structures. In the former, two sets of threads or yarns are interlaced in a regular pattern. In the latter, one set of threads is looped into others to provide bulk and elasticity to the fabric. The threads/yarns need to be flexible and are therefore made by assembling and twisting together flexible materials called fibres. Assembling and twisting staple fibres (fibres of discrete length of a few centimetres) into yarn is complex and the resulting packing fraction of the fibres in a yarn lies within the range 0.45 to 0.65. This means that there are many interstices in a yarn that are air channels and act as capillaries to transport sweat. During yarn spinning and subsequent post-spinning operations, many fibre ends protrude from the yarn to give hairiness to the yarn, which provides softness to the fabric and the resulting garment. Thus the presence of the interstices and hairiness contribute to the thermal comfort of clothing.

Ring spinning is one of a number of methods for assembling and twisting fibres to form a yarn of required thickness and strength to enable the yarn to sustain stresses during the various processes of conversion of yarn to fabric. To fully explain the fundamentals of the ring spinning process, a review of the general principles of yarn formation is first described.

2.2 Basic principles of spinning

The construction of yarn involves the linear and lateral positioning of the required number of fibres into a fibre strand and, by suitable means, consolidating the strand so as to utilise the strength of the individual fibres in order to give the yarn strength. To make yarn from a bunch of fibres which are randomly oriented, these fibres must first be aligned to form the fibre strand. The strand is then thinned, compacted and twisted, which increases the inter-fibre frictional forces giving the yarn sufficient strength so that when in use it can withstand tensions up to a specified value without breaking. The process of assembling and twisting together fibres to make yarn is called spinning. The spinning process therefore consists of two parts:

1. Assembling the required number of fibres
2. Imparting strength to that assemblage usually by the insertion of twist.

2.2.1 Fibre assembly in ring spinning

Assembling the required number of fibres prior to twisting is done by means of drafting of the fibre strand by roller drafting. In a roller drafting system, the rollers run at higher speeds from the back- to the front-rollers and in the process the fibres are redistributed over a longer length of the fibre strand and the fibre strand becomes thinner, i.e. with fewer fibres in the cross-section of the final fibre strand. The draft between any pair of rollers is defined as the ratio of the surface speed of succeeding rollers to that of the preceding rollers. The cotton sliver having 20,000–40,000 fibres is thinned down to the form of roving having 1500–3500 fibres by the previous process, ‘roving’. A 3-over-3 roller drafting system with double apron is used to draft the roving at the ring spinning machine. For cotton spinning, the drafts from the back-to the front-zones usually vary from 1.1 to 1.5 (break draft) and from 6 to 30 (main draft) respectively. Selection of a break draft depends on the fibre properties and is crucial in controlling the irregularity of the yarn. Break draft other than optimum exhibits stick-slip phenomena of fibre movement that gives rise to uneven yarn. For cotton, the number of fibres at the nip of the front rollers of the ring spinning machine is around 100 to 400 for the finest to the coarsest yarn respectively. These fibres on leaving the front roller nip are subjected to twisting in the downstream operation.

2.2.2 Insertion of twist

Various mechanisms can be used to give one of two types of twist insertion into a fibre: real or true twist and false twist.

Real twist

The principles of inserting real twist into an assembly of fibres are illustrated in Fig. 2.1. In Fig. 2.1(a) one end of the strand of the assembled fibres is held whilst the other end is made to rotate on the strand axis by a twisting device. Figure 2.1(b) graphically shows a bunch of filaments from a package placed on a rotating spindle being held in a bend configuration like a winch and gripped at the top. When the package is made to rotate, the filaments revolve about the central axis joining the gripping point and the package, consequently the inclined length of the assembled filaments gets twisted. Figure 2.1(c) depicts an open end of a yarn in contact with a fibre strand rotating about its axis. Fibres are caught on the yarn core and with additional rotation gradually the fibres towards the periphery also become twisted into the yarn. Hence, the twist proceeds from the inside to the outside of the new length of yarn being formed; this action is called twisting-out. The fibres caught on the core are highly twisted and the twist level gradually decreases from the core to the sheath.

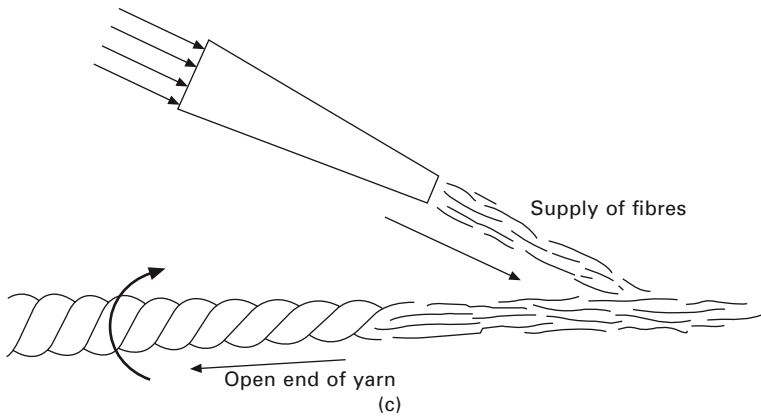
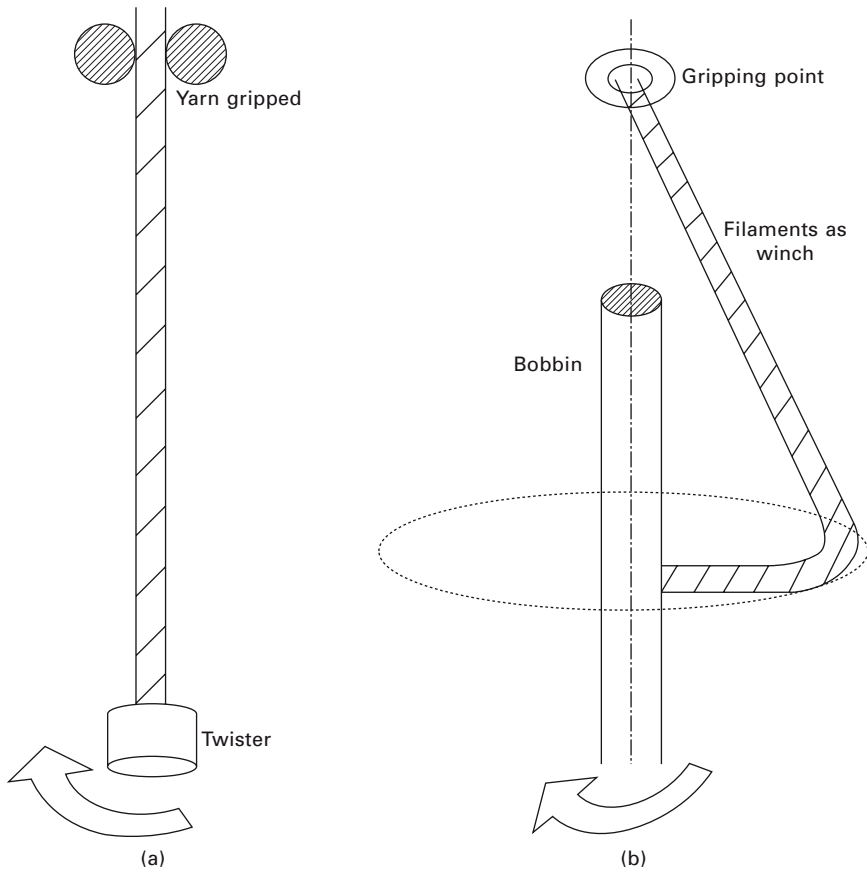
False twist

If a fibre strand that is kept stationary by gripping it at both ends is twisted at some point in between, the strand length on each side of the twist insertion point, i.e. the twisting element, will obtain the same number of turns of twist, but with opposite directions (Fig. 2.2(a)). On moving the fibre strand through the point of twist insertion, the torque present in the upstream length will be cancelled as it passes the twisting element by the opposite torque present in the downstream length of the fibre strand. Thus, on passing the twisting element, the fibre strand would be twistless (Fig. 2.2(b)).

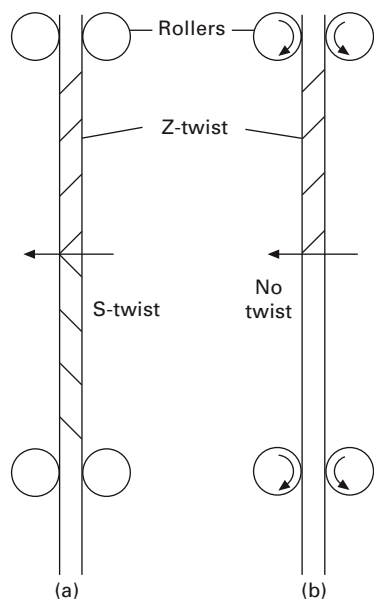
During spinning the fibre strand is supplied to the twisting device on a continuous basis and therefore the formed yarn has to be continuously wound onto a bobbin to form a package of yarn. The twisting of the fibre strand into a yarn and the winding of the yarn onto a bobbin may be carried out simultaneously or sequentially. Different spinning technologies are available wherein the method of twisting may be based on real or false twisting. The twisting is usually done by means of mechanical or aerodynamic actions, and ring spinning involves the former.

2.3 Ring spinning

Roving is continuously supplied from the creel to the back-drafting rollers of the ring spinning machine. The drafted fibre strand reaches the nip of the front rollers (Fig. 2.3). A bobbin is mounted on the rotating spindle. A small curved element, the ‘traveller’, is placed over the ring (dotted line). The yarn



2.1 Principles of real twisting.

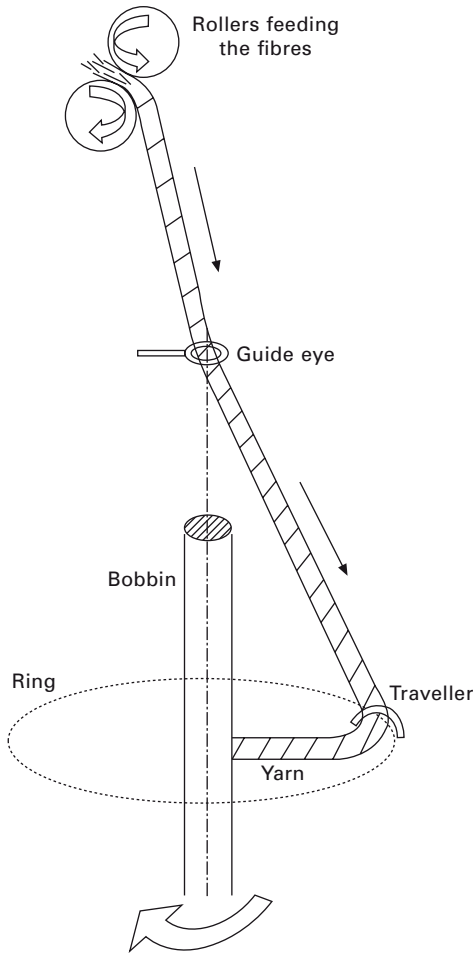


2.2 Principles of false twist insertion.

from the bobbin is taken underneath the traveller, passes through the guide eye and is then made to contact the emerging fibre strand at the front roller nip. The axes of the guide eye and spindle lie on the same line. The rotating bobbin pulls the yarn onto it and the yarn drags the traveller.

Due to the friction between the traveller and the ring, the traveller revolves around the package at a slower speed than the rotational speed of the package. The segment of yarn between the traveller and the guide eye, termed the balloon length as will be explained later, is pulled by the traveller and therefore also circulates the ring. On each revolution of the traveller, the balloon length rotates once on its axis to insert one turn of twist. Since the yarn is continuous, twist propagates through the thread guide reaching a point (termed the twisting point) very close to the nip of the front rollers issuing the fibre strand but not actually reaching the nip. The fibre strand from the front roller to the twisting point assumes a triangular configuration. The twist flow is therefore up to the apex of the triangle. The fibres forming the sides of the triangle are more tensioned than those towards the centre, and twist insertion is from the outside to the inside of the fibre strand, i.e. 'twisting-in'. The twist insertion rate is governed by the rotational rate of the traveller. However, for each rotation of the spindle faster than that of the traveller, the yarn is wound once around the bobbin.

The insertion of twist causes a contraction of the fibre strand (normally 2–3%) as it is converted into yarn, i.e. the continuous formation of the balloon



2.3 Yarn formation in ring spinning.

length. Consequently, the winding rate must equal the difference between the delivery rate of the fibre strand (V_F) (or linear speed of the front drafting rollers) and the contraction of the strand on twisting. This is achieved by the traveller automatically adjusting its speed of rotation. The rate of winding yarn onto the package is therefore given by:

$$V_y = \pi D_B (N_s - N_t) \leq V_F \quad 2.1$$

where

D_B is the diameter of the package

N_s = spindle rotational rate, rpm

N_t = traveller rotational rate, rpm.

Normally the package diameter varies from 24 to 57 mm. For a delivery rate of the ribbon of fibres of about 25 m/min and a spindle speed of about 25,000 rpm, the difference between spindle and traveller speeds is only 332 rpm at the start of winding onto the empty bobbin and decreases to 140 rpm as a full bobbin is made; this is 1.32% and 0.56% of the spindle speed respectively. Thus, although twist is inserted by the traveller rotations, for practical purposes, the twist per unit length of yarn is expressed as the ratio of spindle rpm to front roller speed (m/min), as a substitute for the ratio of traveller rpm to front roller speed.

2.3.1 Spinning triangle and fibre consolidation

The fibre ribbon that emerges from the nip of the front drafting rollers is quite wide (especially when a high front zone draft is used) and converges towards the twist insertion point, forming what is called the spinning triangle; the base of the triangle is the nip line of the front drafting rollers, the apex of the triangle is the twist insertion point, and fibres forming the sides of the triangle are termed edge fibres. If the leading end of an edge fibre has less frictional contact with the other fibres, the frictional forces would not be enough for integrating the fibre into the yarn, leaving the leading end as a protruding hair. An edge fibre whose leading end is integrated into the fibre strand loses its tension when its trailing end is released from the nip of the front rollers. This may result in its trailing end projecting as a hair.

In a Z-twisted yarn, fibres in the right-hand side of the ribbon can fold over freely towards the left at the point of yarn formation. But fibres in the left-hand side are not similarly free to fold under towards the right because of obstruction by the top arc of the bottom-front drafting roller; thus, they are likely to be concentrated on the surface of the yarn (Morton, 1956). In a Z-twisted yarn, twist propagates from the right of the fibre convergence towards the left side of the spinning triangle. Therefore, fibres in the right-hand zone tend to be twist biased, i.e. receiving the greater insertion of twist and consequently offsetting the convergence point (i.e. twist insertion point) to give an asymmetrical spinning triangle. This twist bias reduces the height of the triangle at the right-hand side, but despite the imbalance, fibres in the triangle are well controlled and unlikely to escape the full twist consolidation to become hairs. However, a consequence of the imbalance is that most of the trailing hairs are formed at the left-hand side of the spinning triangle (Wang *et al.*, 1999).

During twisting of the ribbon, the constituent fibres follow helical paths that are longer than the yarn length being formed; those at the periphery of the ribbon follow the longest path, directly proportional to $\sec^{-1}\alpha$, where α is the helix angle of the fibres at the surface of the yarn, i.e. the yarn twist angle. A greater tension will then be induced into these peripheral fibres

as they are twisted with those comprising the bulk of the ribbon to form a new yarn length. This causes them to push their way towards the centre of the fibre strand in order to relieve the stress, displacing the other fibres as they move. The displaced fibres get pushed outwards to become periphery fibres, and now, being more highly tensioned, their tendency is to move back towards the centre, displacing other fibres. This action among the fibres is iterative and results in them migrating from their initial radial position to other radial positions in a cyclic manner along their lengths. The edge fibres in particular move from the yarn surface to the core in a cyclic configuration along their lengths. This fibre motion is unique to ring spinning and is called ‘tension migration’. It produces a high degree of interlacement of the fibres in the yarn cross-section, imparting strength to the yarn.

2.4 Ring spinning systems

The ring spinning system was initially developed to spin two types of natural fibres, cotton and wool. Cotton fibres are finer and shorter than wool; but both have a wide range of fibre length distribution. Accordingly, their processing requirements prior to ring spinning differ and hence the designs of ring spinning machines for processing these fibres are quite different, though the fundamental principles are the same. These staple fibres are processed through two separate systems: the short-staple or cotton system and the long-staple system.

Natural fibres provide better comfort and are poor in strength, whereas synthetic fibres have excellent durability characteristics and are poor in providing comfort. Blending of natural and synthetic fibres provides a compromise between comfort and durability and hence blended yarns such as cotton/polyester, viscose/polyester, wool/polyester and acrylic/wool are produced. To spin man-made fibres on either the long- or short-staple ring spinning system, their cut lengths have to be matched to the particular system.

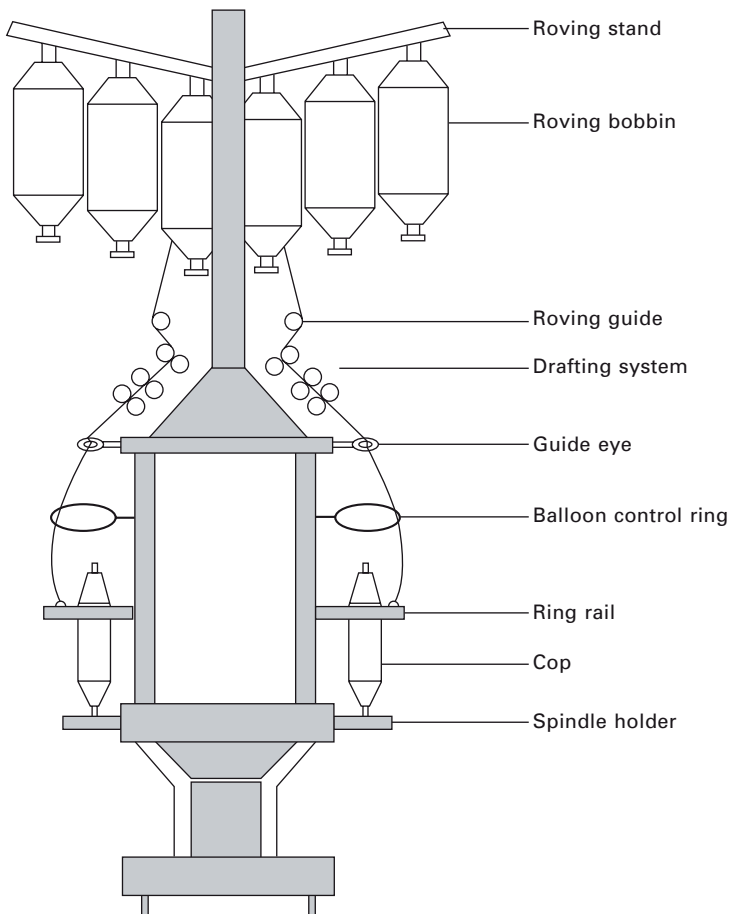
2.5 Description of the ring spinning process

The current ring spinning machines are designed by default with certain features to perform the following main tasks:

- Attenuation of the feed material, i.e. ‘roving’, by a double apron roller drafting system, to the required fineness for the yarn (yarn count) to be made
- To consolidate the fibre strand that emerges from the drafting system into the yarn by twisting and thereby also imparting strength to the yarn
- To wind the resulting yarn on to a ‘bobbin’ in a precise and controlled

manner, termed ‘cop building’, so that the yarn package (cop) is suitable for storage, transportation and further processing.

The basic features of a ring spinning machine are shown in Fig. 2.4. The major functional elements are a creel to house the roving bobbins, a 3/3 double apron roller drafting system to attenuate the fibre strand, the twisting region from the front roller nip to the traveller, and the winding elements, comprising a spindle that holds the bobbin and a ring rail. There are many auxiliary/sub-elements that support or complement the functions of the main elements such as the main shaft, gears, belts and cam. However, only the major elements will be discussed hereafter.

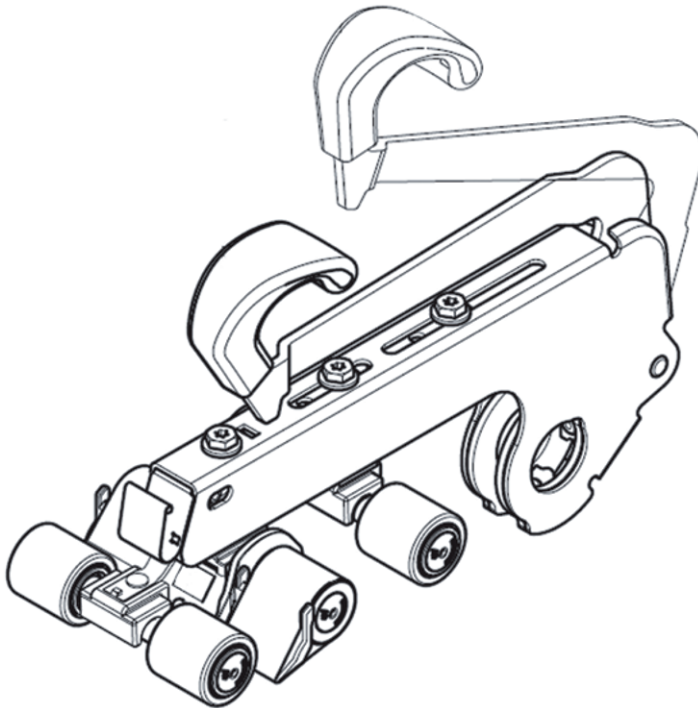


2.4 Ring spinning machine.

2.5.1 Roller drafting

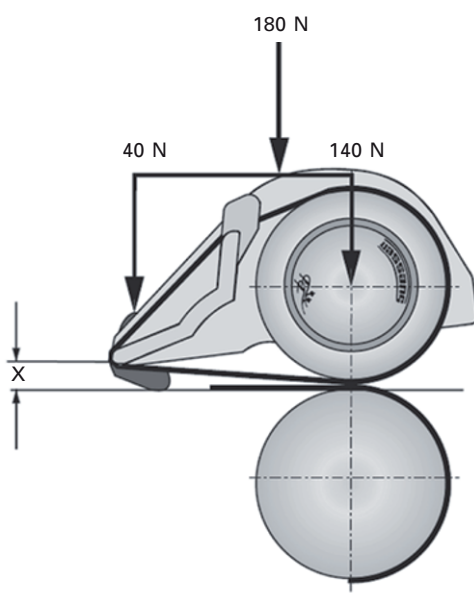
A double apron drafting arrangement, comprising 3-over-3 rollers (Fig. 2.5), with long bottom aprons and short top aprons is mostly used for short-staple spinning. The rollers are made of steel and the top rollers are covered with synthetic rubber. The bottom rollers are positively driven whereas the top rollers are run by frictional contacts with the former. The top rollers must be pressed with relatively high force over bottom rollers by springs (mostly), air pressure or magnetically; different machinery manufacturers follow different approaches. The drafting force (F) needed to draft the fibre strand comes in effect from the loading of the top rollers (N) as $F = \mu N$. Selection of top roller force depends on the fibre types and volume of fibres present between the top and bottom rollers. The adjustment of top roller force may be done in steps or continuously, depending on the systems offered by the machine manufacturers. The purpose of having a synthetic rubber surface on the top rollers is to improve the contact between the fibres and top rollers. Top roller forces per roller shaft are within 100 to 300 N.

A force is applied to the top middle roller that presses the fibres to be gripped. As the fibre strand is progressively thinned down, the number of



2.5 Double apron drafting system (courtesy of Suessen).

fibres at the nip of the middle roller of the ring spinning machine is very much less than that observed in the drawing machine. Under this condition the frictional forces between the fibres held by the middle rollers drop rapidly towards the front roller. A short fibre whose trailing end is released from the nip of the middle rollers has poor contact with the other fibres held by the middle rollers. This short fibre can be easily pulled out by the fibres held by the front rollers and it accelerates, reaches the front roller earlier than it should do. This leads to uncontrolled movement of short fibres, resulting in poor irregularity to the yarn. In this context, it is essential to extend the grip over the short fibres very close to the front rollers so that they are guided to move at the velocity of the middle rollers till they reach very close to the front rollers. For this, two revolving aprons (made of synthetic materials) kept under tension by cradles/nose bars are driven by the middle rollers to guide the fibre strand in the front drafting zone. In order to exert controlled pressure on the fibres, the top apron is forced by spring pressure against the lower apron and also constrained with an exit opening close to the front rollers. With this arrangement, the forces acting on the fibres due to the external load applied on the middle top roller do not drop rapidly towards the front rollers (Fig. 2.6). Thus, the frictional forces between the fibres held by the middle rollers do not drop rapidly towards the front rollers. This helps in regulating the motion of the short fibres. The exit opening between the aprons is determined by spacers or distance clips of different sizes that must conform precisely to the volume of fibre strand; the 'rule of thumb'



2.6 Change of force on drafting system (courtesy of Suessen).

is smaller sizes correspond to finer yarns, but the correct setting of the gap is established by practice. For a give yarn count, the specific gravity, crimp and rigidity of fibres must also be taken into account as these parameters differ with the type of fibres processed and accordingly suitable spacers must be selected. Spacers are inserted between the nose bar of the lower apron and the cradle edge of the top apron at the exit opening. Fibre guidance length (from the nip of the middle roller to the apron exit) depends on the length of fibres to be processed and is set by selecting cradles of appropriate lengths.

The bottom roller surfaces (except the middle roller) are helically fluted to flex the fibres between the flutes so as to improve their grip over the fibres. The middle bottom roller is knurl fluted to improve the static friction between the apron and the roller so that apron slip is kept under control. Knurled flutes improve the service life of aprons compared to helical or axial flutes.

Top rollers

The top rollers are double-boss rollers supported in their centre sections by the forcing arm. Available variants of double-boss rollers are fast boss rollers and loose boss rollers. In the former, two bosses on the left and right form as a single and can be rotated only in unison. In loose boss rollers, two bosses can be rotated independently. The roller bodies are mounted on one or two rows of radial ball-bearings.

The shore hardness of synthetic covering materials used on the top rollers varies in the range 63–83°. The suggested shore hardness values based on the recommendations of Reiter for G-35 ring spinning machines with Ri-Q drafting arrangement are given in Table 2.1.

Hard coverings on the top roller have better wear resistance and reduce

Table 2.1 Hardness of top roller covering

Fibres	Optimum yarn count (Ne)	Hardness (°shore)
100% cotton	28–160	} 63 (front) 83 (back) 80 (middle)
Blends of cotton and man-made fibres	40–90	
100% man-made fibres	50–90	
100% cotton	20–27	} 70 (front) 83 (back) 80 (middle)
Blends of cotton and man-made fibres	30–39	
100% man-made fibres	30–49	
100% cotton	10–19	} 75 (front) 83 (back) 80 (middle)
100% man-made fibres and blends of cotton and man-made fibres	18–29	
100% cotton	5.5–9	} 83 (front) 75 (back) 80 (middle)
100% man-made fibres and blends of cotton and man-made fibres	5.5–17	

the tendency of the fibres to lap around the rollers. Soft coverings increase the area of contact between the rollers and the fibres but have low wear resistance. When spinning finer yarns, the number of fibres at the front roller nip is less, providing fewer inter-fibre contacts. As a consequence, the fibres at the front roller nip can be easily spread out, forming a spinning triangle with a large base leading to inefficiency in twist insertion, i.e. difficulty in trapping the edge fibres into the yarn. Having low shore hardness on the front top roller encloses the fibre more completely and provides better gripping of fibres while processing finer yarns. For coarser yarns or synthetic fibre yarns, harder coverings are used to reduce roller lapping and wear on the covering. For the back roller, hard coverings are recommended since the roving, with a large number of fibres with a twist that binds them, does not call for additional grip on the fibres.

There is one inherent limitation on the way the bottom apron is currently driven by the bottom roller. This can be explained as follows. Let the tension on the apron under static conditions be T_i . During operation, the apron experiences a frictional force, dF , over the arc of the bottom roller and subsequently its tension at the roller nip reaches a maximum, $T_2 = T_i + dF$; the tension just before passing around the roller is $T_1 = T_i - dF$. As the apron passes around the roller, it extends by an amount e_t proportional to $T_i + dF$; this extension is released as excess length of the apron into its working region where it guides the fibres in the front drafting zone, thereby affecting the controlled fibre motion. To alleviate this problem, bottom cradles that guide the apron have a convex design that accommodates the excess length, improving fibre control in the front drafting zone.

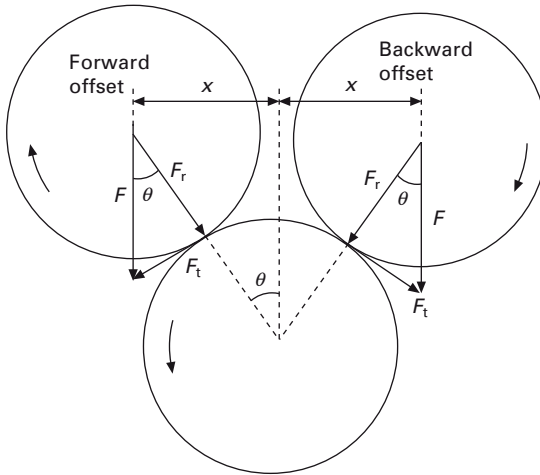
Offset of top roller over bottom roller

In ring spinning the front and back top rollers' central axes are displaced forward and backward respectively by 2–4 mm relative to the corresponding central axes of the bottom rollers. A further advantage of forward offset of the front top roller is the decreased height of the spinning triangle which enables the twist to flow very close to the nip of the front rollers. The back top roller is backward offset in order to obtain the best control of fibre motion, as fibres leaving the nip have to flex in passing over the curved surface of the bottom back roller.

Figure 2.7 illustrates the importance of the top front roller offset. If the offset is, say, x mm, the angle, θ , subtended by the applied force F of the top roller can be calculated from the following equation:

$$D \sin \theta = x \quad 2.2$$

where D is the sum of the top and bottom radii. The tangential component of the top roller force F_t (Fig. 2.7) is given by



2.7 Tangential components of top roller force.

$$F_t = F \sin \theta \quad 2.3$$

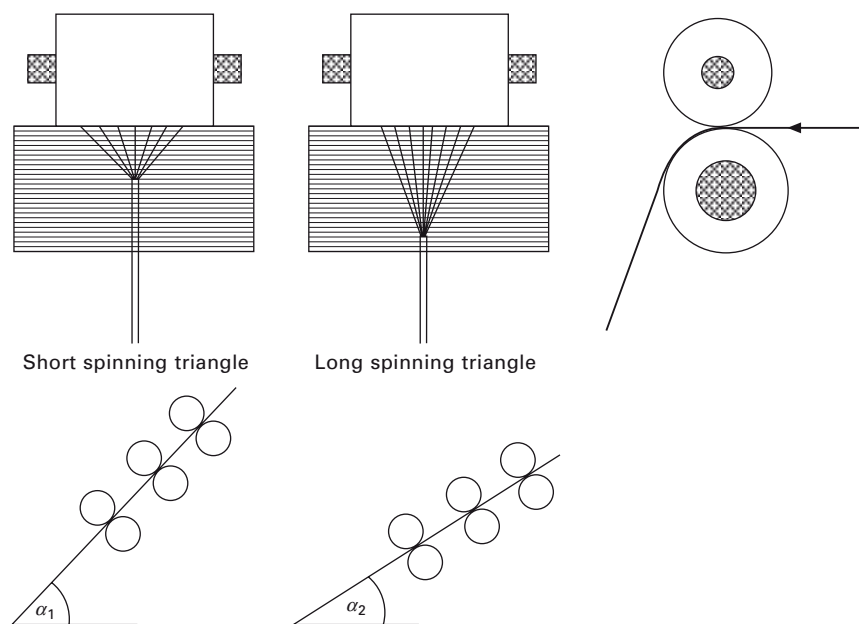
The tangential component of the top roller force (a small fraction of the applied force, F) assists the rotation of the top roller in the intended direction. This benefit would not be available for a backward offset of the top roller; rather the tangential component would counteract the rotation of the top roller, necessitating the application of a higher load on the top roller.

2.5.2 Inclination of the drafting arrangement

The drafting system is mostly inclined at an angle $\alpha = 45^\circ$ with respect to the horizontal plane. Fibres emerging out of the front rollers converge and form the spinning triangle. The angle of inclination is therefore one factor which determines the height of the spinning triangle.

The flow of twist from the yarn balloon is partially blocked due to the friction of the yarn at the guide eye, and a lower level of twist propagates up to the apex of the triangle and no twist passes the apex, hence the fibres in the spinning triangle are twistless. The yarn balloon tension is, however, readily transmitted to the apex of the spinning triangle and into the fibres forming the triangle. Considering the slippage of fibres under tension at the triangle apex, high mean tensions and/or tension fluctuations will cause most yarn breaks to occur at the spinning triangle.

With a low inclination angle of the drafting system, the angle of wrap of the fibre strand over the curvature of the front bottom drafting roller is large, resulting in a long spinning triangle (Fig. 2.8). A large inclination forms a short spinning triangle. The importance of the height of the spinning triangle



2.8 Inclinations of drafting arrangement and sizes of spinning triangle.

is in respect of the frequency of yarn breaks (i.e. the end breakage rate) during spinning. A short triangle is a small weak point whereas the longer one is a long weak point; hence the longer spinning triangle results in more end breaks. However, a very short spinning triangle will have a large apex angle; the edge fibres would be deflected strongly before their leading ends are bound into the apex of the fibre strand. Few edge fibres may escape as fly; others may get bound-in at their leading ends only, with their trailing ends subsequently projecting from the yarn surface as hairs, and thus a hairy yarn is produced.

2.5.3 Ring and traveller

The traveller, supported by the ring and in combination with the rotation of the spindle, circulates the ring to insert twist to the fibre strand and simultaneously enables winding of the continuously spun yarn length onto the bobbin.

In designing the ring–traveller combination, the stability of rotation of traveller and the yarn clearance between traveller and ring (Fig. 2.9) are of importance. Travellers are therefore made with different cross-sections (wire profiles) suitable for different fibres and yarns (Fig. 2.10). The traveller circulates the ring at a very high speed, N_s , and the centrifugal force generated



2.9 Ring and traveller combinations (courtesy of Bracker).

f Flat wire

Good seating on the ring, hence low hairiness results. Suitable for fine cotton yarn and viscose

dr Semi-round wire

For blends, cotton and synthetics. Good results with low twisted (knitting) yarn. For high speeds

udr Ultra semi-round wire

For cotton, blends and synthetics. This wide profile offers large contact surface and good heat conduction at high speeds

fr Flat round (combined profiles)

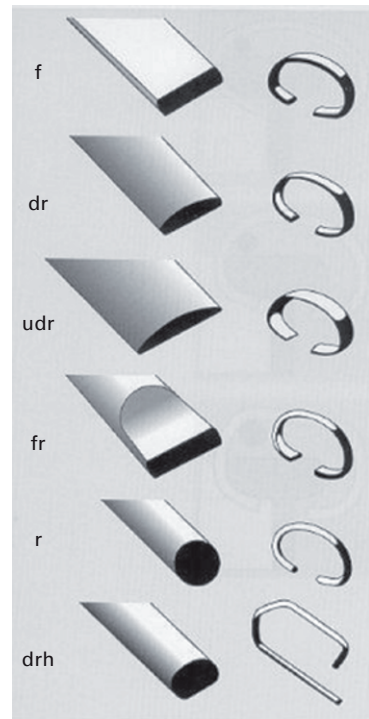
For acrylics, special synthetics and core yarn. Flat toe, round yarn passage, for higher speed

r Round wire

For wool, synthetics and core yarn, for lower speeds. Small area of contact with ring leads to instability

drh Semi-round high

Special section, designed for SU travellers



2.10 Cross-section of travellers (courtesy of Bracker).

on it results in a high contact pressure at the traveller–ring interface of the order of 35 N/mm^2 and this leads to frictional heat and wear. The frictional wear of the traveller is proportional to N_s^3 . The temperature at the interface can reach 400 to 500 °C and the traveller undergoes annealing and ‘burns out’. At these high pressures and temperatures, micro-welding of traveller fragments occurs at the interface and the ring gets roughened, leading to instability of the traveller motion. To decrease the temperature build-up on

the traveller and its wear, the contact area between the ring and traveller at the inner side of the ring has been increased over the years. Orbit and SU ring-travellers have a high contact area between them (Bracker, 2008; Vijayakumar, 2003). These designs provide better running stability to the traveller and better heat dissipation. To greatly reduce the wear, both the ring and the traveller are hardened by special treatments. The traveller is nickel plated to reduce the friction on the ring. Rings are made of high-carbon cold-drawn seamless steel tubes that give high strength and durability. The hardness of the traveller is, however, less than that of the ring so that most of the wear occurs on the traveller; traveller replacement is less expensive. A special hardening process is applied to the traveller for better metallurgical grain structure. Often the traveller is treated by chemical diffusion for deeper penetration into the base material of additives to improve the elongation of the traveller for easy insertion onto the ring.

2.5.4 Yarn tensions and balloon geometry in ring spinning

The following notations are used unless otherwise specified:

- V_F = Feed rate of fibres from the delivery rollers
- V_R = Ring rail speed
- D_B = Bobbin diameter
- μ_{YL} = Coefficient of friction between the yarn and guide eye
- μ_{YT} = Coefficient of friction between the yarn and traveller
- μ_{RT} = Coefficient of friction between the ring and traveller
- β_1 = Angle of wrap of yarn at lapet/guide eye
- β_2 = Angle of wrap of yarn at traveller
- m = Mass per unit length of yarn
- R = Ring radius
- ω = Angular velocity of traveller
- C = Centrifugal force on traveller = $MR\omega^3$
- F = Friction drag on traveller
- M = Traveller mass
- H = Balloon height
- T_{B1} = Yarn balloon tension immediately below the guide eye
- T_{B2} = Yarn balloon tension above the traveller
- T_W = Yarn winding tension
- C_y = Yarn tex
- D_R = Diameter of ring
- N = Reaction force on the traveller from the ring
- θ_1 = Angle of yarn in the balloon with respect to the y-axis
- θ_2 = Angle of yarn in the balloon with respect to the x-axis

- θ_3 = Angle of yarn in the balloon with respect to the z -axis
 θ_4 = Angle of inclination of the traveller with respect to y -axis
 R_B = Bobbin radius
 α = Angle of lead of the yarn, defined as $\sin\alpha = R_B/R$
 f = Vibration frequency of a string/yarn
 ω = Angular velocity of yarn = $2\pi f$
 F_D = Horizontal component of air drag
 ρ_A = Density of air
 C_d = Air drag coefficient
 d_y = Yarn diameter
 $r_{\max}$ = Maximum radius of the balloon

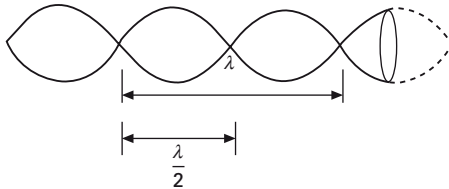
In ring spinning the yarn length between the traveller and guide eye is made to circulate the spindle axis which passes through the guide eye. This is external to the yarn axis. As the yarn length circulates the spindle axis it adopts an arc shape. The speed of circulation of the arc shape gives it the visual appearance of a balloon shape. The yarn length is consequently called the balloon length, and its circulation balloon rotation. The revolving balloon is similar to a circularly polarised standing wave (Fig. 2.11). The balloon may form one or more nodes depending on the yarn length and its frequency of revolution and the tension on the yarn. Considering the yarn balloon as the circularly polarised transverse vibration of a string, the velocity of propagation of the transverse waves along the yarn is given by:

$$c = \left(\frac{T_{B1}}{m} \right)^{1/2} \quad 2.4$$

The length of node, l ($= \lambda/2$), is related as

$$\frac{\lambda}{2} = \frac{c}{2f} = \frac{1}{2f} \left(\frac{T_{B1}}{m} \right)^{1/2} \quad 2.5$$

$$\frac{\lambda}{2} = \pi \left(\frac{T_{B1}}{\omega^2 m} \right)^{1/2} \quad 2.6$$



2.11 A circularly polarised standing wave on a rotating string.

when

$$P = \left(\frac{T_{B1}}{m\omega^2} \right)^{1/2} \quad 2.7$$

the value of P can be written as

$$P = 2992 \left(\frac{T_{B1}}{C_y N_t} \right)^{1/2} \text{ (cm)} \quad 2.8$$

In the absence of air drag force, the yarn balloon lies in the axial plane (the x - z plane). The height of the balloon when only one node is formed, this being at the apex, is given by $H = \pi P$. If $H/P > \pi$ then a balloon of multiple nodes will occur. The yarn tension in the yarn and the revolving speed of the traveller influence the dynamics of the balloon. The spinning, balloon and winding tensions are related by the Capstan equation:

$$\frac{T_{B1}}{T_s} = e^{\mu_{YL}\beta_1} \quad 2.9$$

$$\frac{T_w}{T_{B2}} = e^{\mu_{YT}\beta_2} = \frac{1}{a} \quad 2.10$$

Further, the balloon tensions are shown to have the relationship:

$$T_{B1} = T_{B2} + \frac{1}{2} mR^2\omega^2 \quad 2.11$$

The position of the traveller and the various forces acting on it under steady state are shown in Fig. 2.12. While winding the yarn, the traveller mostly contacts the inner side of the flange of the ring. The centrifugal force generated by the high traveller rotational speed acts on the inner side of the flange and is much greater than the horizontal component of the winding tension. The component forces at equilibrium in the horizontal, tangential and vertical planes are:

$$C + T_{B2} \cos\theta_1 = T_w \cos\alpha + N \cos\theta_4 \quad 2.12$$

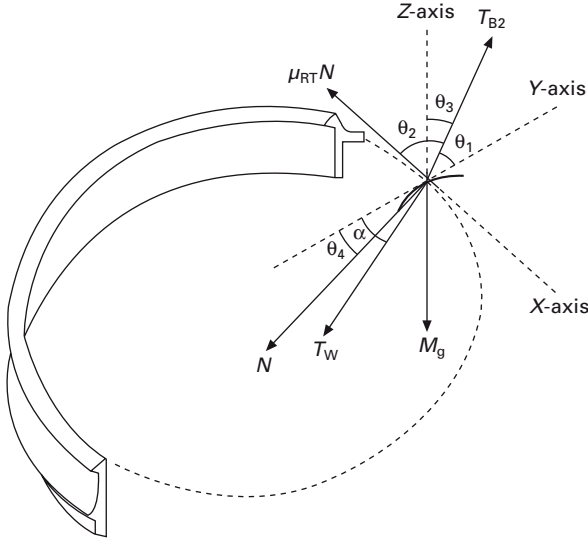
$$T_w \sin\alpha = \mu_{RT}N + T_{B2} \cos\theta_2 \quad 2.13$$

$$T_{B2} \cos\theta_3 = Mg + N \sin\theta_4 \quad 2.14$$

From the above equations, the yarn balloon tension above the traveller is

$$T_{B2} = \frac{a\mu_{RT}MR\omega^2}{\sin\alpha \cos\theta_4 + \mu_{RT} \cos\alpha - a(\mu_{RT}\cos\theta_1 + \cos\theta \cos\theta)} \quad 2.15$$

$$\sin\theta_4 = \frac{a\mu_{RT}(T_{B2}\cos\theta_3 - Mg)}{T_{B2}(\sin\alpha - a \cos\theta_2)} \quad 2.16$$



2.12 Forces acting on traveller during spinning.

When $r_{\max} = R$, $\theta_3 = 0$, then $\cos \theta_3 = 1$. With no air drag, $\theta_2 = 90^\circ$, $\cos \theta_2 = 0$; $\theta_1 = 90^\circ$, $\cos \theta_1 = 0$; and $\theta_4 = 0^\circ$, $\cos \theta_4 = 1$.

When the ring–traveller friction is small, further approximation leads to:

$$T_W = \frac{\mu_{RT} M R \omega^2}{\sin \alpha} \quad 2.17$$

$$T_{B2} = \frac{a \mu_{RT} M R \omega^2}{\sin \alpha} \quad 2.18$$

The tensions on the yarn depend on the friction at the ring–traveller interface, the mass of the traveller, the ring radius, the traveller speed and the angle of lead; the last of these depends on the bobbin diameter (full/empty bobbin or the position of the ring rail). To reduce the possibility of high tension at the start of winding the yarn onto the bare bobbin, the ratio of diameter of bobbin to ring diameter is kept at ≥ 0.5 .

Air drag on yarn tension

With the presence of air drag under normal operating conditions, each yarn element of the balloon length deviates from the axial plane slightly more than its predecessor. The balloon length is therefore longer than in the absence of air and it inclines towards the rotational direction of the traveller. In the absence of air drag, there is only a vertical component of tension in the

balloon length. Since the balloon inclines with the air drag, a horizontal component of tension is present, which adds to the frictional drag on the traveller. This additional resisting force F_D is

$$F_D = T_{B2} \cos \theta_2 \quad 2.19$$

This force has been expressed by De Barr and Catling (1965) as

$$F_D = \frac{\rho_A C_d d_y \omega^2 H r_{\max}^3}{4R} \quad 2.20$$

With a good degree of approximation by assuming that $\theta_1 = 90^\circ$, $\cos \theta_1 = 0$, then $\theta_3 = 90^\circ - \theta_2$, $\cos \theta_3 = \sin \theta_2$ and neglecting the traveller weight,

$$T_{B2} = \frac{a(\mu_{RT} MR \omega^2 + F_D \cos \theta_4)}{\sin \alpha \cos \theta_4 + \mu_{RT} \cos \alpha}$$

$$\text{si } \theta_4 \quad \frac{a \mu_{RT}}{\alpha} \quad \frac{\theta_2}{a} \quad \frac{\theta_2}{\theta_2} \quad 2.21$$

The balloon tension below the guide eye is

$$T_{B1} = \frac{a(\mu_{RT} MR \omega^2 + F_D \cos \theta_4)}{\sin \alpha \cos \theta_4 + \mu_{RT} \cos \alpha} + \frac{1}{2} m R^2 \omega^2 \quad 2.22$$

The spinning tension T_S can be computed as

$$T_S = \frac{\frac{\mu_{RT} MR \omega^2 + F_D \cos \theta_4}{e^{\mu_{YT} \beta_2} (\sin \alpha \cos \theta_4 + \mu_{RT} \cos \alpha)}}{\mu_{YL} \beta_1} \quad \frac{1}{2} m R^2 \omega^2 \quad 2.23$$

This expression for spinning tension shows that in addition to the variation of the angle of lead, the angles of wrap of the yarn around the traveller (β_2) and the guide eye (β_1) considerably influence the spinning tension. Both β_1 and β_2 vary from the beginning to the end of the cop build-up. In the case of a C-type traveller, $a = 1/e^{\mu_{YT} \beta_2}$ and a varies from 0.55 to 0.62 as $\sin \alpha$ varies from 0.5 to 0.95, from the top to the bottom of each chase, i.e. ring rail traverse. The angle between the yarn and the axis of the guide eye at the spinning region, γ , varies from 15° to 30° from the lowest to the topmost position of the guide eye. This alters the wrap angle of the yarn on the guide eye (β_1). Further, the up-and-down movement of the ring rail affects continuously the wrap angle on the traveller. The values of yarn wrap angle over the guide eye fluctuate from zero to 50° , as the traveller moves towards the operator and moves away (towards the machine side). The parameter β_1 can have at least four distinct values for every quarter-revolution of the traveller.

In the presence of air drag, the balloon tension increases and consequently

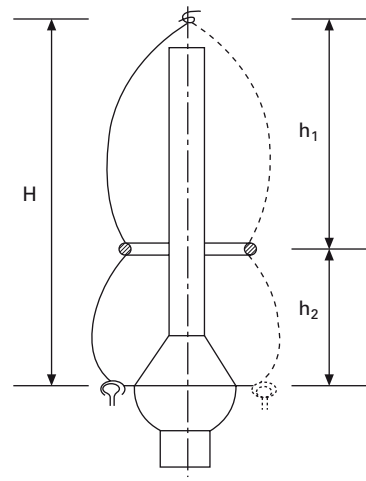
the value P increases and hence the possibility of having $H/P > \pi$ forming multiple nodes decreases. In the presence of air drag, the horizontal component of the yarn balloon tension increases from the guide eye to the traveller and the balloon deviates progressively from the axial plane. The work done by the rotating yarn balloon per revolution is the product of the tangential component of balloon tension and the circumference of the radial path of the balloon; as $(T_{B2} \cos \theta_2)(2\pi r) \neq 0$, neither of them could be zero. With a finite radius for the balloon ($r > 0$), the balloon portion could never be at the axis of the balloon. As a result, the balloon forming the nodes (as seen in Fig. 2.11) is not possible. The balloon can form necks as depicted in Fig. 2.13.

Balloon collapse

Balloon collapse is likely to occur when the neck of the balloon contacts the bobbin, resulting in a yarn break. Balloon collapse occurs most likely with the longest balloon at the beginning of the cop build-up. Having a smaller lift (from the ring to the guide eye) and ring radius are useful to avoid balloon collapse. Reducing the spindle speed and increasing the yarn tension by using a heavier traveller improves the value P and reduces the probability of balloon collapse. However, a compromise has to be made between spinning productivity and increased yarn breakage rate, owing to the increased spinning tension. The ratio of balloon height to ring diameter should therefore be kept ≤ 5.2 and a balloon control ring placed above the



2.13 Balloon with neck formation.



2.14 Balloon control ring dividing a large balloon into two halves.

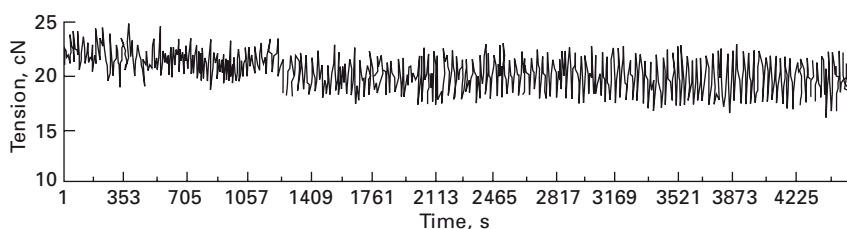
ring rail, a little below the midpoint between the guide eye and the ring. The balloon control ring divides the balloon into sub-balloons of height h_1 and h_2 such that both h_1 and $h_2 < H$, avoiding the likelihood of balloon collapse albeit the overall balloon height could be increased (Fig. 2.14). It restricts the balloon radius, reduces the air drag on the balloon, and lowers the yarn tension and hence the end breaks.

2.5.5 Practical spinning tension variation

The study of spinning tension has been the subject of a number of investigations (Stalder, 1991, 1994; Lünenschloß and Bünger, 1984; Sonntag, 1993, 1994; Azarschab, 1995). The amplitude and frequency of the tension fluctuations in the winding zone are higher than those in the spinning zone (Lünenschloß and Bünger, 1984). The spinning tension increases with the increase in traveller speed and ring–traveller frictional force. An eccentric yarn guide does not change the average spinning tension significantly but the tension distribution becomes wider and peak tension increases. A cross-correlation has been found between the spindle vibration and the spinning tension (Sonntag, 1993, 1994). It is reported that the spinning tension is a function of spindle speed, traveller mass, ring diameter, coefficient of friction between ring and traveller, and angle of lead (Stalder, 1991, 1994).

An example of the variation in spinning tension, from the beginning to the end of the cop build, is shown in Fig. 2.15. It can be seen that the average spinning tension is highest at the base of the cop and declines during the course of the cop build. There are two reasons for this. First, when winding the yarn at the base of the cop, the balloon will be at its longest length. The air drag forces acting on this length will therefore induce the highest balloon tension. Secondly, due to the dynamic loading of the yarn during spinning, tension amplitudes from the winding and balloon regions are transmitted to the spinning region and result in a high spinning tension.

The CV% of spinning tensions at different positions of cop build are 18.7%, 23.1% and 24.5% at the bottom, middle and top positions of the cop respectively (Rengasamy *et al.*, 2004). The higher CV% of the spinning



2.15 Spinning tension variation from beginning to end of cop.

tension at the end position of the cop build can be attributed to two factors. A statically balanced spindle (the spindle axis and the principal mass axis coinciding) may develop quasi-static imbalances as the yarn is wound over the bobbin. At any instant while winding the yarn on the bobbin, the mass distribution around the spindle axis is never uniform. This shifts the principal mass axis of the spindle–bobbin unit continuously with the presence of excess mass always at one side of the spindle. When more and more yarn is wound from the base to the top of the bobbin, the mass distribution around the spindle axis becomes more uneven. This leads to more vibration in the rotating spindle, resulting in high fluctuations in the spinning tension. Further, while winding the yarn onto the top of the bobbin, the size of the balloon is small. With this shorter yarn length in the balloon region, the damping of the vibrations transmitted from the winding region is less effective, as the ballooning yarn has less energy of absorption and hence causes transfer of more tension fluctuations to the spinning zone.

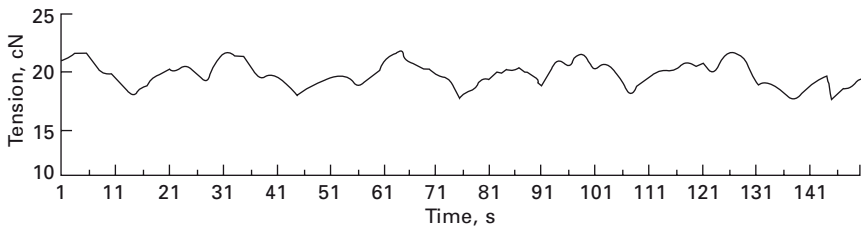
The variations in spinning tension for a full traverse of ring rail movement are given in Figs 2.16 (damped) and 2.17. A progressive decrease in spinning tension is observed while the ring rail moves downward. The spinning tension approaches the peak value at the top position of the ring-rail movement. This can be attributed to the progressive decrease in the angle of lead and the transfer of more yarn from the balloon region to be wound onto the bobbin as the ring-rail traverses upwards. The following equations apply to the rail movement. For upward motion of the ring rail,

$$N_s - N_t = \frac{V_F + V_R}{\pi D_B} \quad 2.24$$

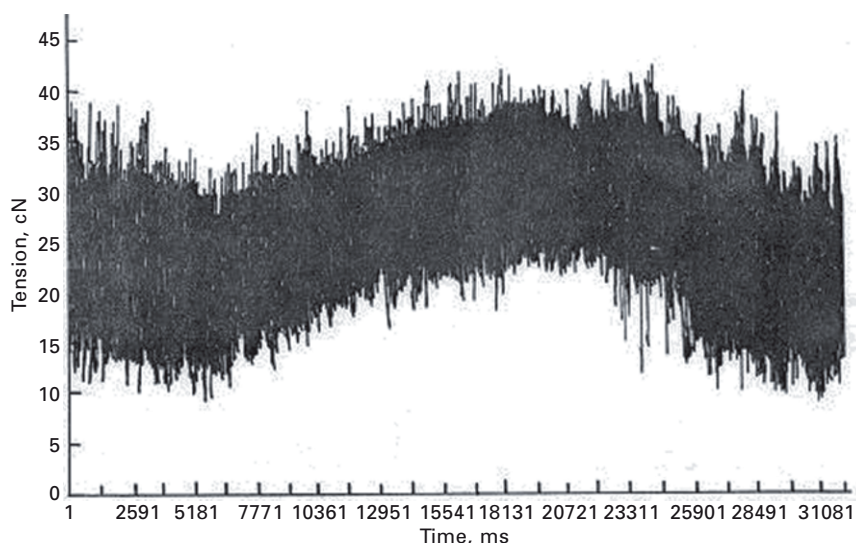
$$N_t = N_s - \frac{V_F + V_R}{\pi D_B} \quad 2.25$$

For downward motion of the ring rail,

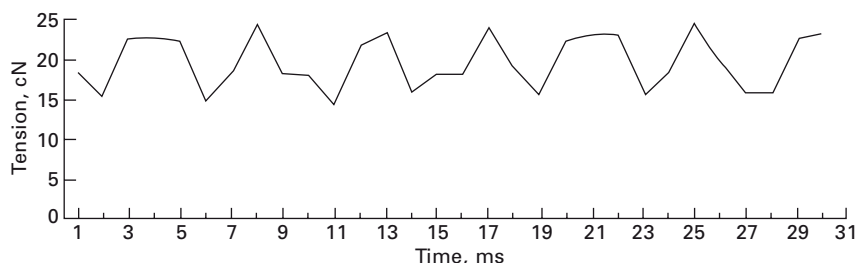
$$N_s - N_t = \frac{V_F - V_R}{\pi D_B} \quad 2.26$$



2.16 Spinning tension variation for a traverse of ring rail.



2.17 Spinning tension variation for a traverse of ring rail, damped.



2.18 Spinning tension fluctuations in milliseconds.

Hence during upward motion of the ring rail, the traveller speed decreases, signifying increased frictional drag on the traveller and yarn tension, and the reverse is the case for downward motion of the ring rail.

It is also observed from Figs 2.16 and 2.17 that the time required to obtain the lower minima from the higher maxima of the spinning tension is half of that required to reach the maxima from the minima. This is due to the faster traverse of the ring rail during downward movement than during upward movement.

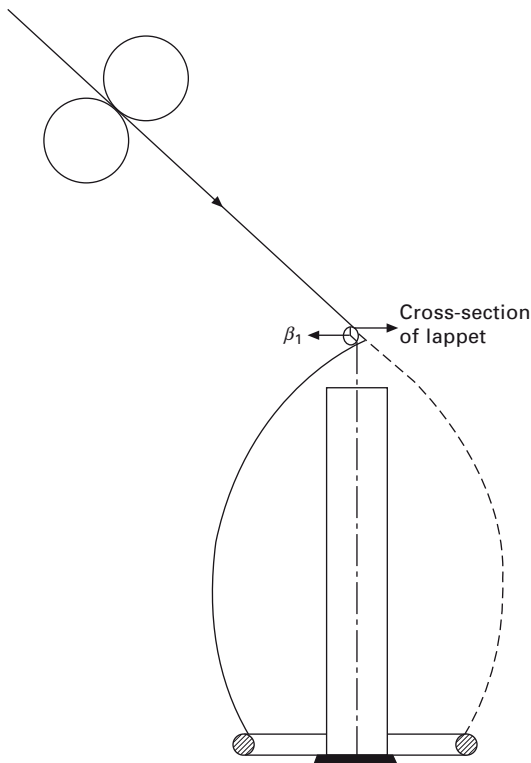
The spinning tension measured at 1 ms response time is given in Fig. 2.18 with a spindle speed of 16,500 rpm corresponding to a time of 3.6 ms for one revolution of the traveller. It is observed that, on average, for every 4 ms one peak is generated, which implies that each revolution of the traveller produces at least one peak value of the spinning tension. In fact, in each rotation of the traveller, there are five peak tensions (De Barr and

Catling, 1965). The observation of only one tension peak in each rotation of the traveller is due to the limitation of response time of the measuring system. For each revolution of the traveller the angle of wrap of the yarn over the guide eye (β_1) changes periodically (Fig. 2.19).

The angle of contact is low while the traveller moves away from the machine (towards the operator) and it is high when the traveller moves towards the machine. The periodic change of this angle influences the transfer of tension amplitudes from the winding zone to the spinning zone, resulting in fluctuations in the spinning tension.

2.5.6 End breaks in ring spinning and spinning tension variation

The end breakage rate is an important parameter which determines the productivity and yarn quality. The weakest part of a forming yarn is the spinning triangle below the front drafting rollers. Most end breakages occur there. The end breakage phenomenon in this region is based on fibre slippage;



2.19 Angle of wrap of yarn over the lappet.

there is no evidence of fibre breakage. At the spinning triangle the fibre ribbon is in a partially twisted state. The force required to break the forming yarn in this partially twisted state is actually the force required to pull out the twist insertion point away from the front rollers; this is somewhat greater than about one-third of the single thread strength (De Barr and Catling, 1965). Three important factors therefore govern the end breakage rate: (1) the number of fibres in the triangle and the variation of this number as subsequently new ribbon length forms the spinning triangle, (2) the ease of twist propagation to the apex of the triangle, and (3) the mean yarn tension and tension fluctuation.

Mechanism of end breakage in ring spinning

It may be assumed that the yarn is composed of a series of successively linked fibre bundles. The length of any given link is poorly defined, because the elements of the fibre bundle are not separate entities but each gradually merges into its neighbour at either end. The links may therefore be taken as the mean overlap of fibre ends. Therefore an average element length may be considered to exist. For carded cotton yarns the average length of the link is approximately 3 mm (Lord, 1961). The yarn breaks are governed by the weakest link, which is about one-third of the yarn strength (Peirce, 1926). The strengths of the links of the fibre bundle just issuing from the front rollers are independent variables and follow a normal distribution, i.e., a link of maximum strength may follow immediately one of minimum strength. The strength is constant within a link but varies from link to link. The strength of this link is proportional to the number of fibres forming the link. The coefficient of variation of the strength of this link is equal to the coefficient of variation of mass per unit length of the yarn (Ghosh *et al.*, 2004). The total number of links moving from the nip of the front rollers per revolution of the traveller, n , is given by

$$n = \frac{V_F}{\bar{l}_h N_t} \times 10^3 \quad 2.27$$

where V_F = front roller delivery speed in m/min, and $\bar{l}_h$ = average length of the links of fibre bundles, i.e. 3 mm.

Assuming that P is the probability of the number of weak links just emerging from the nip of the front rollers causing an end to break, then the number of end breaks per spindle rotation (B) is given by the following equation:

$$B = nP \quad 2.28$$

Now, the strengths (x) of the links of fibre bundle issuing from the front

rollers follow a normal distribution $N(\mu, \sigma^2)$ with mean μ and variance σ^2 (Fig. 2.20). The standard deviation σ is then

$$\sigma = \frac{V\mu}{100} \quad 2.29$$

where V = the coefficient of variation of mass per unit length of yarn.

The variations of spinning tension in ring spinning are mainly caused by the instability in the rotation of the the traveller. It is an established fact that in each rotation of the traveller there are five peak spinning tensions. For an end to break, the peak of spinning tensions is a more decisive factor than the average value. Let the mean of the peak values of spinning tensions be T . The average time taken in milliseconds to pass a link through the nip of the front rollers can be calculated as

$$t_1 = \frac{\bar{l}_h}{V_F} \times 60 \quad 2.30$$

During spinning, the average time taken for a rotation of the traveller is $t_2 < t_1$. Thus each link experiences at least several peak spinning tensions. A yarn break will occur when T is greater than the strength of a link just passing from the front roller. Therefore, the strength of the links, which are lower than T , would lie at a distance of $Z\sigma$ from the left side of μ in the normal distribution curve, where, Z is the standard normal variate.

A linear transformation of the normal distribution $N(\mu, \sigma^2)$ into the standard normal distribution $N(0,1)$ is obtained by (Ghosh *et al.*, 2004)

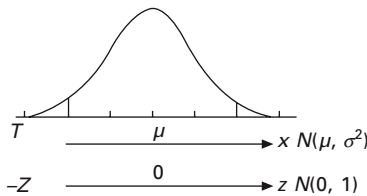
$$z = \frac{x - \mu}{\sigma} \quad 2.31$$

The probability, when T is greater than the strength of the links just passing from the nip of the front rollers, can be found by the relationship

$$P = 1 - \Phi(Z) \quad 2.32$$

where $\Phi(Z)$ can be expressed as

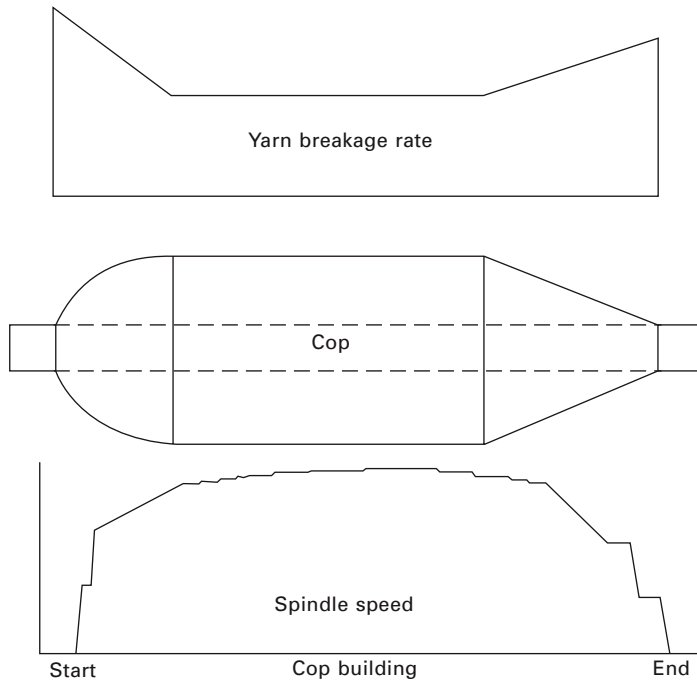
$$\Phi(Z) = \int_{-Z}^{\infty} e^{-z^2/2} dz \quad 2.33$$



2.20 Distribution of strength of fibre bundles.

To test the validity of the above mechanism, 30 tex carded cotton yarns were produced at a spindle speed of 16,500 rpm and a yarn delivery speed of 20 m/min (Ghosh *et al.*, 2004). The spinning tension was measured using a Rothschild tensiometer-2000 with a frequency of 1000 Hz (the response time is 1 ms). Thus it was possible to observe only one peak of the spinning tension in one revolution of the traveller instead of the four or more peaks that usually occur. The time scales are $t_1 = 9$ ms and $t_2 = 3.6$ ms. The measured strength of the yarn is 375 cN, which indicates that the mean breaking force of the link is 125 cN. The measured peak spinning tension is > 40 cN. When the strengths of the links follow a normal distribution the standard deviation value, σ , with measured $V = 13.1\%$, would be 16.34 cN. For a break to occur (i.e. the strength of the links being lower than the value of the peak spinning tension), the standard normal variate (Z) would equal 5.2. Therefore, to fulfil the condition of end breaks, the strength of the links x that are lower than the value of the peak spinning tension would lie at a distance of 5.2σ from the left side of the mean (μ) in the normal distribution curve, i.e. $x = 125 - 85 = 40$ cN. Thus using Equations 2.32 and 2.33 the probability (P) of the strength of the links being lower than the mean value of the peak tension is 1×10^{-7} , which means that one link out of 10^7 links is the weakest one that causes an end to break within a particular spindle.

It is logical to assume that thin places emerging out of the front drafting rollers are the potential sources of end breaks. Thin places undergo overtwisting due to their lower rigidity, and hence are the weakest. The strength of fibre links also depends on the grip exercised by the top front roller over the lower roller, since poor gripping leads to slippage of the fibre link itself, and consequently to end break. A higher force on the top roller and the use of softer top front roller coverings enhance the grip of the fibres. A reduction in friction between the ring and the traveller reduces the mean spinning tension. The sources of peak tensions are the vibration of the machine elements – main shaft, pulleys, spindle and traveller instability – which are superimposed on the basic tension. Of these, the spindle and traveller contribute more to the vibrations. The spindle is one of the most unbalanced rotating parts where it is supported at its bottom and hip, leaving its tip to oscillate. The spindle always experiences dynamic imbalance due to the variation of yarn mass on the bobbin in the radial and axial directions (with tapered cop build-up). This is converted into traveller speed variations. Further, the up-and-down ring rail movement and its association with the change of yarn length to be wound and balloon size result in variation of the tilt and friction drag on the traveller; hence the traveller continuously experiences acceleration and deceleration. All these lead to high-frequency tension fluctuation with variable amplitude to the winding tension that are transferred to the spinning region, causing end breaks. There is no design solution in sight to alleviate this. Typical end break rates for a cop build-up are shown in Fig. 2.21. The



2.21 Yarn breakage rate and control of spinning speed.

practical approach to reducing end breaks is to control the spindle speed from the start to the end of the cop build, so that the spinning tensions and peak tensions on the yarn are kept as low as possible. Reducing the traveller weight also helps to some extent to control end breaks, provided it does not lead to balloon instability.

2.5.7 Package formation and sizes

The winding of yarn in ring spinning is complex. The yarn is wound in layers along the length of a tapered plastic bobbin, mounted on the spindle, the action of which is termed 'cop building'. This layering of the yarn enables it to be easily unwound without slough-off and with undue tension variations during high-speed yarn rewinding. The point of lay of yarn on the bobbin is periodically moved up and down by the motion of the ring rail, and after each cycle (one chase), the bottom-most point of yarn lay is shifted upwards a little by means of a step in height of the start position of the ring rail's periodic motion. The wound bobbin or 'cop' has three distinct parts: a lower curved base, a cylinder in the middle, and a conical tip. While forming the base of the cop, the upward shift of the ring rail at the bottom of the chase is kept low, giving a shorter traverse. Since the length of yarn delivered during

each traverse stroke is the same, the volume per layer is increased, thereby generating the curvature (Fig. 2.21). The average speed of traverse of the ring rail is slower during its upward stroke than during its downward stroke. The slow traverse of the rail during its upward stroke helps in laying more coils of yarn, i.e. with short pitch. These coils are called 'winding coils'. Since the bobbin is tapered with its diameter reducing from the bottom to the top, the winding rpm must increase from the bottom to the top. This leads to a progressive decrease in the pitch of the coils or an increasing package density from the bottom to the top. In order to maintain a constant package density, the ring rail is accelerated during its upward motion. For the same reason, the ring rail decelerates during its downward stroke. The yarn coils laid during the downward stroke are 'binding coils' with long pitch.

The winding and binding coils are considered to be screws of opposite hands. This method of layering the coils provides poor frictional contacts between these two types of coils yet higher frictional contacts within winding coils. As a result, during unwinding the cop, the likelihood of yarn slough-off is reduced.

The cop size in ring spinning is very much limited both by the size of the ring and by the permissible balloon height. The ring diameter varies from 41 to 51 mm and the lift (length of the bobbin over which yarn is wound or ring rail traverses) from 175 to 205 mm. The ratio of lift to ring diameter is around 4 to 4.7. Since the yarn tension is inversely proportional to $\sin\alpha$, i.e. R_B/R , reducing the bobbin diameter below the ring radius leads to excessive tension on the yarn and end breaks. The maximum yarn content in the cop is around 60 to 110 g, which necessitates frequent stops of the machine for doffing the package. Increases in package height and diameter above the values indicated would result in uncontrollable yarn tensions and excessive power consumption, as the power to rotate the package is proportional to the ring diameter to the power 2.75.

2.6 Post-spinning

Ring spun yarns wound on the bobbins are not suitable to be employed directly in weaving and knitting as these processes require large-sized packages. Yarns should be rewound onto a large package in a separate post-spinning operation and any faults in the yarn removed and the cut ends joined by splicing (Lawrence, 2003; Lord, 2003). The production of yarns for heavy-duty applications such as sewing threads, cords, cables and ropes requires assembling two or more to produce the required linear density yarns. This is achieved by twisting two or more yarns together. To reduce warp breakages in the weaving of worsted fabrics, two yarns of the same count are twisted together. This process is called doubling or plying and the resulting plied or doubled yarn has sufficient abrasion resistance to withstand the weaving

process and so dispenses with the need for applying a size coating to the individual, constituent yarns, i.e. the singles yarn. Yarn rewinding together with fault clearing and doubling/ply-twisting are the operations that constitute post-spinning operations on spun yarns.

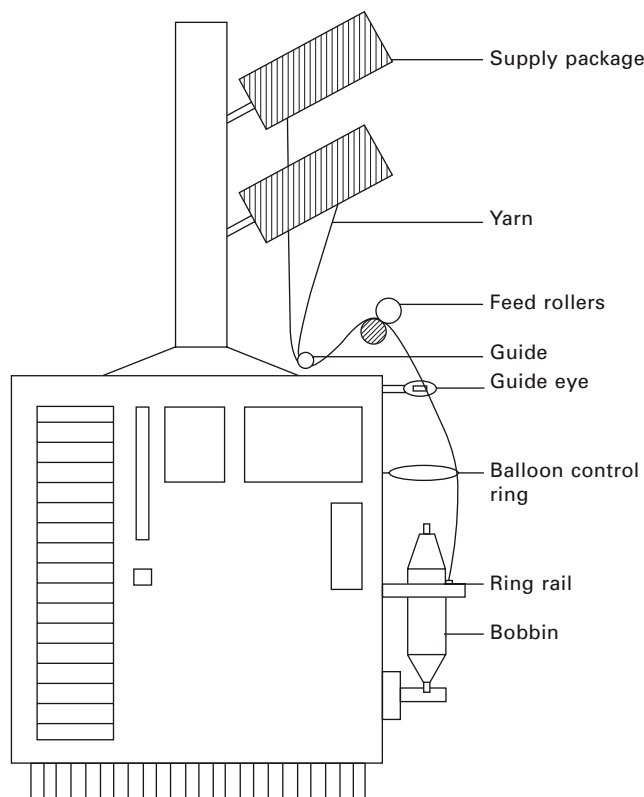
2.6.1 Yarn rewinding and fault clearing

The low yarn content of the ring cop requires combining several of them to make a larger package of around 2 kg in the yarn rewinding operation, suitable for high-speed warping. Further, yarn faults must be removed in the yarn winding operation so the yarn can withstand the stresses that are imposed during warping, weaving and knitting processes. With high-speed winding at up to 1200 m/min and the use of electronic yarn clearers, the machine efficiency in winding is not affected much by the sizes of current ring cops.

2.6.2 Ply-twisting

Ply-twisting is the process of combining two or more yarns by twisting them together. Twisting of two or three or more yarns (2-ply, 3-ply, etc.) in an assembled form is performed either on a down-twister/ring-twister or on a two-for-one twisting machine. The ring twisting machine consists of feed rollers, thread guide eye, ring, traveller, traversing ring rail and spindle with bobbin similar to those found on a ring spinning machine (Fig. 2.22). The supply yarns from individual packages are withdrawn by feed rollers and pass through the guide eye, then underneath the traveller and finally to the bobbin. The principle of twist insertion is identical to that in ring spinning. The tension in all the single yarns should be the same to avoid the low-tension yarn spirally wrapping the high-tension component. Yarns to be plied can also be wound together under controlled conditions into a large-sized package in a separate operation. This large package becomes the feed material to the ring twisting machine or the two-for-one twisting machine.

The single yarns are mostly spun with Z-twist and during plying S-twists are inserted (the exception is sewing threads which have an S–Z combination). The single yarns undergo untwisting and are twisted together with respect to the ply yarn axis. The ratio of ply to single twist is usually kept at 0.6–0.67. The surface fibres on the single yarn become straightened whereas the fibres at their axes become more oblique. The surface fibres protruding as hairs are entrapped during plying and contribute to strength of the plied yarn. Further, the evenness of plied yarn is better than that of a single yarn of the same count, due to statistical phenomena and the frictional support provided by one yarn to thin places on the other.



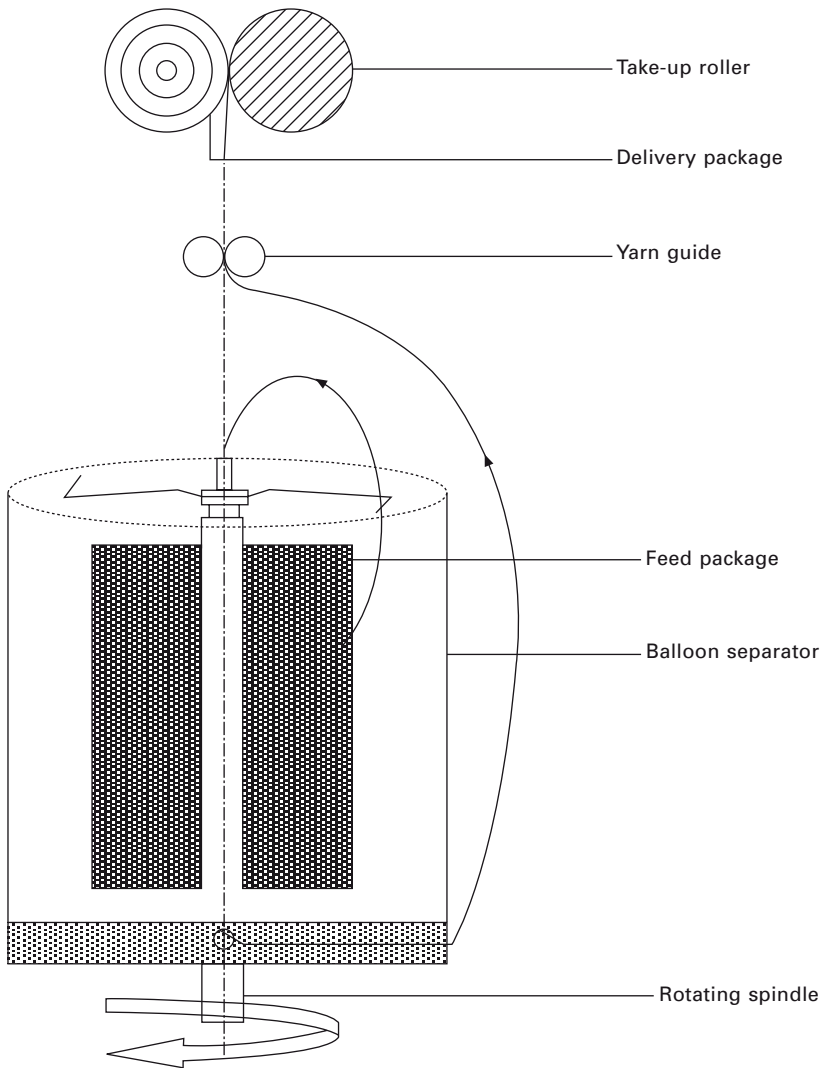
2.22 Ring twisting machine.

Two-for-one twister

The assembled yarn package having the required number of single yarns is kept stationary on a rotating spindle. Yarn from the package passes through a yarn guide mounted on freely rotating arms and through the axis of a hollow rotating spindle, at the base of which it passes through an eyelet and on to the winding head (Fig. 2.23). Each rotation of the spindle simultaneously inserts two turns of twist to the yarn: one turn of twist in the length of yarn inside the spindle, and another turn of twist in the length of yarn between the eyelet and the take-up rollers by forming a revolving yarn balloon.

2.7 Applications of ring spinning

Classical ring spinning is widely used to convert a wide range of short-staple fibres and long-staple fibres into yarns (Table 2.2). Ring spinning of bio-synthetic fibres such as PLA fibres is also of growing interest (Ingeo Technical Bulletin, 2005). Many derivatives of ring spinning systems produce



2.23 Mechanism of two-for-one twisting.

distinct yarns to cater for different applications (Table 2.2). In the case of the long-staple sector, the spun-plied spinning systems produce wool-based plied yarns with low hairiness requiring no doubling and plying operations.

The single yarns intended for core-spun sewing threads such as polyester/cotton and polyester/polyester are produced using ring spinning by having an attachment on the creel of the ring spinning machine that feeds high tenacity polyester filaments into the nip of the front rollers. Stretch-to-fit garments require yarns of high stretch with elastic recovery. Feeding of elastic

Table 2.2 Applications of ring spinning

Range of fibres		
Short staple	Long staple	Derivatives of ring spinning
Cotton, regenerated, polyester and blends	Wool, polyester, acrylic, Nomex, Kevlar and blends	Core spinning (hard and elastic core), spun-plied spinning (double rove spinning, solo spinning), compact spinning systems

filaments directly into the nip of the front roller under controlled stretch is achieved by retrofitting an elastic core attachment to the creel of the ring spinning machine. Commercialisation of compaction fibre strand has opened new avenues to produce less hairy cotton yarns with moderately improved strength and evenness. The compact yarns pick up less size and encounter fewer breaks during rewinding, leading to cost savings. Fabrics made from these yarns exhibit enhanced print clarity.

2.8 Future trends

Classical ring spinning has so far been able to withstand the competition from other spinning systems largely because of its inherent advantage of producing yarns with high strength and a wide range of yarn counts from a wide range of fibre types. Its production speed is currently limited to 25 m/min, in spite of developments in designing new ring and traveller combinations. Improving productivity beyond this level requires crossing three hurdles. The first is traveller burn. With the sliding traveller motion, the limiting traveller speed is less than 50 m/s. A major technological breakthrough to operate travellers at higher speeds would be possible only if the mode of friction could be changed to rolling friction. A rolling traveller might solve this problem with less frictional drag.

A review of the research activities on the metallurgical and design aspects of rings and travellers and their pace of outcome does not indicate any foreseeable future innovations that will produce a quantum jump in traveller speed. Rotating rings based on magnetic fields are unlikely to be commercialised owing to their high cost, requirement for a large spindle gauge, high noise level, the need for regulating the start-up and shut-down speeds, and the requirement of a special roving brake device to prevent material waste during yarn breaks and piecing up. If the ring spinning system could be developed to overcome the first obstacle, it would need a spindle that could operate beyond 30,000 rpm. The ring spindle is one of the least dynamically balanced rotating devices. To operate at high speeds above 30,000 rpm with negligible vibrations requires advanced engineering. The problem does not end with the development of high speed spindles. The difficulty arises due

to the fact that twisting and a complex yarn winding method are combined in one action that has to be accomplished by the traveller. The traveller has also to perform a delicate balancing task between maintaining the balloon stability and reduced yarn tension. There is a minimum traveller mass needed to maintain balloon stability which also generates the yarn tension and consequently the potential for yarn breaks and loss of productivity. With increasing spindle speed the yarn tension increases rapidly and the control of yarn breaks becomes a very difficult task.

Notwithstanding these obstacles that stand in the way of improving the productivity of ring spinning, classical ring spinning will continue to dominate the spun yarn market at least in the near future, as there are no foreseeable developments in other spinning technologies that can provide the production of high strength yarns over a wide count range from a wide range of fibre types. It is reasonable, however, to forecast possible developments of new variants of the ring spinning system, since a number of them already have been successful, namely core spinning, compact spinning and spun plied spinning.

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