15. Advanced Ring Spinning

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Learning objectives

By the end of this lecture, you should have:

- an appreciation of why ring spinning is so slow and expensive
- an understanding of improvements to reduce costs, including Sirospun, Solospun, Compact and collapsed-balloon spinning, and their benefits and limitations
- a knowledge of the post-spinning steps needed to prepare a yarn for weaving or knitting
- an awareness of the way synthetics can be added during spinning

Key terms and concepts

Whole package rotation needed for each turn of twist inserted. Tension provided by traveller friction to control yarn balloon limits rotation speed. Each spindle is a low production unit which limits amount that can be spent to improve quality and production. Post spinning steps aim to prepare long lengths of fault-free yarn with good strength and abrasion resistance as needed for knitting and weaving. Ring-spun yarns are of high quality and fundamental limitations mean that most improvements are incremental.

Introduction to the topic

Insertion of twist is very expensive. Ring spinning is more expensive than the total cost of all the processes from scouring up to the spinning frame but it produces a yarn with the desired attributes. A lot of effort has gone into improvements to ring spinning in order to increase production and performance (quality) or to reduce costs. These include methods to avoid the need for two-folding of yarns in order to make them weavable (Sirospun, Solospun) and to allow higher spinning speeds (Compact and collapsed-balloon spinning). Blending of wool with synthetics during spinning particularly to provide stretch in woven fabrics is briefly considered. Recent improvements are covered in this lecture together with the other steps involved in preparing a yarn for use in weaving or knitting. These are winding, waxing, clearing, twisting (folding) and steaming.

Note: Some more complex topics and points of interest which have been included for completeness are marked in *italics*. These can be omitted if the reader prefers.

15.1 Top in – to yarn out

When people talk about "Spinning" they can mean either just the ring spinning frame or all the steps involved in turning clean fibre into yarn. A complete worsted spinning mill contains all the processes needed to further blend, clean and colour the top if necessary (dyeing, backwashing and re-combing), to produce a fine sliver from top (drawing and roving), to insert twist (spinning), make larger packages and remove faults (winding and clearing), to further twist (e.g. two-fold twisting), steam and condition, test and package the yarns ready for dispatch to the weaver or knitter.

In the worsted route the most common place to colour wool is as top, but it can also be dyed as yarn (in packages or hanks) and fabric. Top dyeing is mentioned here because it can improve spinning by better cleaning of the fibre and allow the addition of fresh lubricants and antitstats that are the most appropriate for spinning. However, dyeing can also cause significant damage to the fibre. It is normal to rinse or wash the wool before and possibly after dyeing as part of the dyeing cycle. Sometimes the undyed (ecru) top is also washed (backwashed) but this is now rare because of the cost. After a wet treatment it is almost always necessary to re-comb the top to remove any new entanglements. However, it has become routine for spinning mills working with superfine wool to re-comb ecru tops to give improved spinning performance and to protect against any faulty practices by the topmaker or in transport of the top. Finally, the comb is an excellent means of blending fibres so colour blends and blends of wool with synthetic staple fibres are generally made at or before re-combing.

The steps involved in thinning the sliver down into packages of strands (roving) ready to be mounted on the spinning frame (creeled) and input to the drafting arms are collectively called drawing. Apart from re-combing, which is usually followed by two gillings, there are usually three to five gilling stages (where the fibres are controlled by pins) and one or two roving stages (where the fibres are controlled by balloon rollers and/or aprons). One drawing line will usually produce enough fibre to feed about 5000 ring-spinning spindles. On the spinning frame, the roving strand is typically thinned (drafted) by a factor of 20 and then twisted to form a yarn. The quality of drafting on the spinning frame is the key determinant of yarn evenness but this can be influenced by the quality of the roving and faults in the roving can give rise to faults in the yarn. Part of recent advances in the spinning mill have included improving roving quality and increase the speed, automation and reliability of drawing.

The bobbins of yarn that get unloaded (doffed) from the spinning frame are small and the yarn is twist-lively and may contain faults. Therefore, the yarn (100 to 300 g/bobbin) is usually steamed (to remove the twist-liveliness) before being wound off the bobbins at high speed and joined together into large packages (1 to 4 kg) in a process called winding. At the same time sensors, called clearers, detect and cut out sections of yarn containing faults. When the yarn is cut, winding stops, the machine finds the two ends, overlays the segments some way from their ends, cuts and splices the tails. The clearers can detect thin and thick places and also contaminants if they are a different colour and the user can set the sensitivities for the size and length of faults to be cut out, but it is not practical to remove more than about one fault per km of yarn.

If you take one of the above (singles) yarns and rub your fingers back and forward along its length you will find that it will become much more hairy, that bundles of fibres will be pushed together to form thick places, and the yarn will tend to disintegrate. Such yarns, when used as the length-ways (warp) yarns, cannot survive the abrasive forces and repeated cyclic stresses of weaving. Historically, this has been overcome by taking two or more such yarns, laying them side by side (folding), and twisting them about each other in the opposite direction. Originally, this was done on a second ring-traveller frame called a ring twister. Now it has become much more common to use a two-for-one twister (explained later) to perform the same operation. The new twist can be in the same or opposite (normally used) direction. The aim is to bind in the surface fibres so that the yarn does not rub-up or disintegrate in weaving. Twisting in the opposite direction makes for a softer, bulkier yarn while twisting in the same direction produces a stiff (crepe) yarn. After twisting, the yarn may be steamed a second time.

Knitting yarns may also be twisted together (plied) mainly to achieve bulkier softer yarns. Knitting is a more gentle process as the same yarn segment is not repeatedly stressed. Twisting in the opposite direction can also produce a torque-balanced yarn in which the yarn has no tendency to snarl (wrap around itself). This is useful for avoiding spirality in the knitted fabric where the fabric distorts in response to the residual tendency of the yarn to untwist. Steaming only temporarily removes the tendency to untwist. If steaming can be avoided before winding then, after two-folding, the yarn will be torque balanced and not need a subsequent steaming.

The spinning mill will also have a quality control laboratory to measure the properties of the yarns to confirm that they meet customer specifications. Finally, the yarn regain will be measured and the packages weighed, boxed and invoiced.

15.2 The advantages and limitations of ring spinning

You cannot hold both ends of a fibre strand (or yarn) fixed and insert real twist. Any amount of twist in one segment will be exactly matched by the total number of turns in the remaining segments. In order to insert real twist during ring-spinning the whole package must rotate once for every turn of twist inserted. A very fine yarn, say 10 tex (g/km), will require around 900 turns/m. If the spindle rotates at 10,000 turns/min this means a production of 11.1m/min or 0.67 km/hour/spindle or 40 kg/spindle/year (given 6000 hours of running or 24 hours per day, 6 days per week at 80% efficiency). A similar calculation for a 20 tex weaving yarn yields 113 kg/spindle/year. The key observation is that a single spindle is a very low production unit. Hence, a large number of spindles are needed, they cannot cost too much, and cannot use much labour. A typical mill will have at least 10,000, and in a few cases as many as 100,000 spindles. To reduce the costs of spinning either the production per spindle must be increased or the associated costs (labour, energy and capital) must be reduced.

Twist is inserted by the rotation of the package but must propagate along the yarn right up to where the fibres exit from the front roller nip. Ideally, all the twist should be inserted instantaneously as the fibres emerge. Any impediment, such as a yarn guide, will block twist so that part of the twist is not inserted until after the yarn segment passes this point. Twist will flow (be inserted) into the segments that are easiest to twist so that relatively more twist is inserted into thin places. *[In a fascinating little experiment, the forming yarn was treated with a small jet of steam. The wool fibres became set in their twisted state and more pliable and were easily able to take more twist. The net result was that twist would not propagate upstream of the steaming point and the upstream strand drafted apart, i.e. spinning was impossible.]*

The drafting arms of the worsted spinning frame typically thin the input sliver (roving) by a factor of twenty. In this case the front rollers would be rotating at twenty times the speed of the back rollers. In between these two pairs of rollers are a third set that also drive a pair of soft rubber aprons. The top roller of this middle set is recessed in the central section so that fibres are loosely gripped. Typically this roller pair pre-tensions the strand using a draft of 15% (i.e. rotating at 1.15 times the surface speed of the back rollers). The majority of fibre control is provided by the aprons and the strength and position of the front apron nip can be altered by a clip-on spacer. The underlying aim of this drafting system is to softly restrain fibres so that only fibres gripped by the front rollers are accelerated immediately to front roller speed. It doesn't matter if some fibres move randomly out of turn, it is correlated movement between fibres that leads to worse-than-random evenness (Lamb 1987). Hence, one aim is to minimise interaction between fibres and any process that compacts the strand inside the drafting zone will increase interaction and worsen yarn evenness.

The drafted fibres emerge from the front roller nip in a ribbon about as wide as the input roving. The emerging leading fibre ends are caught by the wrapping strand and the rotating trailing ends of earlier fibres and are pulled into the narrow line of the forming yarn. This region is called the spinning triangle.

The tension in the yarn is determined by the frictional drag of the traveller sliding on the ring and the air-drag on the yarn balloon. *The frictional force from the traveller is $\mu m \omega^2 r$, where μ is the coefficient of friction, m is the mass of the traveller, ω is the angular velocity and r the radius of the ring. The tension from the traveller increases as the square of the rotational speed and as the ring diameter increases. Additional tension arising from the yarn balloon increases in proportion to the mass of the yarn segment in the balloon, the radius of the balloon and the increase in air drag with velocity. In all normal circumstances most of the tension is imparted by the traveller because it is this tension that is used to prevent the balloon from growing indefinitely. The traveller rotates slightly slower than the spindle speed by an amount that on average equals the delivery speed of the fibres. The new fibres act to lengthen the forming strand which reduces the force pulling the traveller round the ring, so the traveller slows, winding more yarn onto the bobbin and restoring the size of the balloon.* It is this elegant self-regulating system that enables ring-spinning to work.

The rotational speed cannot be increased indefinitely because the tension becomes larger than the strength of the occasional weak place in the strand. The yarn then breaks, known as an end-break, and the spindle must be stopped, the end found, looped through the traveller and brought up to the spinning triangle (or behind the front rollers) and released just after the spindle is allowed to start rotating again. The process is called piecening. Automatic pieceners are available but they are slow, expensive, and cannot handle all eventualities such as a roller lap, broken roving, missing traveller etc. A second speed limitation is the traveller surface speed against the metal ring which is limited by tribo-mechanical effects to about 35m/sec. This limit is only a concern for coarse yarns on large rings or when spinning strong synthetic fibres. *A novel way of overcoming this speed limitation has been the proposal to use a small disc as a traveller which rolls between an inner and outer ring (Kurkow 2001). However, the patented system necessarily increases the size of the yarn balloon and does not appear to have been successfully commercialised. The worsted system uses lubricated rings in which a wick carries lubricant from a bath in the ring rail to the surface on which the traveller slides. The traveller is J – shaped and slides mostly on the long arm surface. Cotton rings are not lubricated and a C-shaped traveller is used in which the load is borne by an internal face of the C. Loose cotton fibres are crushed at this contact region and form a lubricating film. The different traveller and ring shape allows surface speeds of 45 to 50m/sec for cotton and with smaller rings speeds of 20,000 rpm are possible whereas speeds for pure wool are rarely above 11,000 rpm.*

Spinning speeds can be increased by reducing ring size and by reducing the height of the balloon. *(A smaller balloon provides a smaller centripetal force and needs less frictional drag to control.)* However, both of these options reduce the volume of yarn that can be wound onto the bobbin before it has to be doffed and replaced by an empty bobbin.

One potential means of reducing costs is the weavable singles yarn. If the need for two-folding can be avoided then two fine yarns and two stages of twisting can, in principle, be replaced by one twisting step working on a yarn of twice the mass. Considerable progress has been made towards this goal as will be presented below. As outlined above, yarns for knitting do not necessarily have to be two-folded except to avoid spirality or to produce a bulkier yarn. The cross-ways yarns in weaving, the weft yarns, also do not need to be two-folded so it is becoming more common to use a singles weft yarn. Because there are more fibres in the yarn cross-section the yarn can be spun with less twist and sometimes slightly coarser and therefore cheaper wool is used.

A knitting yarn must pass through the metal eye of a small needle and be formed into a loop. To reduce the tensions it is standard practice to wax the yarn, that is, to apply a good boundary-layer fibre-to-metal lubricant.

Ring-spun yarns have a number of attractive features. The first is that, because twist is directly applied and because fibres are tensioned during yarn formation, most fibres spiral about the axis in a straightened configuration with similar helical angles. This gives the yarn a relatively clean, uniform appearance and properties. Secondly, provided that there is no slippage in the spindle drive, all spindles rotate the same amount per unit length of input strand, thus the average amount of twist is constant within and between yarns. Finally, small pieces of debris, fibre and contaminants can be thrown free by the centripetal forces and do not build up in the yarn-forming zone.

15.3 Improvements to (worsted) ring spinning

Over recent years, spinning speeds have been increased by reducing ring diameter and bobbin height. The time between doffs reduces as the speed increases and as the amount of yarn (mass) that can fit on the bobbin decreases. Finer yarns require more twist (hence slower delivery speed) and allow a longer length of yarn (for a given mass) so the size of ring chosen, when the spinning frames are purchased, will depend on the average fineness of the yarns that it is planned to spin. All modern ring frames are available with automatic doffing in which the last bit of yarn from the full bobbins is wound onto the new bobbins before the yarn is broken. This avoids the need for piecening except when a new supply of roving (creeling) is required or travellers have to be replaced. If the time taken to doff a yarn (lost production time) is known then the optimum ring size can be calculated (Sonntag and Artzt 1994). Currently, this is much smaller than the ring diameters used. However, the increased labour if yarns are broken during automatic doffing and the increased number of splices (which are potential downstream faults) needed to join the smaller packages must also be taken into account.

The tension on the yarn reduces as the yarn package grows closer in diameter to that of the ring. This is because the yarn is pulling the traveller more nearly in the required direction of motion. The yarn tension also decreases as the yarn gets nearer the top of the bobbin. This is because the needed height of the balloon is smaller and hence the centripetal force less. The latest spinning frames begin spinning at a slower speed and increase the speed as the package builds. Some spinning frames even have sensors that monitor the number of end-breaks and increase or decrease the speed until the allowed level of end-breaks is achieved.

Weavable singles yarns

The first step towards achieving a weavable worsted singles yarn was taken at CSIRO in the mid-1970s (Plate and Lappage 1980). Two strands were delivered through the front roller before passing through another roller that intermittently blocked the twist from propagating up to the main nip. The two strands formed a large, long spinning triangle and the twist-blocking roller caused the twist in the two arms to increase and decrease. This intermittent twist was then trapped below the convergence point as alternating twist in the strand arms. This is a difficult mechanism to picture but what it means is that a fibre that starts on the outside of one of the strands will occasionally be caught between the two strands. If the twist in the two arms were constant then a fibre that starts on the outside always remains on the outside and is not trapped by the other strand. This is the basic reason why ordinary singles yarns are not weavable. There is some fibre migration due to varying spinning tensions and movement of the delivery position of fibres but overall many surface fibres are poorly trapped and will get rubbed up along the yarn during weaving.

The amusing discovery was that the yarns were nearly as resistant to abrasion when the twist-blocking roller was removed! *It turned out that the natural variation in the number of fibres in the strands caused some twist variation and that there was a second mechanism of fibre ends being caught in the vee (which is really another way of saying that a free fibre end can have more or less twist than the strand). The binding mechanisms increase as the strand spacing increases but the number of spinning breaks rapidly increases with strand spacing once the length of the strand arms approach the mean fibre length. The reason is that only about half of the final twist propagates up into each strand and so the arms do not have enough twist to fully prevent drafting.*

The final step was to introduce a break-out device that will prevent just one strand being spun into a yarn by itself. Such a half-weight strand would cause an extremely serious fabric fault. The elegant break-out device became the core patented part of the Sirospun process (http://www.tft.csiro.au/). The changes for Sirospun are thus a double creel (for twice the number of roving packages), a double set of roving guides (including a wider middle roller recess) and the break-out device. The yarn count per spindle is doubled and the amount of twist inserted is usually the same as would be inserted in the two-folding operation (*a metric twist factor of 120 to 130*) which is similar in turns/m to that put in the singles yarn. The recommendation is still to have the same total number of fibres in the yarn cross-section (i.e. at least 2 x 35 = 70). The twist level and number of fibres are needed to ensure good spinning performance by avoiding drafting of the strand arms. Longer fibre length is also a distinct advantage for Sirospun. The cost of the spinning stage is roughly halved because production per spindle is doubled and two-folding is eliminated. One drawback is that winding and clearing are carried out on the final yarn rather than the singles. This means that the joins (splices) must survive weaving unaided by a good (unspliced) yarn. The performance of splices in weaving is so critical that Sirospun could not gain wide commercial adoption until improved splicing (the Thermosplicer®) was available.

Many, if not most, people think that Sirospun is really a two-fold yarn in which real twist is trapped in the strands. This is impossible, real twist cannot be inserted when both ends are held fixed. It is much better to think of Sirospun as a singles yarn with improved binding of the surface fibres. It still has the uni-directional twist and will give rise to the same spirality as a singles yarn. As singles, Sirospun yarns are leaner than the equivalent two-fold yarns. This is a potential cause of more visible streakiness in plain-weave piece-dyed fabrics where the uniform colour and simple pattern provides the least hiding of the yarn irregularity that is always present.

Work on producing weavable singles yarns continued at CSIRO and it was discovered that if the strand was rubbed after drafting and before twisting then a satisfactorily abrasion-resistant yarn was achieved. The problem was that the mechanism for rubbing of a single strand mimicked the rubbing aprons of a roving frame and was thus complicated and considered too expensive to be implemented on a spinning frame. If a spindle only produces 60 kg of yarn per year and an improvement increases the value of the yarn by $1 per kg then, for a 3 year payback, the allowed cost is only $180 per spindle. Scientists at WRONZ (New Zealand 1993) discovered that just adding an extra zone with a negative draft, which caused the fibres to bunch up, greatly increased abrasion resistance. Knowing that a new way had been found, but not what it was, lead to increased effort at CSIRO which resulted in the process now known as Solospun.

Solospun (Prins et al. 2001 and Solospun patents, also http://www.tft.csiro.au/) consists of an additional small roller clipped onto the spinning frame so that it is driven by the bottom roller. The new roller is slotted with the lands and slots alternating (4 times) around the circumference (Figure 1a). The effect is to split the roving strand into multiple sub-strands that are continually being altered (Figure 1b). In this way the fibre-trapping mechanisms of Sirospun are enhanced. Several methods were evaluated in a joint development between CSIRO, WRONZ and IWS and the CSIRO method was adopted because of better performance at lower cost. A great advantage of Solospun is that the attachment can be quickly added or removed from existing spinning frames without the need for additional drive shafts or components. Unlike Sirospun, the method operates on a single strand. It would degrade spinning performance compared with spinning a singles yarn with 35 fibres in the cross-section. However, with (2 x 35 =) 70 fibres, spinning performance is much improved relative to singles or Sirospun. As a result, spinning speeds can be increased and lower twist factors (down to metric twist factors of 100, and possibly lower when using long fibres) can be used or fewer fibres (down to about 60). Solospun can thus lead to both higher production and finer yarns than Sirospun and the lower twist significantly reduces the streakiness problem.

Figure 15.1a Solospun components. Source: CSIRO Textile and Fibre Technology.

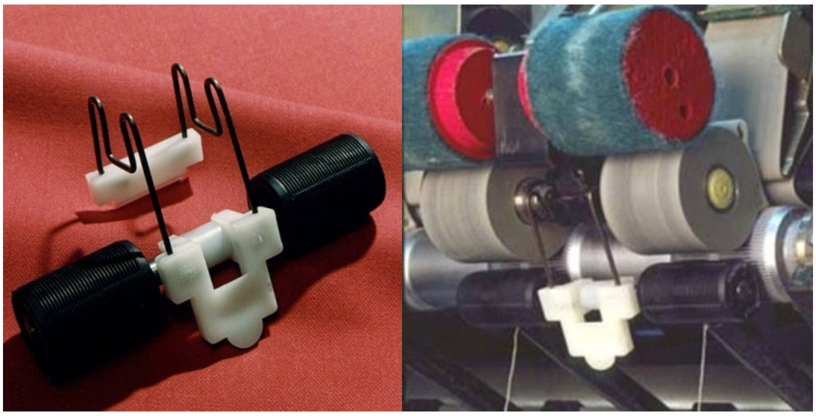
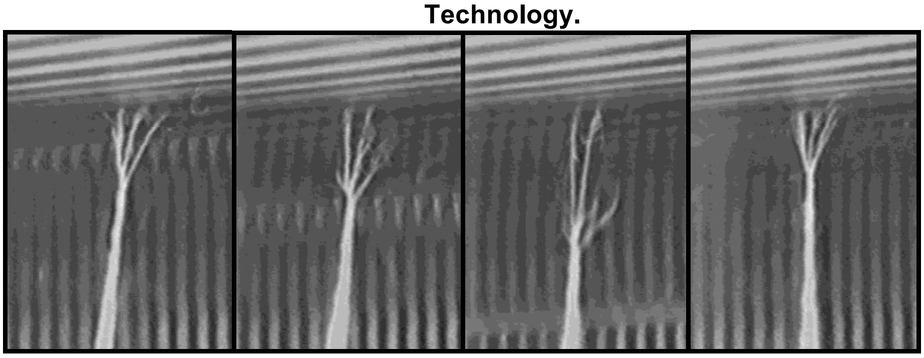
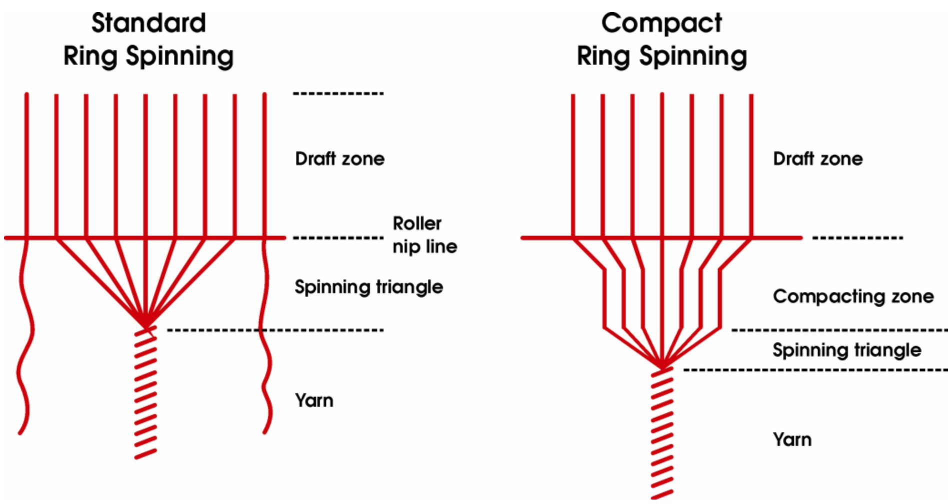


Figure 15.1b Splitting of strand in Solospun. Source: CSIRO Textile and Fibre Technology.



A different approach to improving spinning performance was to make modifications aimed at reducing end-breaks. It was argued that most breaks occurred at the spinning triangle where there was less twist and where the load was not shared equally between the fibres – higher loads being borne by the more highly tensioned outer fibres. A number of ways of compacting the drafted strand before insertion of twist have been developed and can be collectively referred to as Compact spinning. The added compacting zone uses air or mechanical means to reduce the width of the drafted, but untwisted, fibre stream to almost the same diameter as the yarn; see Figure 2.

Figure 15.2 Compact Spinning Principle. Source: CSIRO Textile Fibre Technology.



In conventional ring spinning, the drafted fibre stream has a width of a few millimetres. The compact spinning systems reduce the width and length of the spinning triangle which improves the sharing of the load amongst the fibres, and fibres are trapped sooner and more reliably with fewer fibres being lost. The result is a less hairy and slightly more even, and therefore stronger, yarn. It is claimed that higher production rates than equivalent conventionally spun yarns are therefore possible which would reduce the cost of spinning if it were not for the added capital cost. *The reduced hairiness does not automatically mean that the fibres are more securely bound and less prone to rubbing up in subsequent processes. Theory says that the wide spinning triangle increases fibre migration, the movement of fibres between the central and outside layers of the yarn, which is a key aspect of binding of fibres. Lower hairiness does not necessarily reduce prickle from coarse fibre ends because the shorter distance to the free end means the fibre end is less able to buckle.*

There are currently four variants of the condensed spinning system available from different spinning machine manufacturers. Variants of the systems have been developed for short-staple (cotton) spinning sector and for worsted spinning. The first system exhibited for wool appears to have been that by CSM (Hechtl 1996). The four current variants are as follows.

1. An apron system where air is drawn through a central line of small holes to consolidate the fibre stream (Zinser). The apron can be either above or below the fibre stream; an example is shown in Figure 15.3.
2. A large diameter, perforated roller system (Rieter and Cognetex). The perforations are situated in a central line around the circumference of the large diameter roller; Figure 15.4.
3. An air-permeable mesh apron system (Suessen). The air-permeable mesh apron runs over an elliptical suction tube containing a slot, or slots, which may either be parallel to the fibre stream, or offset at a small angle to the fibre stream to effect consolidation of the fibres. Figure 15.5.
4. Mechanical compaction using an angled roller in conjunction with a zone of negative draft (Gaudino).

Figure 15.3 Compact Spinning system – Zinser 451 C³ (CompACT³). Source: Zinser/Saurer, Switzerland.

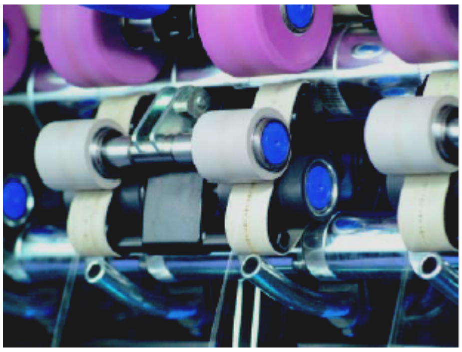


Figure 15.4 Compact Spinning system – COM4 WOOL. Source: Cognetex, Italy.

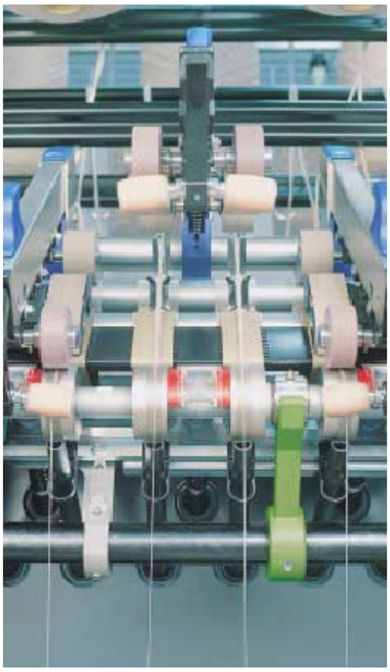
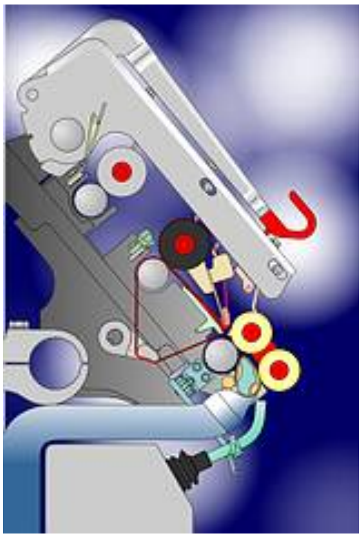


Figure 15.5 Compact Spinning system - EliTe® CompactSet-L. Source: Suesson, Germany.



Collapsed balloon spinning

The tension on the yarn imposed by the traveller controls the balloon and this tension is normally transmitted all the way to the spinning triangle. However, a system known as the collapsed balloon system, adapted from woollen spinning, can significantly reduce the tension at the spinning triangle. The collapsing of the balloon is achieved by passing the yarn around a spindle finger attached to the top of the spindle; Figure 15.6. The forming yarn is looped once or twice around the slightly bent spindle finger creating a capstan effect. This prevents the yarn balloon from forming such that the yarn path spirals around in contact with the bobbin (or the yarn that has already been wound onto the bobbin) before passing through the traveller and also being wound onto the bobbin. The full amount of yarn twist is positively inserted at the spindle crown (bent finger) and the yarn passes straight up to the pigtail guide and spinning triangle. The tension above the crown only has to be enough to prevent a new balloon forming in the straight segment. Tension measurements have shown that the mean yarn tension above the spindle finger can be reduced to about 1/5 to 1/10 to that of equivalent yarn without a spindle finger. However, with the same traveller the yarn tension will be as high or higher at the traveller than for the conventional system. A slightly lighter traveller can be used because the collapsed balloon provides less centripetal force. Most of the advantage comes from reducing the tension where the yarn is still forming. The shorter segment near the traveller can withstand higher loads. Spinning speeds can therefore be increased. A disadvantage of the yarn-to-yarn contact during spinning is the teasing out of fibre ends from the yarn surface resulting in an increase in fibre ends protruding from the yarn surface; i.e. an increase in yarn hairiness. The method needs larger diameter spinning tubes (in order to fit over the bent finger) and modified arrangements at start-up, for piecening and doffing, to trap or release the yarn from the bent finger.

Figure 15.6 Partially collapsed (bent-finger) FP99/260 spinning frame.
Source: Gaudino, Italy.

EliTwist (Brunk 2004) is the combination of Sirospun and compact spinning. The two strands are separately compacted using angled slots underneath a perforated apron. The slots are angled towards each other so that the two-strand spinning triangle is reduced. This reduction will improve spinning performance but should also reduce the fibre-trapping mechanisms and so reduce abrasion resistance in weaving (unless the compaction somehow enhances fibre-trapping). So far the combined system appears to only be offered for short-staple spinning.

Improving quality

The double apron drafting system of worsted spinning frames has been essentially unchanged over the last fifty years apart from modifications to simplify the replacement of the bottom apron, to simplify loading and releasing of the drafting arms, and the use of new materials. No-one has found a better way of gently restraining fibres while allowing drafting. In fact, it can be shown that the evenness of fine drafted strands approaches (but does not reach) the statistically possible limit. Maintenance of components and machine settings becomes increasingly important as finer yarns are being spun as does the quality of the roving particularly in terms of rare faults (e.g. from earlier sliver joins) and entanglements that may disrupt drafting on the spinning frame.

Drafting in woollen spinning is quite different. The hooked and disoriented fibres which give character and bulk would severely disrupt the smooth flow of fibres at a draft of 20. Instead a draft of about 1.3 is used, which is predominantly an aligning and de-crimping of the fibres. In mule spinning long lengths of forming yarn are first drawn out and twisted as the spindle carriage withdraws then wound onto the packages as the carriage returns. There is some evidence that as more twist flows into the thinnest places the thicker places are preferentially drafted thus making the yarn slightly more even than the normal statistical limit. This mechanism is known as draft against twist.

In order to reduce creeling and aid automation there have been a number of attempts at using very high drafts (100 to 400) to feed sliver directly from a can to the spinning frame. This requires two zones of high draft (i.e. 20 x 20), also known as two-stage drafting. The problem is that successive drafts in the same direction amplify any irregularity introduced in the first stage whereas the strand reversal that occurs between the conventional roving and spinning stages inhibits this amplification because the variable fibre length washes out the bunching of fibre leading ends (Lamb and Junghani 1991).

A key aspect of improving quality is the ability to benchmark existing performance even when the input fibre properties and yarn parameters are continually changing. A know-how package that could successfully predict best practice performance for worsted spinning was developed well in advance of any for short-staple spinning (Sirolan Yarnspec, Lamb & Yang 1997). The software package does not identify the reason for under-performance but has been used as a tool to distinguish causes (e.g. damage in dyeing) from variations in the quality (e.g. fibre diameter) of the raw material.

Savings by automation

In high labour-cost countries it is essential to minimise the amount of operator time needed to look after each spindle. It is now possible to purchase ancillary equipment that will sort empty spinning bobbins, load them on a conveyor, deliver them to the spinning frame, doff the full bobbins onto a conveyor and transport them to the winding frame via an intermediate steaming operation if necessary. A supply of full bobbins will be kept up to the winder, the yarn ends will be found and a new bobbin placed into the winding head and spliced to the end of the yarn package while the empty bobbin is returned for sorting. It is even possible for the system to keep track of from which spindle the bobbins came and use the winding sensors to measure yarn quality then to automatically generate reports that identify potentially faulty spindles on the ring-frame.

Conveyor systems have also been developed for delivering full roving packages and automatically mounting them on the spinning frame (creeling). These are currently limited to large mills with long runs of identical material, which tend to be cotton mills, whereas worsted mills tend to have small batches.

Automated end-break repair (piecening) is available and is in use in some mills. Because of its complexity, and therefore cost, one unit will travel along a rail and service a large number of spindles. Many frames also have end-break detection (usually by monitoring the regular passage of the traveller around the ring), these can activate a light to call an operator or electronically signal the automatic piecener. They can also activate a roving stop motion so that material does not begin to, or continue, to lap the drafting rollers. End-break detection can be used to monitor spinning performance and can be coupled with automated speed control of the spinning frame to maximise production for an allowed end-breakage rate.

The potential for automation has become so complete that it has been joked that a whole spinning mill could be run with just one man and a dog. The dog is there to guard the mill and the man is there to feed the dog!

Adding synthetics

Spinning performance can be improved and new fabrics with advantageous properties can be produced by combining wool with synthetic fibres. The synthetic can be cut into staple fibres of similar length to the wool and must be blended as uniformly as possible with the wool. The blending usually happens after dyeing because the synthetics and wool mostly require different dyes and dyeing conditions. These mixtures are called intimate blends. The most common blend for weaving yarns is with polyester. Usually, the mean diameter of the polyester is slightly finer (typically 2µm less than the wool), the diameter distribution lower and the mean fibre length slightly longer. The polyester fibre has a markedly higher tenacity than the wool fibre but the initial modulus of the load/elongation curve is fairly similar. The finer, longer, stronger polyester fibres significantly improve spinning performance relative to pure wool yarns of the same tex and consequently these yarns tend to be spun at speeds close to the limits imposed by the ring/traveller velocity or by localised heating on the balloon control rings. For knitwear it is more common to use (higher bulking) acrylic in staple fibre blends.

Blends can also be made by adding filaments during spinning, plying or on the knitting frame. Nylon, in particular, is often added during hosiery knitting, for example in socks. It has fairly similar dyeing properties to wool and so dyeing can occur before or after knitting. Ring-spinning frames can be modified to have a multi-filament strand fed in behind the front rollers which then gets spun in as part of the normal spinning process (for example EliCore Twist®, http://www.suessen.com/54.html). There are also special spinning machines (hollow spindle spinning) in which continuous filaments are wrapped around a core of untwisted staple fibres.

Sirospun lends itself to bi-component spinning in which the two strands can be of completely different fibres or just of different colours. It also has a unique advantage for blends of wool with continuous filaments. If the multi-filament strand is fed in line with one of the two wool strands *(which one depends on the direction of yarn twist)* then the wool provides excellent covering for (hiding of) the filament and very effective binding that prevents "strip-back" whereby the wool fibres are rubbed along the filament and into lumps in subsequent processes. This method has been widely adopted for producing stretch weaving yarns using an elastomeric filament (e.g. Lycra®). These yarns were the key to making tight-fitting wool-rich stretch jeans or trousers when fashion required.

Woollen

There have been far fewer developments in woollen spinning, primarily because it is a much smaller market and so wool specific that developments in short-staple spinning are not relevant. *There have been increases in automation and a re-vamped mule-spinning machine was released (http://www.s-bigagli.it/Inglese/prodg-e.htm). An alternate drafting system (Delpiano SNC, Italy) was introduced in which the pair of front draft rollers also rotate within an outer cylinder. In this way the false twist carries all the way to the roller nip giving improved fibre control and slightly more even drafting*

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Exotic improvements

In the early stages of drawing there is a procedure called auto-levelling. During gilling the input sliver density is monitored and the draft is then varied a short time later in order to achieve an output sliver of more nearly constant weight. An extensive investigation (Johnson 1994) has been made to see whether the same principle, feedback to beat the random limit, could be applied to the drafting head of a spinning frame. The answer is that it is possible, in principle, but needs accurate, drift-free sensors and fast-acting control motors, and consequently is unlikely to be commercially feasible on such a low production unit as a single spindle.

More than one hundred years ago the idea of rotating rings was first put forward. The idea is that, if the ring is driven in some way, then the relative speed between ring and traveller will be reduced allowing higher speeds. This can potentially overcome the tribo-mechanical metal-to-metal speed limit but does not, by itself, reduce the centripetal force or the tension needed to control the balloon. None of the implementations has survived commercially.

A development which combines the rotating ring concept and cap spinning is Cerifil (Oxenham & Huang 1992). Cap spinning was an alternative to ring spinning that has now died out. The forming yarn passed down through a central guide and then slid or ballooned over the outside of an inverted cylindrical bowl and under the rim onto the yarn package. The bowl was stationary but either it or the bobbin was vertically traversed to build the package. In the Cerifil system a lightweight cap is driven by the yarn. The system looked promising but it is believed that the difficulties of doffing and piecening rendered the implementation too complex
.
Another idea that has been tried in various forms is to provide additional false-twist in the region of the spinning triangle, for example, by using an air-jet nozzle or a rotating yarn guide. In this way the forming yarn is given additional strength in the region of the spinning triangle. None of the implementations seems to have taken off commercially and, to some extent, their potential advantages have been supplanted by compact spinning.

Basically, ring-spinning only lends itself to low-cost, easily automated, highly reliable improvements.

15.4 Post-spinning yarn preparation

If a length of yarn is pulled off a freshly spun bobbin and un-tensioned then it will tend to snarl, that is twist back on itself. It is said to be twist-lively. It was therefore routine practice to steam newly spun yarns. The temperature and moisture takes the wool above its softening (or glass-transition) temperature, it then relaxes and loses its tendency to un-twist. *Under normal steaming conditions this is what is called a temporary set in that, if taken out of the yarn and dipped in warm water, the fibres would not only untwist but try and take up the crimp they had in the fleece (or when last permanently set e.g. by dyeing)*. Nowadays, the tension control mechanisms on the winders have been greatly improved and they can easily handle knitting yarns (low twist) and sometimes weaving yarns without snarling causing problems. Steaming is generally a batch operation, energy expensive and can lead to fibre damage and dyeing problems. In addition, better splices can be made in unsteamed yarns (Prins & Lamb 1992). Steaming is still the norm but if the yarn is going to be two-folded (and become twist-balanced) it is now avoided where possible.

Apart from steaming, the next step after spinning is the combined operation of winding and clearing. The relatively small lengths of yarn on each bobbin are wound into large packages of a set length (and weight) on cones at speeds of up to 1200m/min. Hence, one winding head can look after the yarn from many spinning spindles. The winding of the yarn into large packages is carefully controlled to avoid patterning which may affect dye uptake or induce tension peaks when the yarn is pulled off end over end. As the yarn is wound it passes through a sensor or sensors called a clearer. The clearer senses the yarn linear density (capacitively) or the thickness (optically) and the latest clearers can also monitor for coloured contaminants and a separate sensor for measuring hairiness is available. The sensors monitor both the size and length of faults and the operator can select the combinations that will be cut (cleared) from the yarn. This can be done for thin, thick and coloured places. The total faults measured and cut-out from each yarn batch can be monitored. *For ease of understanding the thick place faults can be divided into a number of categories: neps, short thick and long thick. These fault categories tend to have different causes but do not necessarily have an immediate relationship to the similar categories measured in a top or by a yarn evenness tester in the testing laboratory. This is a subtle point that needs to be appreciated by mill quality control staff. The faults labelled as neps in the top are generally too small to be counted as neps in the yarn. However, the faults counted as neps by a laboratory yarn evenness tester tend to be loose accumulations of fibre (called "fly" but not actually arising from air-borne fibre) and the number detected often has a strong correlation with the number of much larger short thick places that* *are cut from the yarn during winding. The lesson is that the name of the fault category does not necessarily give the cause. This can only be established by investigations which include collecting examples of the different fault categories. For example, it might be found that most long thick places are bad piecenings. In some trials it has been found that excessive long thick places have arisen from not increasing the ratch on the roving frame when processing longer than normal fibres. In other trials it was found that poor (disrupted) web edges in combing and overloading of the gill boxes after combing could both lead to more neps and short thick places in winding.*

The development of the first sensor for coloured contaminants has an interesting history. Siroclear was developed at CSIRO as a means of detecting and removing vegetable matter from wool yarns (Lamb et al. 1988 and Siroclear patents). The principle is quite simple. Undyed wool fibres behave a lot like very fine glass rods that appear white because they scatter light. When diffusely illuminated from all directions they almost disappear against a white background. The sensor worked so well that when it was implemented it found all sorts of other coloured faults and, in particular, dark fibres. The largest existing manufacturer of yarn clearers was approached to commercialise the device and they sent cotton yarns to be evaluated. A number of coloured faults were found in these yarns but the manufacturer approached cotton spinning mills and they said that coloured contaminants were not a problem. After further efforts an alternative manufacturer, Loepfe, became interested and very successfully commercialised the sensor with more than one hundred thousand being sold worldwide. It turned out that the coloured faults were "not a problem" in the sense that they were something that you just had to live with. Once a detector was available the economic attractiveness of automated removal from the yarn versus manual mending from the fabric led to a very rapid uptake of the technology.

If a fault is detected the clearer activates a cutter, winding is halted on that head, the yarn package is reversed until the yarn end is found and a metre or so length sucked off. The two ends are then crossed over and laid into a splicing chamber, trimmed and spliced after which winding resumes. Until relatively recently, yarns were joined with a knot rather than a splice, but a knot is a fault that, in wovens, has to be pushed to the back of the fabric and trimmed during mending. As splicing quality and splice reliability in downstream processing improved then splicing replaced knotting except in some difficult to splice yarns. A key improvement for splicing of wool (or any animal fibre) was the invention of the Thermosplicer® at CSIRO (Plate 1988 and Thermosplicer patents). It is an air-jet splicer that uses hot air. The burst of heat takes the yarn above its glass transition temperature (because the moisture in the yarn takes time to escape) making it easier for the yarn ends to be opened, for the fibres to be entangled and then set into the spliced configuration.

The spinning frame can be linked to the winder by having the automatic doffing system load the bobbins onto carriers which are transported with a conveyor system. Some convenors tip the bobbins into bins that are taken to the steamer. Steaming normally involves a double cycle in which a pressure chamber is evacuated then steam introduced and the cycle repeated. Afterwards the bobbins must be sorted, re-oriented and loaded back onto a conveyor. Consequently, in-line steamers have been developed which treat bobbins while still on the conveyor. Steaming is not as effective but can be sufficient to avoid problems with snarling.

In cotton spinning, singles yarns are sized for weaving. A starch (size), which is a glue that is soluble in warm water, is added to the yarns to help them survive the abrasive action of weaving. Afterwards the glue is washed out of the fabric. For wool yarns an alternative method of avoiding abrasive failure was adopted. The yarns are two-folded; a pair of singles yarns are twisted around each other. For weaving yarns it is normal to insert a similar number of turns/m in the two-fold yarn as in the singles (*the singles will typically have a metric twist factor of 90 and the two-fold a metric twist factor of 120 to 130*). Many knitting yarns are also two-folded but only about 55% of the number of turns/m is inserted (*the singles will typically have a metric twist factor of 70 to 80 and the two-fold a twist factor of 50 to 60*). This amount of twist is just enough to make a torque-balanced yarn that has no tendency to twist or snarl when tension is released. The two-fold twist can be inserted by either a ring twisting frame or by a two-for-one twister.

Two singles yarns can be laid side by side and wound onto a new package ready for two-folding. This step is called assembly winding and was used to prepare a double yarn feed for knitting or a single package for two-for-one twisting. Yarns for knitting are waxed on this machine if not already waxed in the previous winding. The ring twister is similar to a ring spinning frame except that there are no drafting arms and each spindle is fed from two or more yarn packages via tensioners and a delivery roller. The doubled yarn is inherently much stronger than the singles yarn in the spinning triangle so that speeds can be considerably higher except that larger packages are spun on bigger spindles with heavier travellers. The two-for-one twister takes two yarns and feeds them down through a hollow spindle and then completely round the package(s), which is magnetically suspended, in a balloon and up onto a winding head. The central package is held stationary while a lightweight arm and rotating pot drive and form the yarn balloon. The method is difficult to picture but causes two turns of twist to be inserted for each rotation of the balloon – hence the name. It is a higher production system with lower costs than ring twisting and has become standard for weaving yarns particularly in the clip-cone version where two singles yarn packages are mounted one on top of the other, eliminating the need for assembly winding. Lubricant is normally added to the yarns as they pass into the hollow spindle on which the package(s) are mounted. If the yarn is for sale, the completed packages may be steamed but are weighed, measured for moisture content and packaged for sending to the customer (e.g. a knitter).

Readings

The following readings are available on CD

1. Oxenham, W. and Cagle, C. 2005. Developments in worsted spinning. Textile Asia, January, pp. 38-46.

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Summary

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Insertion of twist is very expensive and because production per spindle is so low, ring spinning is more expensive than the total cost of all the processes from scouring up to the spinning frame. However, it is a good method of uniformly twisting straightened fibres and produces a yarn with the desired attributes. Improvements to ring spinning have mostly resulted in modest increases in production and performance (quality) or cost reduction. Avoiding the need for two-folding of yarns by producing a weavable singles yarn (Sirospun, Solospun) has allowed significant cost savings but the yarns still have some deficiencies. Compact and collapsed-balloon spinning allow higher spinning speeds and both Solospun and Compact spinning offer significant reductions in hairiness. Solospun replaces a two-fold yarn while Compact is an improved singles yarn. Solospun appears to offer better binding of surface fibres while Compact offers slightly higher speeds or less twist and better evenness but still needs two-folding to be fully weavable. Wool/synthetic fibre blends can be intimate (staple fibres blended before re-combing) or can use a synthetic filament fed in during spinning. A key application has been to use an elastomeric filament to provide stretch in woven fabrics. After spinning there are the processes sof winding and clearing to produce large fault-free packages, waxing to reduce friction in knitting, twisting (folding several yarns, usually two, about each other in an additional twisting step) and steaming (to remove twist liveliness).

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Glossary of terms

Clear	detect and remove yarn faults during winding
collapsed balloon	a yarn balloon that wraps around the spinning bobbin
compact spinning	any method that has an extra zone after drafting to compact the strand before twist insertion, and thus greatly reduce the spinning triangle, yarn hairiness and lost fibres
Creel	the part of the spinning frame where the roving packages are mounted, or the action of placing new roving packages on the spinning frame
Doff	to remove the full yarn bobbins from their spinning spindles
Draw	to reduce the top sliver down to a much finer sliver (roving) prior to spinning
Ecru	undyed i.e. clean, naturally cream-coloured wool
Piecen	to re-join a yarn after a break in spinning
Size	to apply starch to warp yarns to bind surface fibres so that the yarns can survive weaving
two-for-one	to insert two turns of twist for every rotation of the yarn about the suspended stationary package by taking the yarn through the middle of the package and then in a balloon around the outside
Wind	to join the yarn from spinning bobbins into much larger packages using knots or splices (usually combined with clearing)