16. Latest Developments in Spinning and Non-wovens

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Learning objectives

On completion of this topic you should be able to:

- Describe the latest developments in worsted spinning including ring, collapsed balloon, air condensed and compact spinning
- Outline bicomponent yarns, two-folding, winding and clearing
- Compare the latest developments in ring spinning including open-end or rotor spinning, air-jet spinning, DREF friction spinning
- Describe developments in non-woven processing
- Outline the physical limitations of processing non-wovens
- Describe cross-lapping, and compare bonding systems such as needle punch, stitch and hydroentanglement

Key terms and concepts

Ring spinning, self twist, weavable singles, collapsed balloon, air condensed, compact spinning, bicomponent yarns, winding, clearing, two-folding, twisting, alternatives to ring spinning

Non-woven, cross-lapping, bonding systems, needle-punch, stitch bonding, hydorentanglement

Introduction to the lecture

Spinning is the conversion of fibre or filaments into a continuous strand by the insertion of twist. If you have ever observed a hand spinner, you will have noted that the fibres are gradually teased out between the thumb and forefinger of one hand from a bulk fibre supply held in the other hand. In order to hold the teased out fibres together to make something useful out of the fibre assembly, the fibres are twisted together by the rotating action of a spinning wheel or some other rotating device, hence the term *spinning*. Historically, this was performed by women referred to as *spinsters*. With the introduction of spinning machines during the 18th century (machines to mechanically insert twist into an assembly of fibres) the process became more complex. In order for the spinning machines to tease out the fibres (referred to as *drafting*) before twist insertion to produce a uniform yarn, steps to prepare the fibres prior to spinning became necessary. In the worsted spinning industry, these steps are referred to as *drawing*, and the steps in drawing are designed to draw the weight per unit length of the fibre assembly down gradually to produce a fine, uniform worsted yarn. Depending on the quality of the fibre and the fineness of the yarn to be spun, drawing may consist of three or four steps. An intermediate step is still required between drawing and spinning and the product of this step is known as *roving*. Roving is a lightweight, untwisted or lightly twisted, continuous assembly of fibres that is introduced to the spinning frame for drafting and twisting to form a yarn.

In nonwovens processing fibre is converted directly to fabric in a single continuous process. The wool inputs are usually similar to those chosen for woollen processing, i.e. shorter fibre than for worsted and usually free of vegetable matter and so carbonised wool and broken top is used. Broken top is shorter wools that have been combed to remove VM, very short fibres and neps and is expensive compared to carbonised wool. As with woollen processing, it is also possible to piece-carbonise the fabric having made it with low VM wools but this is rare and the VM may cause other problems in the nonwovens plant if it is not dedicated to this wool process. Blends of wool and synthetic fibres are also possible; a huge range of fibre blends are commonly used in nonwovens processing.

16.1 Ring spinning

Figure 16.1 Ring spinning. Source: CSIRO TFT.

Ring spinning (Figure 16.1) remains the dominant form of spinning used for wool, primarily because it is seen to produce a superior yarn to alternate spinning systems. Several improvements to long staple ring spinning have been developed; examples are:

- compact or condensed spinning – the claimed benefits include improved yarn strength and elongation, reduced yarn hairiness, improved weaving efficiency and less fibre attrition during knitting;
- collapsed balloon spinning – with this system, higher spinning speeds are possible;
- Sirospun produces a two-strand yarn in a single step from two roving strands;
- Solospun produces a weavable singles yarn in a single step from a single roving strand.

Open-end (OE) spinning, air-jet spinning and friction spinning systems are available for wool but have not found wide adoption. Short wool (40 to 45mm) is being spun on the OE system but the speeds achievable are not as high as for cotton. Contaminant build-up in rotors is cited as a problem.

Just as for the spinning of cotton and synthetic fibres, there has been a big move to automation in worsted spinning. Automatic doffing of full spinning bobbins has become standard where the full bobbins are removed from the spindles and replaced by empty bobbins. The empty bobbins are presented to the spinning frame on a conveyor and the full bobbins are taken away by the same conveyor. Using this conveyor system, the spinning frames can be directly linked to winders. However, one problem that has had to be overcome in worsted spinning is that wool singles yarns are normally steamed before winding to reduce twist liveliness. Several companies have introduced in-line steamers where the bobbins are transported from the spinning frame through the in-line steamer on a conveyor before being presented to the winder. At the same time, winder manufacturers have also improved their machines to allow winding of twist-lively yarns by maintaining the yarn ends under tension. As part of the winding operation, pneumatic splicing is routine for wool yarns and quality splicing is particularly important for weavable singles yarns, where hot air splicing (Thermosplicer - Schlafhorst) is recommended.

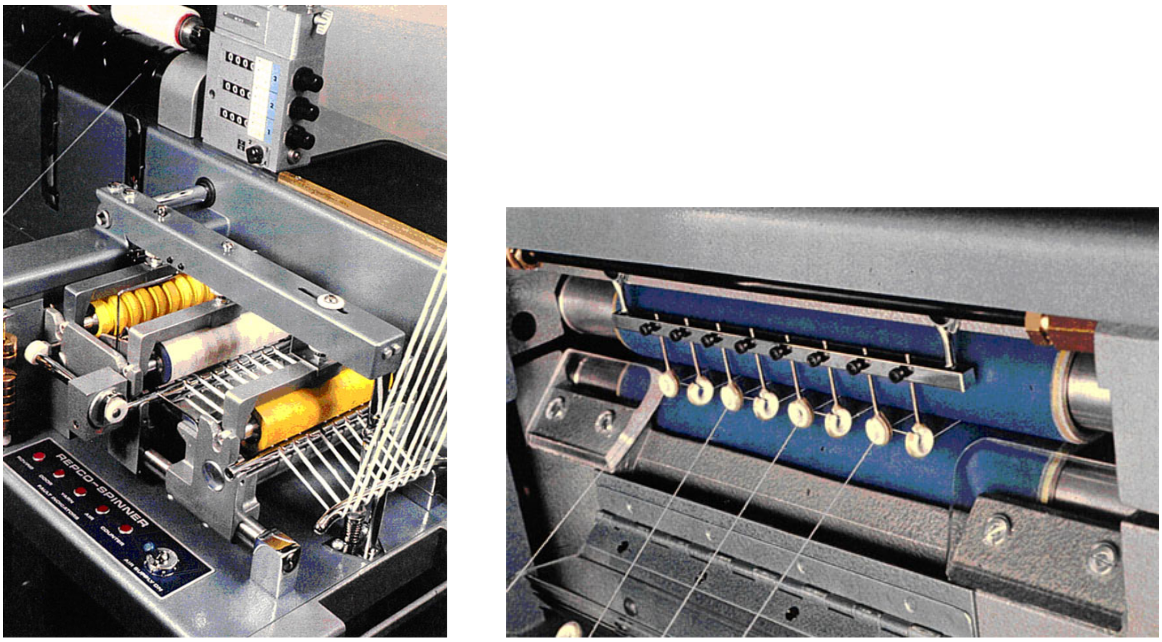
Two-folding in the form of ‘2-for-1’ twisters (rather than ring-twisting) has become the standard method of producing folded wool yarns.

There is strong demand to bring quality control in spinning on-line but at the moment it seems that it is too expensive to be introduced on the spinning frame apart from the detection of ‘ends-down’. However, on-line quality control remains an important part of the winding process. Although coloured fault detection was first developed to remove vegetable matter contamination in ecru wool, the technology has achieved large penetration in both the worsted and cotton sectors. Yarn hairiness can also be measured on-line during winding. Moreover, it is now possible, with electronic tagging of bobbins, to measure yarn quality in winding and generate a list of individual spinning frame spindles that need attention. In general, the demand for automation is increasing in high labour-cost countries while there has been a very marked trend for spinning to move to the low labour-cost countries in Asia and Eastern Europe.

16.2 Self-twist

Self-twist yarn is produced by inserting alternating twist into each of two drafted strands of fibre and immediately bringing them together so that in trying to untwist, they twist about each other (Figure 16.2). This spinning system was developed at CSIRO Textile & Fibre Technology and was first exhibited at the International Textile Manufacturers Association (ITMA) Exhibition held in Paris in 1971. The most convenient way of spinning staple fibres into such a yarn involves the use of a pair of rubber-covered rollers which both rotate and axially reciprocate in opposition. In this procedure, two strands of wool rovings are drafted and passed between the reciprocating rollers so that short sections of each drafted roving are twisted in one direction, and the next short section is twisted in the opposite direction, and so on. As the strands emerge from the reciprocating rollers they are immediately brought together, each strand then becomes twisted about the other to form a stable two-ply yarn. The action of the reciprocating rollers results in a short length of each strand having a twist reversal zone. To avoid the twist reversal zones being aligned when the two strands are brought together, the path lengths of each strand pair differs, resulting in the twist reversal zones being off-set. As produced by the self-twist spinning machine, the yarns are suitable for knitting. However, in the commercial implementation of the process to produce weaving yarns, the wool self-twist yarn still requires a further twisting operation. Production speeds for self-twist yarns are up to 200 m/min. A typical four package machine is therefore equivalent to more than 50 spindles of a conventional ring spinning machine, which results in significant savings in floor space and energy.

Figure 16.2 Self-twist spinning. Source: CSIRO TFT.



Recently Macart Spinning Systems (UK) incorporated the self-twist spinning in their knitting yarn production system. In a continuous operation, this system manufactures yarn directly from slivers where the self-twist yarns are steam relaxed to introduce bulk in the yarn through fibre relaxation before being wound onto yarn packages. Production speeds up to 300 m/min are claimed.

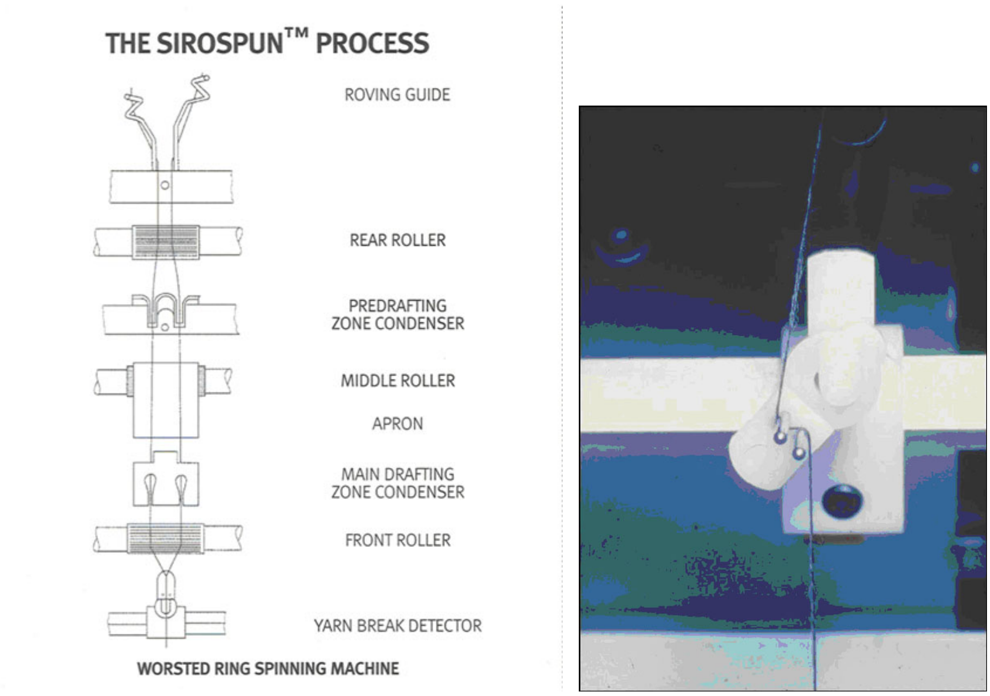
16.3 Weavable singles – sirospun to solospun

The evolution of Sirospun saw the adaptation of some of the self-twist discoveries to the ring-spinning technology of the worsted system. Traditionally for weaving, two singles ring-spun yarns are twisted together to form two-fold yarns. Twisting together to produce the two-fold yarns binds the surface fibres of the singles yarns into the twisted structure so that it is smoother and more resistant to abrasion during weaving. CSIRO Textile and Fibre Technology developed the Sirospun system which in essence is the combination of spinning and two-folding in a single step on the spinning machine. Sirospun uses the torque/friction forces involved in self-twist to bind two drafted roving strands together initially, and then applying twist to the two-fold structure in the conventional ring-spinning manner. Sirospun was formally released in 1980.

The earliest version of Sirospun involved the introduction of an additional roller just below the point of conversion of the two strands. This roller had a recess around part of its circumference, allowing the intermittent propagation of twist from the revolving spindle/bobbin along the two converging strands. The periodic variations in the twist enabled the binding together of the strands into a structure suitable for weaving. An elegant feature of the design was that if one strand broke, the other strand would be pulled out of the recessed section of the roller and also broken. A simplified procedure was then developed, but this needed a device to break out the remaining strand if one of the strands should be accidentally broken. A simple, effective break-out device was developed that acted as a twist block when pulled off centre by the remaining strand and breaking it.

Sirospun is especially suited to the production of light-weight, trans-seasonal 'Cool Wool' fabrics and was promoted by The Woolmark Company for this purpose. The system has two major advantages, the cost of two-folding is eliminated, and the productivity per spindle on the spinning frame is effectively doubled (Figure 16.3).

Figure 16.3 Sirospun spinning process and sirospun yarn break-out device.
Source: CSIRO TFT.



During 1998 a new spinning technology, Solospun™, was released and subsequently displayed at the 1999, Paris ITMA Exhibition. This technology was developed in collaboration between CSIRO Textile and Fibre Technology, The Woolmark Company and Canesis (formerly WRONZ), based on an initial clip-on, roller attachment developed at CSIRO. As the name suggests, Solospun™ is a spinning technology that produces a weavable singles yarn in a single step from a single roving. The Solospun™ technology is a simple, inexpensive, clip-on attachment to standard long-staple (worsted) spinning frames. The hardware consists of a bracket that holds a friction pad and a pair of Solospun™ rollers (Figure 16.4). The bracket clips on to the shaft of each pair of top front draft rollers of the spinning frame, with each Solospun™ roller being positioned just below and parallel to, but not in contact with, its corresponding top front draft roller. The Solospun™ rollers are rotated by being in contact with the bottom front draft rollers. Unlike Sirospun, Solospun™ is spun from a single roving strand, therefore there is no longer a need for a double roving creel or breakout devices. However, the principle of inserting twist into individual strands prior to twisting them together to trap fibre ends can be attributed to the knowledge gained during the development of Sirospun.

Solospun™ differs from condensed, or compact, spinning in both application and principle. It achieves fibre security through the actions of localised twist in sub-strands and fibre migration. Condensed spun yarns, on the other hand, may still require two-folding or sizing to be suitable as warp yarns. Less twist is required which reduces fabric streakiness and higher spinning speeds are possible with much better spinning performance than can be achieved when spinning the singles yarns needed for a similar resultant two-fold yarn. The overall result is a very significant reduction in yarn production time and costs.

As illustrated in Figure 16.5, the Solospun™ roller's operation is to interrupt the path of the drafted fibre strand, nipping it against the bottom front draft roller. The surface of the Solospun™ rollers is made up of four segments. As shown in the sequence in Figure 16.5, a 'land', which is flush with the roller surface and runs parallel to the roller axis, separates each segment. Between each land is a series of slots that are offset in each adjacent segment. The Solospun™ rollers act as intermittent twist blocks, preventing twist from reaching the fibres emerging from the front draft roller nip. The slots in the Solospun™ rollers divide the drafted fibre strand into a number of sub-strands as shown, which, through the intermittent twist-blocking action of the roller lands, converge at varied angles and rates to achieve a subtly entangled structure with locally differing twist levels. Figure 16.5 illustrates how the varied angles and rates are achieved in one-quarter turn of the roller. Following the sequence from left to right, new sub-strands are formed after the main, drafted fibre strand has been nipped by one of the roller lands. As the land rotates away from the nip point, the sub-strands move down into the slots. As this occurs, the angles between the sub-strands increase. The continuing changes in these angles result in increased fibre migration and fibre trapping. When the next land reaches the nipping point, a new set of sub-strands is formed in the offset slots of the following quarter segment. This process is repeated every quarter turn, so that, depending on their length, fibres may undergo many changes in sub-strand position during twisting into the yarn. This action confers greater fibre security as fibres are trapped by neighbouring strands and by migration within and between strands. Consequently, in comparison to equivalent singles yarns, Solospun™ yarns have fewer protruding fibre ends per unit length and increased abrasion resistance, making them weavable without the need for two-folding or weaving assists such as size, typically used in the cotton sector and increasingly used in the worsted sector.

Figure 16.4 Solospun components. Source: CSIRO TFT.

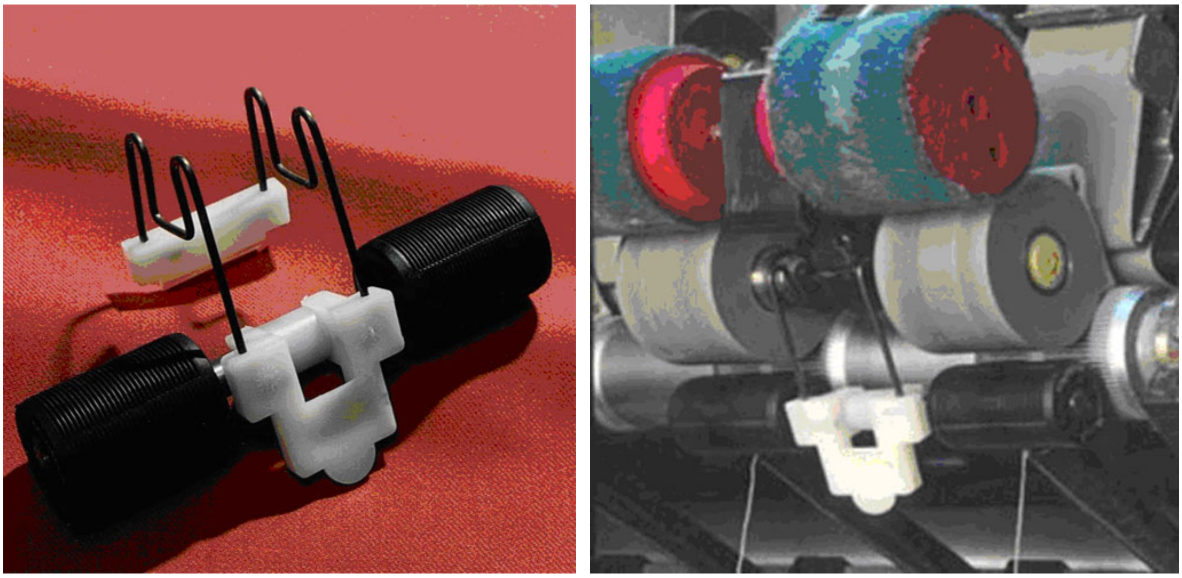
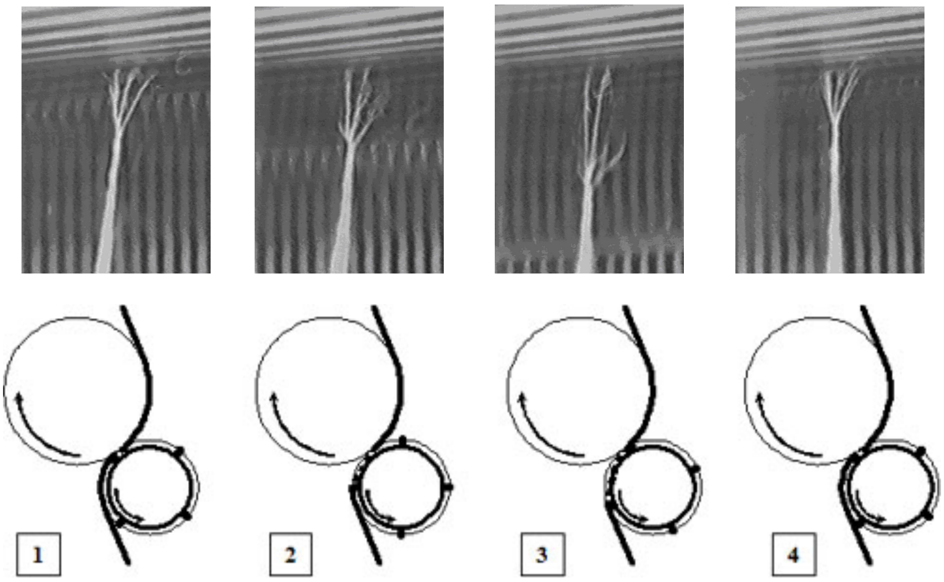


Figure 16.5 Solospun spinning process. Source: CSIRO TFT.



1: A set of sub-strands form as a Solospun roller land passes the bottom draft roller nip point.

2 & 3: The sub-strands move down into the slots and lengthen, varying the angles between each sub-strand.

4: A new set of sub-strands form as the next Solospun roller land passes the bottom roller nip point.

16.4 Collapsed balloon spinning

In conventional ring spinning, twist is inserted into a fibre stream to form a yarn through the action of a rotating spindle. As twist is being inserted in the yarn, it rotates around the spindle before it passes through a traveller that is rotating around and in frictional contact with a stationary ring. After passing through the traveller, the yarn is wound onto a bobbin. The spindle may be rotating at 10,000 rpm or more. As the yarn rotates around spindle, it balloons out. The yarn balloon is subject to air resistance as it is being rotated. This resistance puts strain on the yarn and is one of the limiting factors in production speed; friction between ring and traveller is another limiting factor. Over the last three or four decades, several attempts have been made to reduce the strain, or tension, on the yarn during spinning. One of the systems that has been adopted recently is known as the *collapsed balloon* system. This system has actually been adapted from the woollen spinning sector where a similar system has been in use for some time. By reducing or eliminating the yarn balloon, tension in the yarn is significantly reduced. Tension measurements have shown that the mean yarn tension above the spindle finger is about 1/5 to 1/10 to that of equivalent yarn without a spindle finger. The collapsing of the balloon is achieved by passing the yarn around a *spindle finger* attached to the top of the spindle; Figure 16.6. 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. One consequence 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 decrease in yarn tension can be utilized in a number of ways.

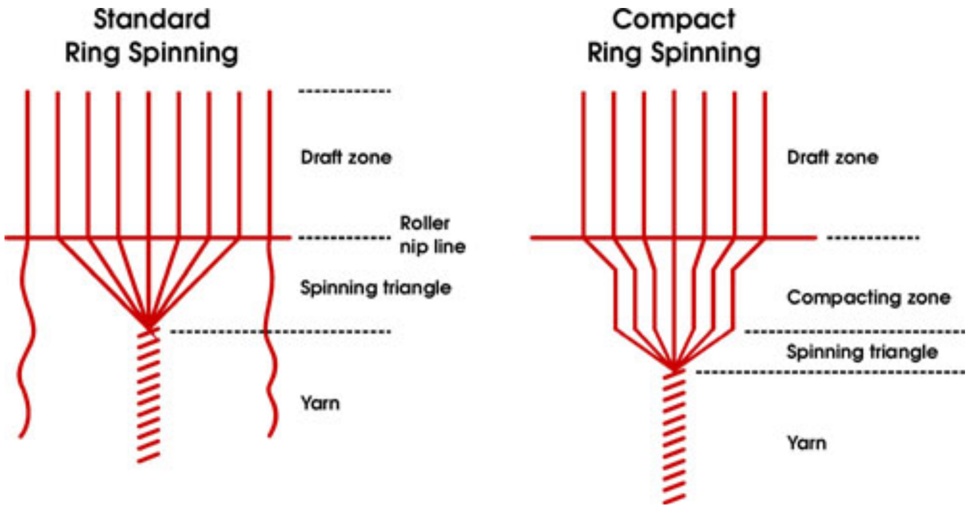
- Increase the spindle speed and hence increase yarn production
- Decrease the twist inserted, also resulting in an increase in production
- Spin yarns with fewer fibres in the cross-section resulting in finer yarns
- Substitute finer fibres with fewer coarser fibres (end product parameters permitting) to produce yarns of the same weight per unit length

Figure 16.6 Spindle finger. Source: Zinser (www.zinser-texma.com).

16.5 Air-condensed or compact spinning

The compact or air-condensed spinning system is an extra fibre stream control zone added to a spinning frame after the main drafting zone, before the twisting zone. The compacting zone uses air to reduce the width of the drafted, but untwisted, fibre stream to almost the same diameter as the yarn; see Figure 16.7.

Figure 16.7 Compact spinning principle. Source: CSIRO TFT.



In conventional ring spinning, the drafted fibre stream has a width of a few millimetres. Twist is inserted in this fibre stream as it emerges from the front rollers of the drafting zone. The action of inserting twist results in a consolidation of the fibres, but not necessarily all fibres, into the yarn. This consolidation results in the formation of a triangle, typically referred to as a spinning triangle. The air-condensed spinning systems reduce the width and length of the spinning triangle, improving the control of fibre ends, resulting in fewer fibre ends poking out of the yarn, i.e. the yarns are less hairy. Reducing, or condensing, the width of the fibre stream after drafting is achieved by using a controlled stream of air to draw the fibre closer together. It is claimed that in comparison to equivalent conventionally spun yarns, the condensing system significantly reduces yarn hairiness, improves yarn tenacity and results in more even yarns. It is also claimed that because condensed spun yarns are stronger and more even, it would be possible to spin them at higher production rates than equivalent conventionally spun yarns. This would reduce the cost of spinning.

There are basically three variants of the condensed spinning system. A number of variants (each manufactured by different spinning machine manufacturers) are used in the short-staple (cotton) spinning sector, and to date three systems have been adapted for wool worsted spinning. The three variants are as follows.

1. An apron system where air is drawn through a central line of small holes to consolidate the fibre stream. The apron can be either above or below the fibre stream; an example is shown in Figure 16.8.
2. A large diameter, perforated roller system. The perforations are situated in a central line around the circumference of the large diameter roller; Figure 16.9.
3. An air-permeable mesh apron system. 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 16.8 Compact spinning system Source: Zinser (www.zinser-texma.com).

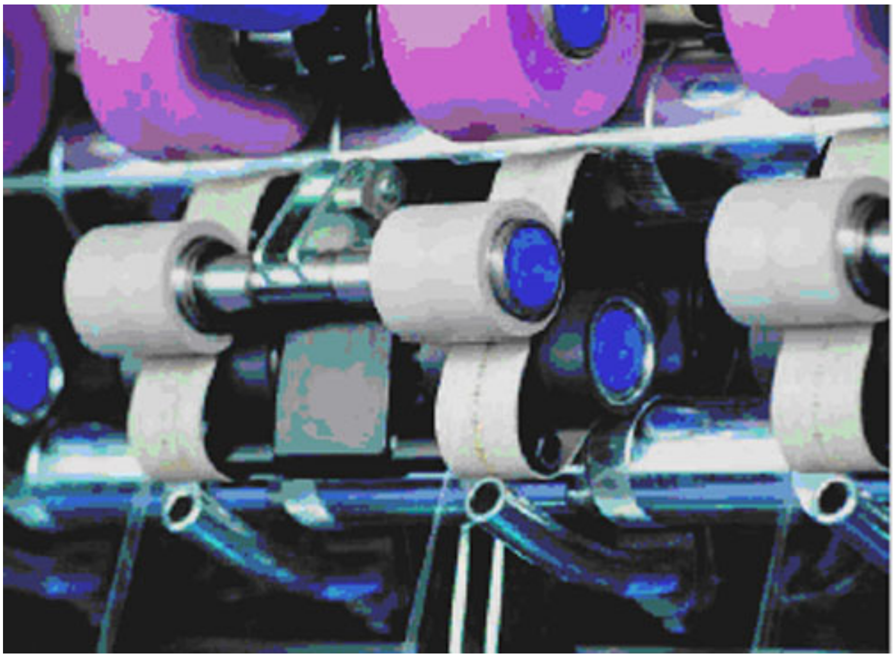
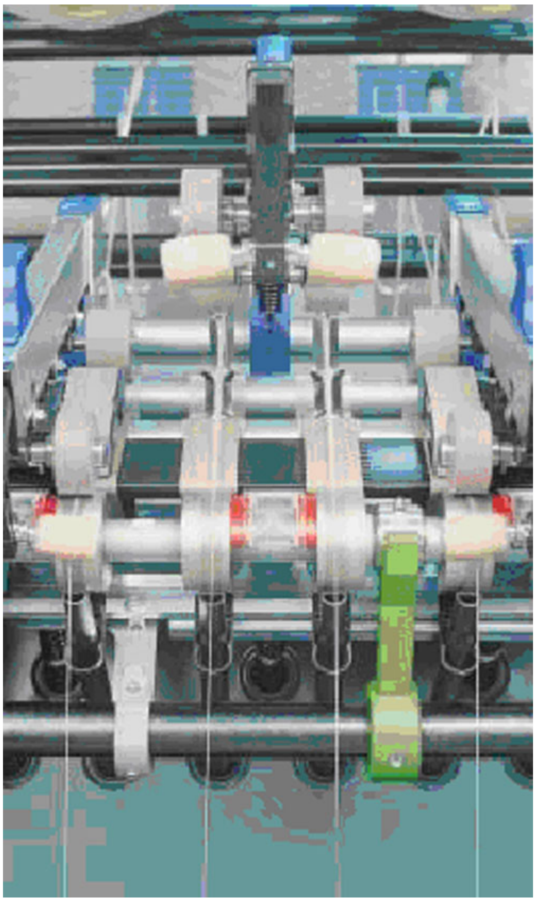


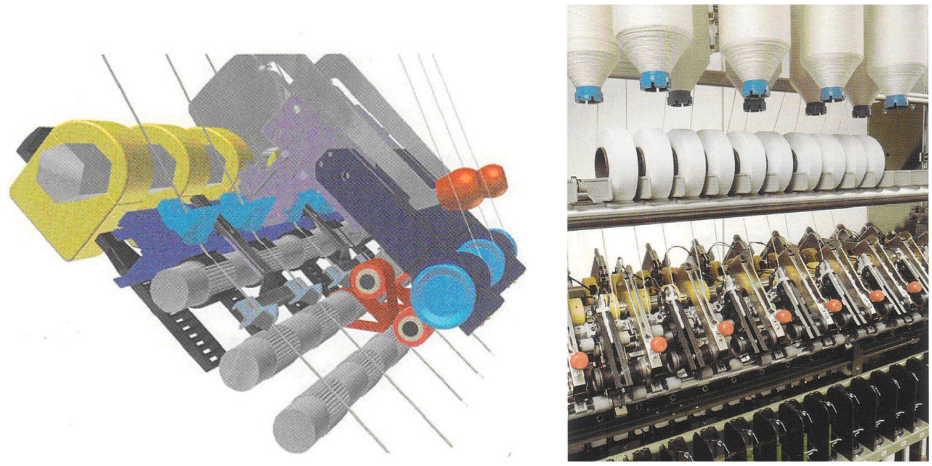
Figure 16.9 Compact spinning system. Source: Cognetex (www.finlane.com).



16.6 Bicomponent yarns

Core spun yarns involve the incorporation of a filament in the centre of a staple fibre yarn; i.e. the staple fibres are wrapped around a central filament. The filaments can be single or multiple filaments of polyester, nylon or elastain (eg Lycra); the latter imparts a high degree of elasticity (stretch) to the yarns and fabrics. The filaments are typically introduced to the staple fibre stream behind the nip of the front draft rollers. Guides and tension devices are required to align and control the introduction of the filaments. Figure 16.10 shows a typical core spinning system.

Figure 16.10 Core spun yarn spinning technology.
Source: Amsler-Tex (www.amslertex.com).



Wrap spun yarns involve the wrapping of filaments around a stream of staple fibres. The filaments may be wrapped around a twisted stream of staple fibres (i.e. a yarn) or an untwisted, parallel stream of staple fibres. Wrap spun technologies gained popularity during the 1970's, however, today they are confined to niche markets. Generally, fancy twisters are required to produce wrap spun yarns. A more recent development to produce wrap spun is the Sirofil system. This system is based on Sirospun technology. Instead of two wool fibre strands being spun, one of the strands is wool and the other is a filament, or a strand of multi-filaments. As the wool and filaments (spaced about 15 mm apart) emerge from the front draft rollers, they are twisted together, resulting in the filament(s) being wrapped around the wool. The Sirospun break-out devices, which ensure that both strands are broken if one fails for some reason, are modified to be able to stop the filament from being spun into the yarn in the event the wool strand fails.

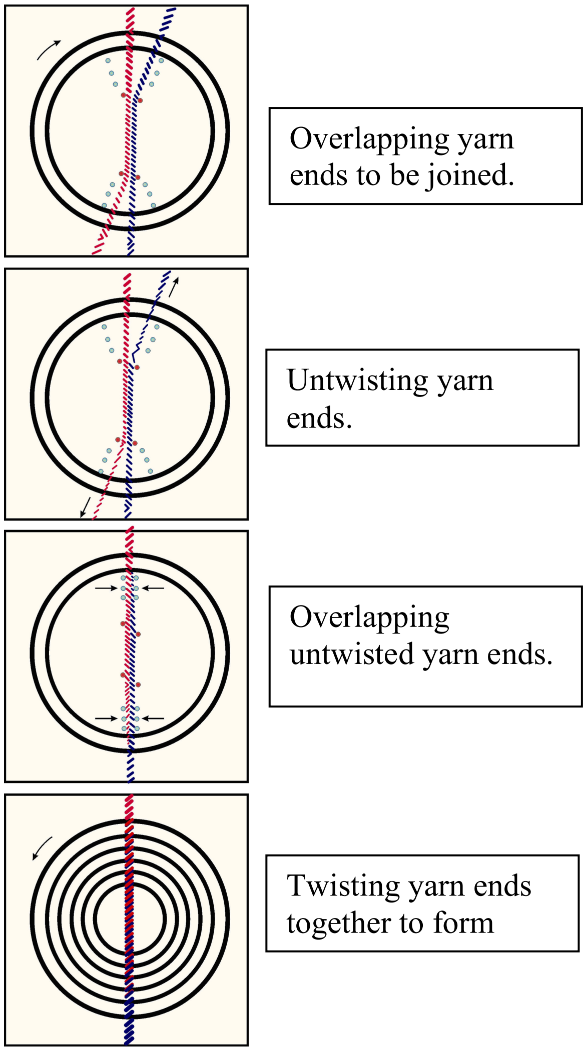
16.7 Winding/clearing

Once spinning has been completed, the yarns are wound from their spinning bobbins onto larger packages. During this procedure the faulty sections of yarns are removed and the fault free yarns are rejoined, either by knotting or splicing. Knots themselves are yarn faults that may fail in subsequent processing, cause other faults in processing, or require labour for their removal during mending of the final fabric. The ultimate solution would be a yarn joint completely indistinguishable form the parent yarn. Today, knotting has been generally superseded by splicing, and CSIRO has been involved in the development of splicing technology suitable for wool yarns, partly motivated by earlier work on Sirospun.

After the detection and removal of a yarn fault, and where the start and end of yarns from two spinning bobbins are to be joined, splicing involves the untwisting of the fibre ends at the two yarn ends to be joined, then bringing the two yarn ends together and inserting twist into the join. The splice must have the same appearance as the parent yarn (i.e. be almost invisible) and have almost the same strength. Two splicing systems have been developed by CSIRO for worsted yarns; mechanical and pneumatic. CSIRO has licensed the mechanical Twinsplicer technology to Savio (Italy) and the pneumatic Thermosplicer technology to Schlafhorst (Germany).

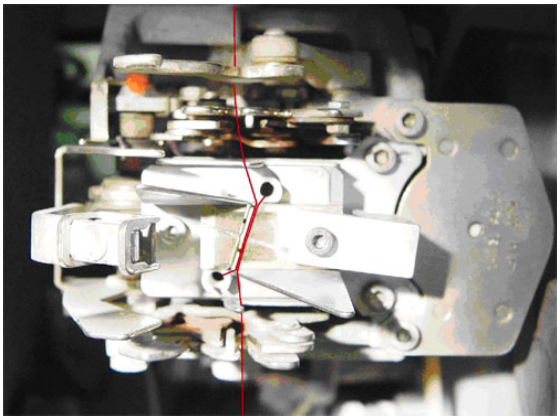
In the Twinsplicer (Figure 16.11), the yarn ends to be joined are sandwiched between two annular discs, which are geared together in such a way that they rotate in opposite directions around their central axes. To produce the yarn splice, the discs are first rotated to remove the twist over a short length of the two yarn ends to be joined. The untwisted ends are then overlapped and twist is inserted into the join by rotation of the discs in the opposite direction. Although initially developed for wool, the Twinsplicer is primarily used for cotton yarns.

Figure 16.11 Mechanical splicer operation. Source: CSIRO TFT.



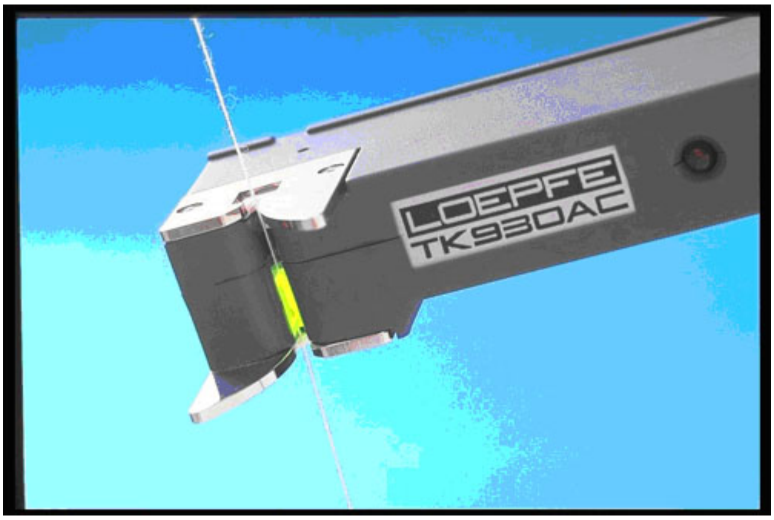
The Thermosplicer for worsted yarns (Figure 16.12) was developed after the observation that heating wool fibres increased their flexibility. The Thermosplicer works by rapidly heating the wool fibres above their glass transition temperature during the yarn joining phase of the splicing operation. This is the temperature at which memory of past stresses is lost. The fibres become more pliable and consequently are easier to bind into the splice. The result is a stronger, more invisible splice. Investigation has shown that hot-air splices in wool yarns, irrespective of yarn type or state are far more abrasion resistant than cold air splices. In weaving, cold air splices recorded the highest failure rate. During fabric inspection, hot air splices were judged to require the least levels of mender attention.

Figure 16.12 Thermosplicer (Hot Air Splicer). Source: CSIRO TFT.



During the winding operation, the opportunity is taken to monitor the yarns for faults. Traditionally, the yarns were monitored for thick and thin faults. It has now also become common practice to monitor ecru yarns for coloured contaminants such as vegetable matter, dark and medullated fibres, non-wool coloured fibres and grease contamination. Siroclear (licensed to Loepfe) is an optical sensor incorporated into the thick and thick fault sensor to monitor the colour of the ecru yarn being wound; Figure 16.13. Both Loepfe and Uster incorporated sensing technology for the detection of polypropylene (undyed) in ecru yarn. The Loepfe technology is based on a triboelectric principle whereas Uster appear to have combined a capacitance detector with an optical detector. Keisokki have also introduced an optical foreign fibre detector into their clearer technology. Any coloured contaminant or foreign fibre that is detected and falls outside preset limits is automatically removed and the yarn spliced as described earlier.

Figure 16.13 Loepfe yarn clearer incorporating Siroclear Sensor (Green Light). Source: CSIRO TFT.



The preference of course is to minimise the presence of coloured and non-wool fibres. Once blended with the wool fibres, fibre-like contaminants are almost impossible to remove. Hence, CSIRO developed a system to detect and remove coloured contaminants early in the wool processing pipeline to prevent the contaminants being blended in to the wool. This system (Dark Lock Sorter licensed to Loptex) is typically incorporated in the fibre opening line after scouring. Recently, Loptex have introduced polypropylene detection into their sorter by incorporating an acoustic reflection measurement system. Another contaminant detection system developed by Jossi uses an ultra-violet light/fluorescence detection system into their sorter for the same application.

16.8 Two-folding or twisting

Two-for-one twisting can be regarded as the standard in the worsted industry; as it is in short staple sector. Two-for-one twisting derives its name from the principle of inserting two turns of twist into a plied yarn in single revolution of the twisting spindle; this is shown in Figure 16.14. Prior to the twisting operation, the singles yarns are wound onto large packages during the winding and clearing operation. When producing a two-fold yarn, either two packages can be placed in the twisting chamber (one package on top of the other), or an intermediate step can be undertaken to wind the two (or more if desired) singles yarns onto a single package which is placed in the twisting chamber. As shown in Figure 16.14, the yarn is taken from and over the top of the packages to the inlet of a rotating hollow spindle. It is within this hollow spindle that the 'first' turn of twist is inserted for every revolution of the spindle. The yarn then exits the bottom of the spindle and around and over the packages to the take-up package. It is while the yarn is rotating around the packages that the 'second' turn of twist is inserted.

Figure 16.14 Two-for-one twisting principle. Source: Murata Machinery Company (www.muratec.net).

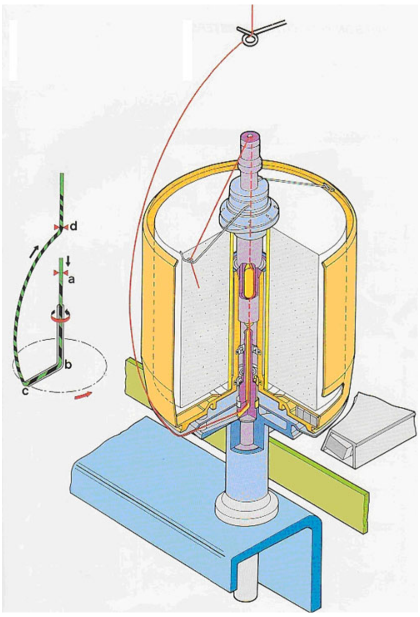
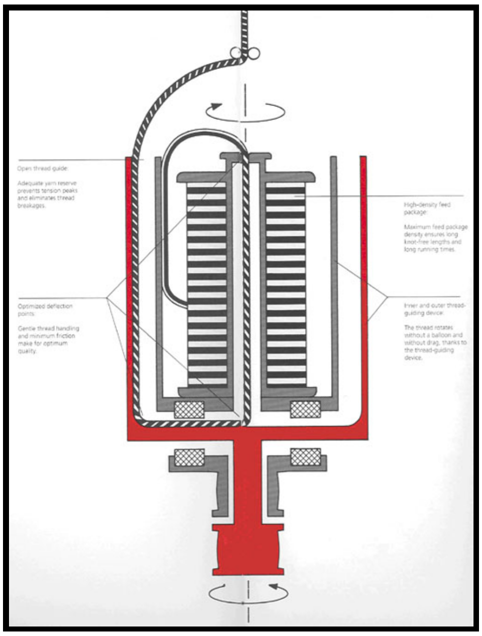


Figure 16.15 Three-for-one twisting principle. Source: Zinser (www.zinser-texma.com).



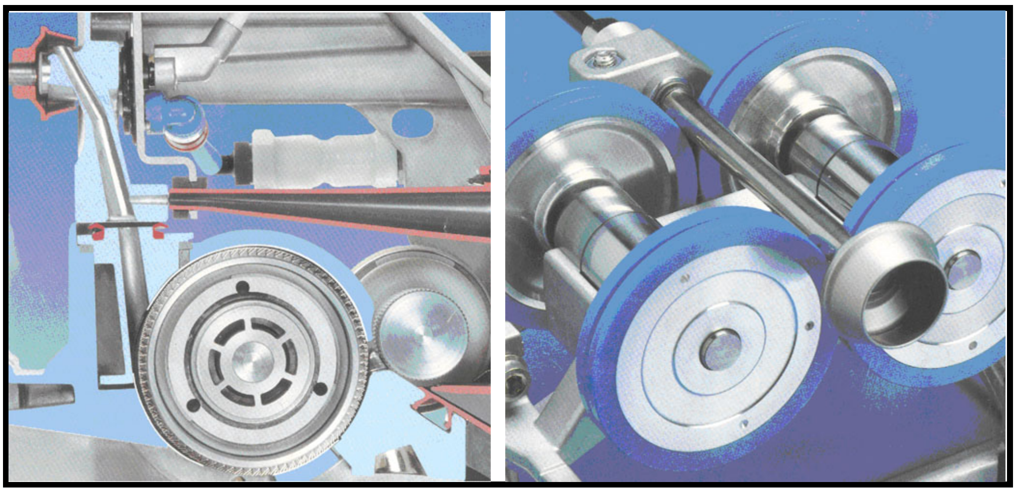
A relatively new development introduced by the Saurer Company (Germany) during the 1999 Paris ITMA was the Tritec twisting system, or three-for-one twisting. The principle is shown in Figure 16.15. The singles yarns are prepared for twisting in the same manner as for two-for-one twisting. The Tritec system differs from conventional two-for-one twisting with the addition of a second, counter-rotating outer chamber or cylinder. The singles yarns are drawn off and over the prepared packages into a hollow rotating spindle. When the yarn emerges from the base of the hollow spindle, it makes contact with the base of the counter rotating outer chamber. It is claimed that this counter rotating action inserts a 'double twist'. As the yarn travels upward, the contact with the inner surface of the outer rotating chamber adds the 'third' turn of twist.

16.9 Alternatives to ring-spinning

Open-end or rotor spinning

Open-end (OE) spinning (Figure 16.16) was initially developed for the short-staple (cotton) sector and where it currently has a significant market share in yarn production. Experiments began during the 1980's in spinning wool using the OE system. Wool typically is coarser and longer than cotton and the wool fibre also has varying degrees of crimp. Therefore a number of modifications were required in order to spin wool OE yarns. OE spinning is a direct sliver to yarn system where the sliver is fed to an opening roller where individual, or small aggregates of fibre are drawn from the sliver, and with the aid of an air stream, the fibres are delivered to an inner groove of a rotor rotating at high speed. Production rate is governed by the speed of the rotor and the speed of the rotor is governed by its diameter. Fibre length governs the diameter of the rotor and therefore wool typically used in the worsted sector required large diameter rotors. The wool OE prototypes produced during the 1980's used large diameter rotors at slow production speeds, hence the economic benefits for long staple wool was not realised. Additionally, due to the structure of OE yarns, greater numbers of fibres are needed in the cross-section in comparison to ring spun yarns; approximately 150 to 200 wool fibres are required for OE yarns. Both the greater fibre diameter of wool and its crimp resulted in greater difficulties in compacting sufficient fibre numbers in the rotor groove to produce a uniform yarn. To some extent, the problems were overcome by using short (32 to 45 mm), fine lambs wool (19.5 to 21.5 micrometres). This allowed the use of smaller rotor diameters, typically 46 mm, which offered higher production rates. Production rates are not as high as for cotton fibres; the rotor speed used to produce wool OE yarns are up to 60,000 rpm, which compares to 150,000 rpm for cotton yarn production on 28 mm diameter rotors. Because of the short, fine wool requirement for OE yarn manufacture, it currently is a niche market and the requirement for wool cleanliness is quite critical.

Figure 16.16 Open end spinning. Source: Rieter Textile Systems (www.rieter.com).



Air-jet spinning

The air-jet spinning principle involves the use of high speed rotating air in one or more chambers to impart twist into a fibre stream. The air jets mainly operate on the surface fibres, creating a fasciated yarn and therefore the yarns have limited application and are mainly suited to the short staple sector. The Murata Machinery Company of Japan has continued the development of the air-jet spinning technology and in 1997 introduced the Murata Vortex Spinning (MVS) system; Figure 16.17. This system imparts a greater degree of twist in the fibre stream, giving the resulting yarn an appearance similar to ring spun yarn. The MVS system was designed for spinning 100% cotton and MVS yarns have a smooth, low hairiness finish and are consequently low pilling. Production rates of up to 400 m/min are possible with the MVS system. The yarn appearance and production speed have obvious appeal for the worsted sector and interest has been shown world wide to adapt the MVS system to spin wool.

The MVS system has three zones:

1. drafting;
2. spinning; and
3. winding.

Figure 16.17 Murata Vortex spinning system. Source: Murato Machinery Company, Japan.

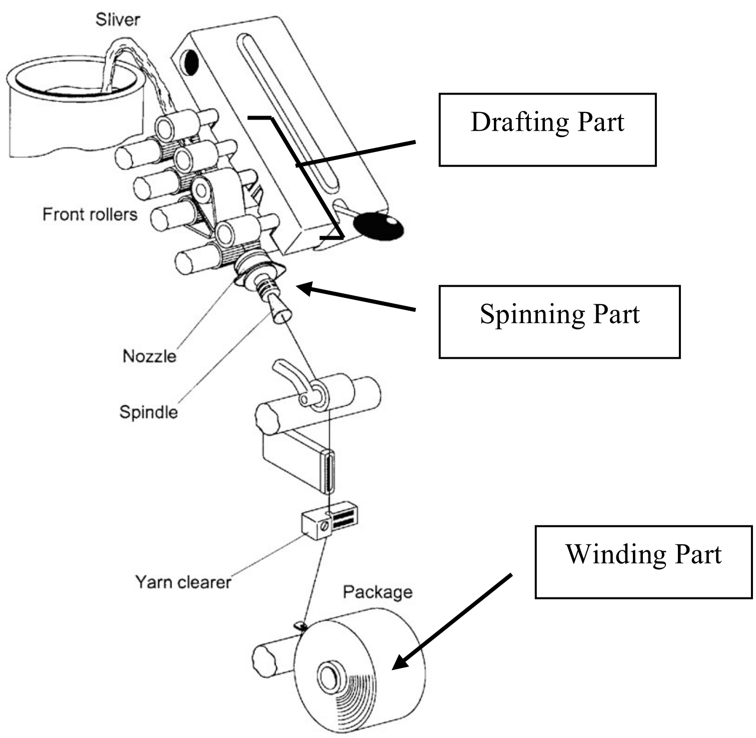
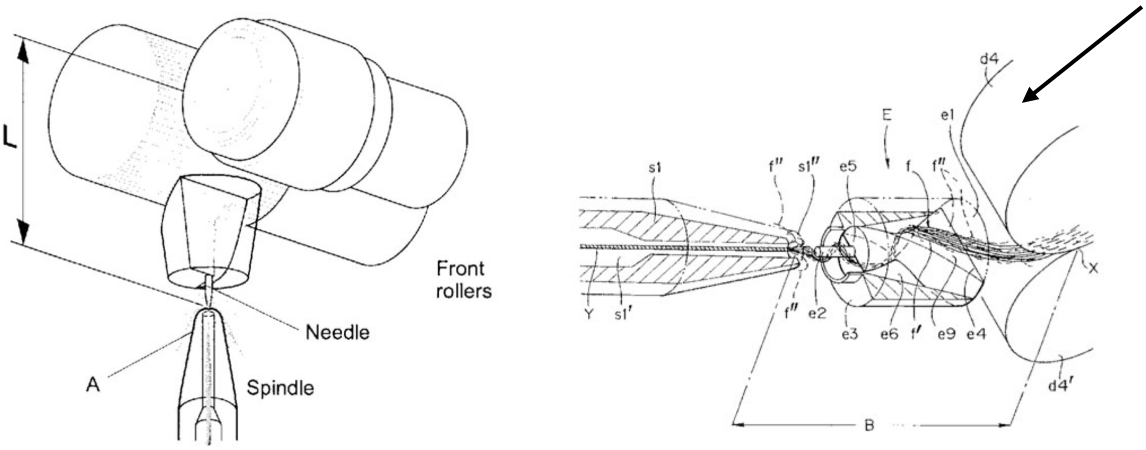


Figure 16.18 Vortex twist insertion principle. Source: Murato Machinery Company, Japan.



The drafting zone uses a high draft ratio (up to 220) in order to reduce the high numbers of fibres in the input sliver cross-section to the number (typically between 70 to 100 for fine yarns) required to spin the yarn. In the spinning zone, the drafted fibre stream is passed through an air-jet nozzle and hollow spindle to make a yarn strand. The rotating fibre balloon and resulting upward twist motion is controlled by an air vortex created around a needle connecting the path of the drafted fibre ribbon at the front rollers to the shaft of the hollow delivery spindle. Twist insertion relies upon the upper portion of some of the fibres separating from the false twist created by the air vortex and expanding outwards in the high velocity air stream as they trail the fibre assembly entering the spindle shaft. The separated fibre ends expand due to the whirling force of the air-jet stream and twist around the entrance of the stationary spindle. The fibre ends are then twisted around the parallel fibre core as they are pulled into the spindle shaft; Figure 16.18.

DREF Friction spinning

The DREF friction spinning system (Austria) was patented by Dr Ernst Fehrer in 1973. In this system, staple fibre in sliver form is drawn into a carding drum. The carding drum creates a fibre stream which is delivered to a pair of parallel, rotating, horizontal cylinders. The cylinders are closely spaced and rotate in the same direction. Air is drawn through fine perforations in the cylinder surfaces drawing and compacting the fibres in the V-groove formed by the close proximity of the cylinder pair. The rotation of the cylinders imparts twist to the surface fibres thus forming a yarn as it is drawn off axially from the cylinders onto a yarn package. This system can spin a range of fibre types, including wool. The earlier versions of this technology were mainly suited to coarse count yarns. The latest versions of the DREF spinning technology allow not only the spinning of relatively finer yarns, but the facility to incorporate other drafted fibre streams, pre-spun yarn and filaments of varying types as cores to the fibre stream, or sheath, introduced by the drafted sliver input. This allows the manufacture of technical yarns with a range of sheath and core combinations; Figures 16.19 and 16.20. Production speeds up to 250 m/min are possible.

Figure 16.19 DREF spinning principle. Source: Fehrer AG (www.fehrerag.com).

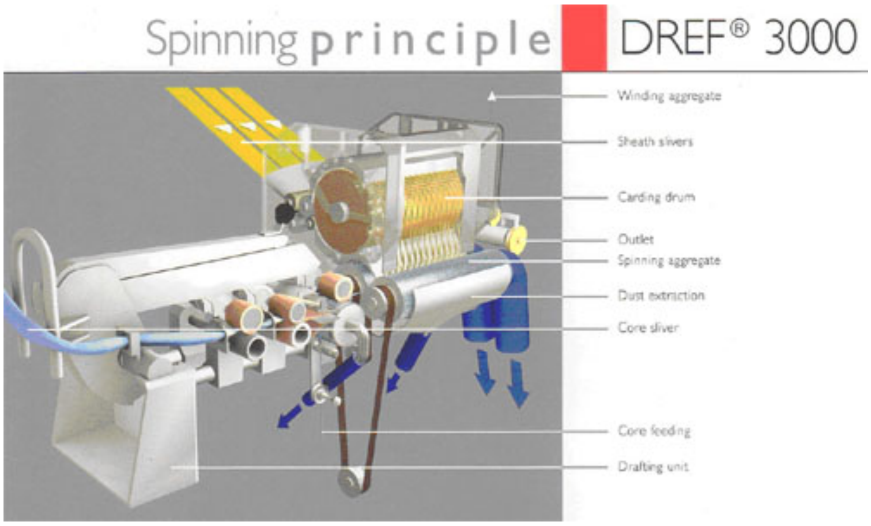


Figure 16.20 DREF 3000 spinning machine. Source: Fehrer AG (www.fehrerag.com).

16.10 Physical limitations of non-wovens

Although the significant savings make nonwovens attractive, nonwoven fabrics have inherent physical limitations that suggest that weaving and knitting will remain the favoured production processes for some time:

- Wovens and Knits

  - Within yarns: intimate fibre contact – strength and elasticity
  - Between Yarns: looser linkages, yarn crimp
  - Drape, bulk, good handle, fluidity

- Nonwovens
  - Intimate fibre contact throughout is required to get strength and fibre security; leads to:

    - Stiffness
    - poorer handle
    - poor drape
    - poor stretch recovery

The strength and elasticity of woven and knitted fabrics is provided by the yarns, the yarn crimp, and the yarn arrangement. This allows high fabric strength and good fibre security within the yarn while the fabric’s flexibility and fluidity is provided by the looser links between the yarns. Nonwovens cannot easily imitate this effect because the strength and fibre security of the nonwoven is derived from fibre entanglement throughout the fabric. These short-comings currently restrict nonwovens to certain applications; these include industrial fabrics and medical and safety apparel but some consumer apparel products are well suited to nonwovens and research is continuing to overcome the limitations and widen their applicability.

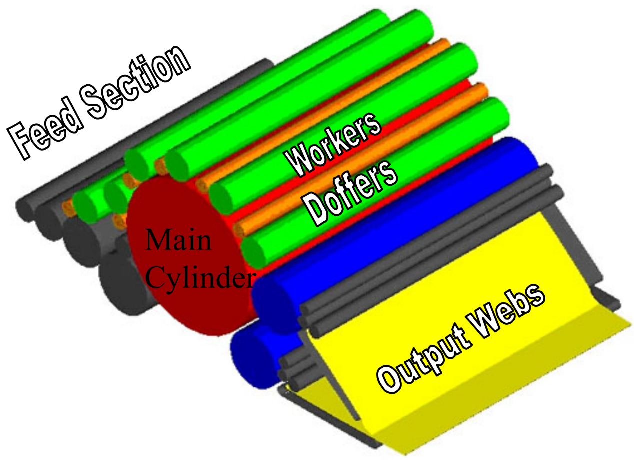
16.11 Developments in non-woven production

Nonwovens production can be broken down into various stages:

– web formation
– web bonding
– finishing
– coloration

Web formation for staple fibres is usually via a carding process; an alternative is air-laid systems e.g. Fehrer, Danweb.

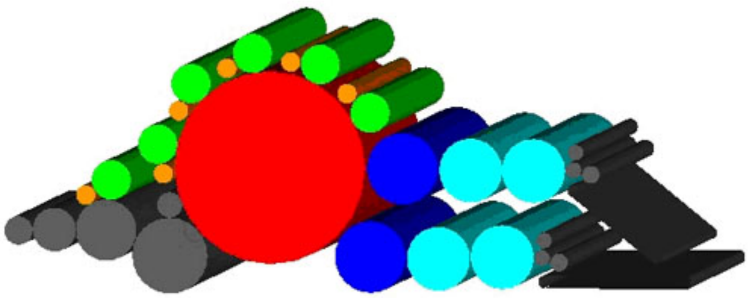
Figure 16.21 Basic nonwoven card. Source: Prins and Finn, 2006.



The schematic diagram of Figure 16.21 shows carded web formation. One possible bonding route that may follow carding is chemical binder impregnation. The binder is applied as an emulsion or foam and then dried and cured by continuously passing through an oven to glue the fibres together. This process is commonly used for the manufacture of light weight fabrics for disposable wipes but is also used to make, for instance, wool blend vertical blinds, usually with stitch bonding, see later. For lightweights, the web produced goes directly into the binding process, for heavier fabrics several cards can be positioned in line and their webs combined. The fibre orientation leaving a card is usually predominantly in the machine direction, even though condensing rollers may be used on the outputs. This leads to the strength being greater in the machine direction (MD) and weaker in the cross machine direction CMD. This leads to a high MD/CMD ratio, which is undesirable for some applications such as wool apparel.

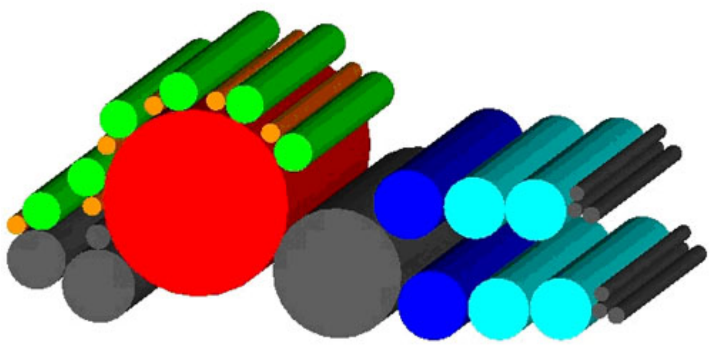
Condenser rollers are a pair of rollers positioned after the doffer covered with special wire and that bring the speed down in steps. Each roller is slower than the one before and so the web is crammed into the wire of the following roller changing the fibre orientation. This also has the added effect of increasing the doffer speed while keeping the line speed the same, the higher doffer speed takes more fibre from the card per revolution of the main cylinder and so lowers the total fibre load of the card and can allow higher production rates. The desire to increase productivity while maintaining quality has lead to nonwovens cards with three doffers being developed (FOR, Spinnbau). The three doffers further increase the rate at which fibre can be cleared from the main cylinder allowing higher throughput and also lead to further averaging of random web variations to improve quality. Heavier web weights are also then possible.

Figure 16.22 Schematic diagram of a typical nonwoven card with condenser rollers, (e.g. Thibeau, Spinnbau, FOR). Source: Prins and Finn, 2006.



A recent development has been the random card. This card has an extra roller between the doffers and the main cylinder with special wire, see Figure 16.23 below. This roller turns counter to the main cylinder and partially strips it, the transfer is said to be mostly via air-flows and a more random orientation is produced, MD/CMD is claimed to come down to 3:1 and with condenser rollers down to 1.5 : 1.

Figure 16.23 A Random Card (extra counter-rotating roller between cylinder and doffers). Source: Prins and Finn, 2006.

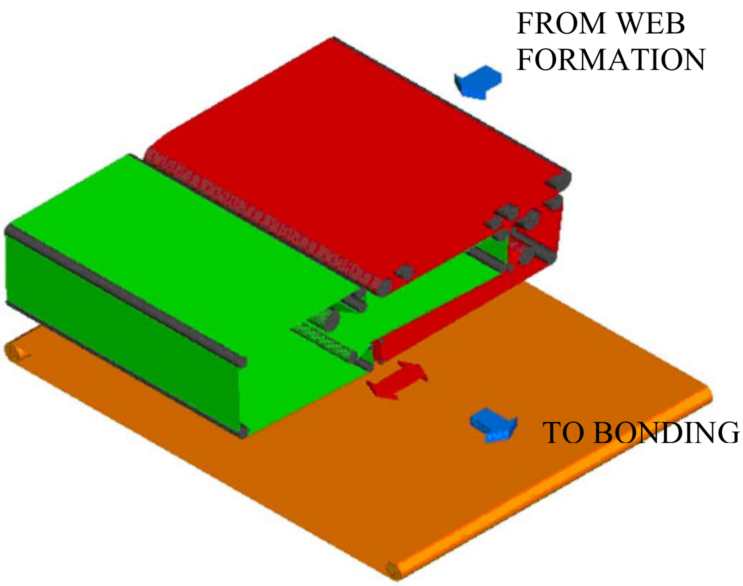


Many new high speed nonwoven cards from, for instance from Spinnbau or Thibeau, have suction systems to control the web as it is doffed at high speed. This has lead to improvements in web quality and production rate. The Turbo card from FOR uses aerodynamic stripping of the workers instead of stripper rollers. The FOR cards now also have a high speed doffing system that does not use suction and is claimed to allow heavier webs to be produced from the card. Another interesting development in carding is the Sirolock card wire from ECC. This has steps in the teeth profile to increase fibre retention. It has been used successfully on workers on and doffers, on a worker the increased retention would improve blending power and on a doffer it would increase the fibre transfer rates, reducing card loading at high production rates.

Cross-lapping

To produce heavier weight fabrics from a single card, a cross-lapper is used. This device layers the light-weight web leaving the card with the layered web leaving the cross-lapper at 90^{o} to the card direction. The ratio of the card speed to the cross-lapper output speed determines the number of layers and the weight of the cross-lapped web. In this case the predominant fibre direction has become across the fabric; the MD/CMD ratio is then less than 1. The heavy cross-lapped web can be drafted, or stretched, to pull the fibre orientation towards the machine direction, in this way MD/CMD ratios close to 1 can be achieved. Cross-lapping and needle punching can produce variations in the density of the fabric across its width. The latest nonwoven Card - Cross-lapper systems have computer control such that the card speed and cross-lapper speed can be varied to change the web weight as it traverses the fabric giving a predetermined profile in density leaving the cross-lapper such that when the fabric is needle-punched provides a very flat density profile.

Figure 16.24 Cross-Lapper. Source: Prins and Finn, 2006.

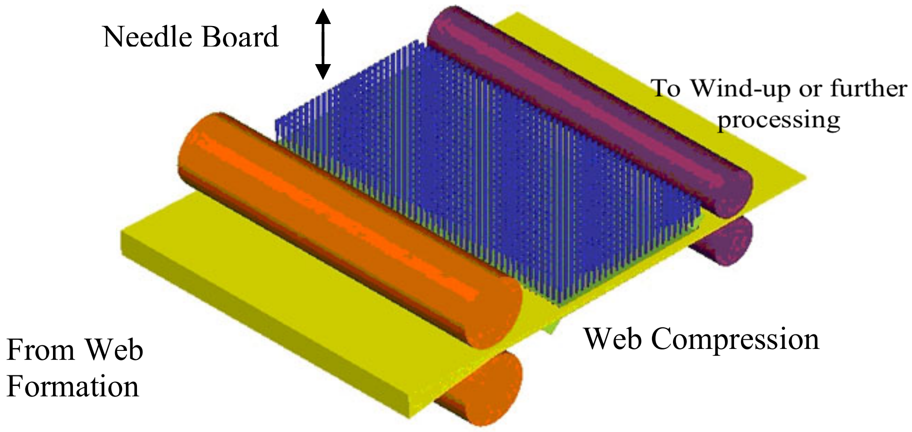


An alternative to cross lapping is to use a recently developed “turbo” and “Airweb” doffing systems from NSC or Spinnbau. These use a conventional card followed by a new system that throws the fibres into an air-stream to be collected suction onto a drum or belt to give a randomised pattern of orientation. These devices are claimed to produce MD/CMD ratios down to 1.2 directly. The output speed can be reduced to produce quite heavy webs without cross-lapping and high bulk is also possible with some fibre orientation in the vertical direction.

Bonding systems – needle punch

Figure 16.25 shows the needle-punching process which is very commonly used to manufacture medium to heavy weight fabrics. The needles are used at a density of several thousand per square metre and reciprocate through the fabrics. The barbs on the needles catch the fibres and entangle them to form a felted fabric. Often several stages of needling from each side of the fabrics are required to give the fabric sufficient strength. Because of the reciprocating motion the speed is limited by the "advance per stroke", the fabric cannot be pulled forward while the needles are in the fabric without damaging either the fabric or the needles. A fairly recent development is the Hyperpunch system where the needles follow an elliptical path rather than straight up and down so that they partially follow the fabric as it advances through the needle-loom. Over needling can lead to excessive fibre breakage and so there is an optimum level of needling with respect to fabric strength.

Figure 16.25 The needle punch process. Source: Prins and Finn, 2006.



For wool nonwoven textiles, an attractive needling process is the velour needle punch. This machine needles the fabric into a brush underneath rather than into a steel stripper-plate with a hole for each needle to strip the fibres from it. The velour needle punch pushes the fibres through the fabric to the opposite surface in a controlled way and produces a velour or velvet-like finish to the fabric. The fabric can also be patterned in this way by using special arrangements of needles and brushes.

Stitch bonding

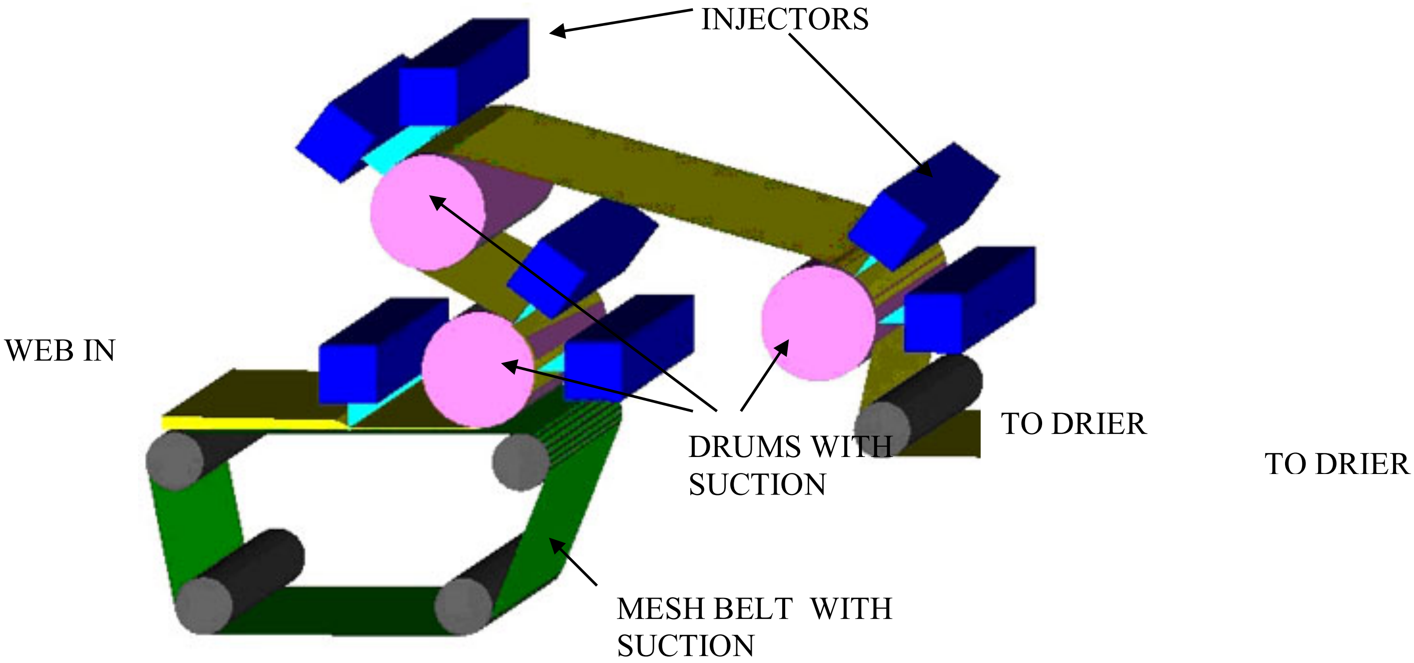
Because nonwoven fabrics need to derive their strength from the intimate entanglement of the fibres and this leads to their stiffness relative to wovens and knits a compromise is reached in pure-fibre nonwovens between handle and performance. However, nonovens can be reinforced so that the fibres can be more loosely entangled but the strength is provided by the reinforcement. One means to do this is called stitch-bonding one example is the Meyer Maliwatt. In stitch bonding sewing threads are inserted by sewing needles aligned across a cross-lapped web. The threads provide mostly machine direction strength while the natural fibre orientation of the cross-lapped web provides the CMD strength. The sewing threads, constituting only about 5% of the fabric weight, are buried into the fabric in finishing where a pile may be raised or the fabric lightly wet-felted so that they are not visible in the final garment. Such wool and wool-blend fabrics can be used in outwear and are limited to heavier than around 250gsm. A fleece-like fabric can also be produced in this way.

An alternative to stitch bonding to give extra strength is the use of a "scrim". These are woven fabrics that are incorporated into the nonwoven, usually by insertion between two webs before bonding. Needle punching the webs through the woven fabric can produce a strong fabric with a lower degree of entanglement and so give a softer fabric. However, the fibre security can then be low and pilling and fibre shedding can become a problem. The cost of the woven fabric often has to be low and so synthetic fibres are used and for disposables often welded nets are favoured. However, for highly specified technical fabrics such as some wool-containing paper-making felts the scrim is a carefully designed key component rather than a cheap reinforcement.

Hydroentanglement

Also known as Spunlace or Jetlace, hydroentanlement uses rows of fine high pressure water jets to entangle the fibres of the web into nonwoven fabrics. The water from the jets is removed by suction slots behind each injector. Because there are no reciprocating parts the production speed is not limited as needle-punching is by "advance per stroke". The speed can be very high and is limited only by the energy that can be injected by the water jets into the entanglement process. Speeds of hundreds of metres per minute are used on lightweight synthetic fabrics for disposables but lower speeds are often used for heavier or more durable fabrics. Power consumption is relatively high but the energy cost per kg remains low because of the high production rates possible. Only two companies supply large scale Spunlace lines, Rieter Perfojet and Fleissner.

Figure 16.26 Hydroentanglement or "Spunlace." Source: Prins and Finn, 2006.



The fine, high pressure water jets are applied against the fabric backed by either a mesh belt or a drum. The drums have mesh shells or in the case of Rieter-Perfojet may have random perforated shells designed to improve entanglement and reduce striping by the jets. Spunlace process speeds may exceed 300m/min but are usually much lower, especially for wool which is harder to entangle than finer synthetic fibres.

Common Spunlace products are:

Wipes, towels, tissues
Filters
Protective apparel
Surgical gowns and covers
Synthetic leather
Sanitary products
Home furnishings
Interlinings (some wool)

Spunlace fabric weights have an upper limit, if the fabric is to be entangled throughout its thickness, of about 400gsm. The main advantage of the Spunlace process for wool is that lighter-weight fabrics can be produced compared to needle-punch nonwovens. Also a higher degree of entanglement can be achieved with less fibre damage compared to needle-punching. Reinforcing scrims can also be used in spunlace fabrics to add strength. While there is currently very little commercial production of spunlace wool fabrics, research and development is ongoing and is expected to provide commercial outcomes in the near future.

Readings

The following readings are available on CD

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Summary

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Ring spinning remains the dominant form of spinning used for wool, primarily because it is seen to produce a superior yarn to alternate spinning systems. Several improvements to long staple ring spinning have been developed; examples are:

- compact or condensed spinning – the claimed benefits include improved yarn strength and elongation, reduced yarn hairiness, improved weaving efficiency and less fibre attrition during knitting;
- collapsed balloon spinning – with this system, higher spinning speeds are possible;
- Sirospun produces a two-strand yarn in a single step from two roving strands;
- Solospun produces a weavable singles yarn in a single step from a single roving strand.

In nonwovens, processing fibre is converted directly to fabric in a single continuous process. The wool inputs are usually similar to those chosen for woollen processing, i.e. shorter fibre than for worsted and usually free of vegetable matter and so carbonised wool and broken top is used. Broken top is shorter wools that have been combed to remove VM, very short fibres and neps and is expensive compared to carbonised wool. As with woollen processing, it is also possible to piece-carbonise the fabric having made it with low VM wools but this is rare and the VM may cause other problems in the nonwovens plant if it is not dedicated to this wool process. Blends of wool and synthetic fibres are also possible; a huge range of fibre blends are commonly used in nonwovens processing.

There are several ways of bonding the webs together in non-woven processing including needle punch, stitch and hydroentanglement

"Nonwoven" is a term used to describe textile products made via manufacturing processes that form fabrics without going through a yarn formation step; they are neither woven nor knitted. The fibre is formed into a web and then bonded, either chemically, thermally, by mechanical entanglement, or by combinations of these. This section describes these processes generally but with particular reference to wool.

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Glossary of terms

Bobbin	a tapered, cylindrical tube placed over a **spindle** on which yarn is wound during the spinning process.
Crimp	the wave-like pattern typically seen in wool fibres and refers to the waves per unit length [eg waves (or crimp) per cm].
Doffing	the replacement of the full **bobbins** (have spun yarn wound onto the full length of the bobbin) with empty bobbins.
Ecru	undyed fibre, yarn or fabric; i.e. retaining its natural, or raw, colour.
False twist	twist that is imparted to a fibre stream as it is drawn towards a twisting device, but loses the imparted twist once the fibre stream passes through the twisting device. The twisting devices can include devices such as an air jet, a rotating ring or cylinder, a pair of opposed oscillating rollers.
Fasciated yarn	where the surface layer of fibres are twisted around the circumference of a yarn with decreasing twist to almost zero twist of the fibres located toward the centre of the yarn.
Filament	a fine, “continuous” length of polymer.
Long staple spinning	typically refers to the system used to process the longer wool and wool blends in the **worsted** sector; average fibre lengths are typically longer than 50 mm.
Medullated fibre	a fibre with a hollow central section running along all or part of its length.
Mender	person responsible for mending faults in fabrics; typically woven fabrics.
Ring spinning	a continuous system of spinning in which twist is inserted by using a circulating **traveller**. The yarn is wound onto the **bobbin** since the rotational speed of the bobbin is greater than that of the **traveller**.
Short staple spinning	typically refers to the system used to produce yarns from cotton, cotton blends and man made fibres of similar length; average fibre lengths are typically shorter than 50 mm.
Singles yarn	a single strand of yarn.
Sizing	the coating of synthetic starches onto warp yarns (yarns that run along the length of the fabric) to cover the fibres ends protruding from those yarns so that weaving efficiency is improved.
Spindle	a long thin (tapered) rod that is rotated to impart twist into textile materials. The **bobbin** on which the yarn is wound is placed over the spindle.

Traveller	a metal or plastic component through which yarn passes on its way from the yarn balloon to the **bobbin**, or package, surface in **ring spinning** or twisting. The traveller is mounted on a ring and is dragged around by the yarn.
Triboelectric	frictional electricity; when two dissimilar substances are rubbed together, they become oppositely electrified; and if either is an insulator, it retains a charge.
Twist-lively	the state where the fibres twisted together to make a yarn still retain a "memory" of their untwisted state creating a torque imbalance in the yarn such that it will twist upon itself when not being held under tension, forming loops or snarls.
Two-folding	the twisting together of two **singles yarns**.
Worsted	yarns spun wholly from combed wool in which the fibres are reasonably parallel and fabrics or garments made from such yarns. Worsted yarns require a greater number of processing steps than other systems to arrange the fibres in a reasonably parallel state in preparation for spinning.