Advances in wool spinning technology

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Abstract: Technologies have been developed, and are continuing to be developed, along the worsted processing pipeline to improve process prediction and control, product quality and production rates whilst maintaining or improving product quality. This chapter reviews a selection of advances made, concentrating mainly on those developed or released commercially since the turn of the 21st century. The advances include the introduction of the updated topmaking prediction formulae (TEAM-3) that is still viewed as an important tool in converting greasy wool to top, new worsted combing machines improving both production rate and quality, air-jet spinning for wool and a new generation self-twist spinning machine.

Key words: scouring, topmaking, spinning, winding, yarn clearing, twisting.

4.1 Introduction

A comparison of the shorn fleece on the shed floor with the attractive, highly desirable garments that are created from it can easily excite a sense of wonder. In the shorn fleece the quite ordered array of the staples on the sheep has already been disturbed and the variable length and state of the wool from different parts of the body are obvious. Compare the wool shorn from the neck, head, belly and crutch with that from the sides and back. There will be differences in the vegetable matter in these components, and there will also be differences in fibre diameter and colour. Add to all this a presence of a significant amount of wool wax or grease, together with some dirt and the unseen sweat salts. All this variability from one sheep, yet a consignment of wool may contain fibres from many sheep, flocks and environments.

How is it possible to profitably re-order and reassemble the fibres in shorn wool to create the fine smooth suiting fabrics, the soft pliable knitwear and the cool lightweight shirting, and to do it in such a way that there is the required uniformity of technical properties and quality in the consignments, batches and deliveries through the textile pipeline? Major issues are costs, blending or homogeneity, the removal and disposal of contaminants, the management of fibre entanglement, the degree and limitations of control of fibre position and number within slivers and yarns, and the uniformity of treatment within and between batches through the pipeline. And there is the major issue of specification and predictability of processing and product performance to meet quality and price demands.
4.2 Brief review of advances in topmaking

4.2.1 Conversion of greasy wool to top

Science takes a higher profile than art in topmaking, particularly since the development of objective measurement for raw wool. The aim is to convert an assembly of greasy wool lots in bales into combed wool or top to meet required specifications at a price. Those specifications will ultimately be governed by the yarn into which the top, often blended with other fibres, is to be spun. Blend engineering with these two factors, specification and price in mind, is really the name of the game.

One of the most important developments in topmaking has been the development of methods of predicting the processing performance of wool from objective measurements made on the raw wool. The greasy wool characteristics and the processing parameters from scouring to topmaking all determine the yield and the properties of the top. The TEAM formulae, developed as a result of the Trials Evaluating Additional Measurements project collaboration between CSIRO, the Australian Wool Testing Authority (AWTA) and the Australian Wool Corporation, is a simple regression formulae prediction tool (TEAM, 1988). It can be used to predict the fibre length characteristics in the top and the combing waste. The predictions are made from the following measurements of the greasy wool:

- fibre diameter (micrometres – commonly referred to as micron);
- staple length (mm);
- staple strength (N/kTex);
- mid-breaks (%);
- vegetable matter base (%).

Since 1988 the formulae referred to as TEAM-2 have been widely used in the industry. With the introduction of new measurements such as coefficient of variation (CV) of fibre diameter, CV of staple length and mean fibre curvature, AWTA Ltd began a review of the TEAM formulae in 2001 to improve the prediction performance. As a result of this review the TEAM-3 equation (AWTA Ltd Research Papers, 2004; TEAM-3 Steering Committee, 2004), was released in 2006. Along with readjustments of some of the coefficients, the review recommended the addition of CV of fibre diameter and CV of staple length to improve the prediction capability. The TEAM-3 formulae are as follows:

\[
H = 0.43L + 0.35S + 1.38D - 0.15M - 0.45V - 0.59CVD - 0.32CVL + 21.8 + MA
\]

\[
CV-H = 0.30L - 0.37S - 0.88D + 0.17M + 0.38CVL + 35.6 + MA
\]

\[
Romaine = -0.13L - 0.18S - 0.63D + 0.78V + 38.6 + MA
\]
where \( H \) = hauteur or mean fibre length in the top
\( CV-H \) = coefficient of variation (CV) of hauteur
romaine = combing waste
\( L \) = staple length
\( S \) = staple strength
\( D \) = fibre diameter
\( M \) = percentage mid-breaks
\( V \) = vegetable matter content
\( CVD \) = CV-fibre diameter
\( CVL \) = CV of staple fibre length
\( MA \) = mill adjustment factor

If all the weighted objective measurements of a consignment of wool lots are known, the important benchmark processing performance parameters and top properties can be calculated. Topmakers, whether associated with exporters or combing plants, are able to buy and assemble consignments by trading off the price against the objective measurements of sale lots. A good source of information is the Australian Wool Testing Authority Ltd, http://www.awta.com.au/. Alternative prediction formulae are available in software packages such as Sirolan TOPSpec™, and Topmaker™ and a description of these is given in Simpson and Crawshaw (2002).

### 4.2.2 Scouring

The efficient scouring (i.e. washing) of raw wool is an essential first step in the early stage processing of wool. The aim of the scouring process is to remove the contaminants from the wool that would otherwise impede further processing of the wool while inducing the minimum amount of felting/entanglement. Fibre entanglement leads to a loss in fibre length and an increase in combing waste (noil or romaine).

The contaminants on the fibre can be divided into four groups: water-soluble material (commonly referred to as suint), wool wax (which can be both oxidised and unoxidised), dirt (of organic and inorganic origin) and vegetable matter. The aim of the wool scouring process is to remove as much as possible of the first three of these contaminant groupings. Vegetable matter, in general, is not removed in the scouring process. The amount of each of these contaminants varies widely depending on the breed of sheep, age, location, etc. Some typical figures for wax, suint and dirt for Australian greasy wool can be seen in Table 4.1.

Because wool consignments may consist of wool lots from various sources, blending is an essential part of topmaking, starting with the scouring operation. Blending may occur through bale lay down whereby the bales of wool of similar type making up the consignment are chosen in a predetermined order,
or through more sophisticated blending by in-line or weigh belt systems, or both. Opening and dusting of the wool generally follow.

The mechanism of wool scouring has changed little over 100 years or so and most of the wool scoured around the world is still scoured in hot aqueous detergent systems using traditional rake and harrow machines. Those developments that have occurred have centred on technology such as bowl design where hopper bottoms have now become the norm to better enable dirt recovery and continuous operation. Developments such as the WRONZ Comprehensive Scouring System and CSIRO’s Lo-Flo and Siroscour systems have greatly advanced scouring technology. A description of the various opening, blending, scouring and drying technologies can be found in Simpson and Crawshaw (2002).

4.2.3 Topmaking

The sequence in topmaking typically involves the addition of moisture and lubricant (to adjust the regain of the wool after post-scour drying and to lubricate the wool in preparation for carding), blending, carding, gilling (typically three passages), combing, followed by two more gilling passages, with the tops being produced at the second post-comb gilling passage. Multiple slivers are creeled at the input of each topmaking stage, continuing the fibre blending from start to finish. Descriptions of the equipment used in topmaking can be found in Simpson and Crawshaw (2002).

Since 2002, two new combs were introduced to the topmaking industry at the 2003 ITMA exhibition held in Birmingham, namely the N. Schlumberger & CIE (NSC) ERA™ comb and the Sant’Andrea Millennium™ comb. NSC has redesigned some key elements of the comb (Schenek, 2003). The circular comb has been reduced in diameter (103 mm) and is now fully pinned around the circumference. The comb rotates at a constant speed and there are 2.86 revolutions per cycle. This provides a staggered starting point for each cycle, spreading the wear of the pins more evenly. Only fine pin segments are used on the circular comb in place of the progressive pinning on previous models. The stroke has been dramatically reduced to 45 mm. Comb speed is

<table>
<thead>
<tr>
<th>Wool type</th>
<th>Total wax (%)</th>
<th>Suint (%)</th>
<th>Dirt (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Merino fleece</td>
<td>13.6</td>
<td>3.1</td>
<td>12.9</td>
</tr>
<tr>
<td>Merino lambs</td>
<td>20.3</td>
<td>3.1</td>
<td>7.4</td>
</tr>
<tr>
<td>Merino pieces</td>
<td>9.7</td>
<td>10.3</td>
<td>15.3</td>
</tr>
<tr>
<td>Crossbred pieces</td>
<td>9.3</td>
<td>9.8</td>
<td>15.7</td>
</tr>
<tr>
<td>Pieces &amp; bellies</td>
<td>10.7</td>
<td>11.6</td>
<td>25.0</td>
</tr>
</tbody>
</table>

Table 4.1 Some typical wax suint and dirt levels for Australian greasy wool
260 cycles/min and through a combination of increase in speed and comb width, the claimed production rate has been increased by about 25% over NSC’s previous model (Strehlé, 2004; NSC website). The Sant’Andrea Millennium comb is an evolution of the P100 which on its introduction was radically different from previous Sant’Andrea combs. Claimed comb speeds are up to 280 cycles/min through its revolutionary drawing-off carriage working cycle with differential motion and continuous feeding. By increasing the circular comb pinned arc to 290 mm improvements in cleaning action while reducing the stress on the fibres are claimed (Schenek, 2003; Sant’Andrea/Finlane website).

4.3 Yarnspec™: predicting spinning performance

The spinner demands that a top meets what can be a long list of technical specifications as well as a price. These specifications are designed to ensure that the top will perform as expected in the spinning mill and also downstream in weaving, knitting and fabric. Some top attributes such as quality of scouring and combing, and suitable lubricant and antistatic agents, are difficult to determine from measurements of the top. Therefore, mills will usually liaise closely with a few selected suppliers who reliably supply to the mill’s requirements. A few attributes such as dark fibre and contaminant levels can affect the suitability of the top downstream of spinning, though not directly impact on spinning performance. Finally, there are the fibre properties, particularly diameter and length, which are so important to spinning performance that allowed limits are chosen according to the yarn being spun.

Spinning performance and subsequent yarn performance are critical because both spinning and weaving cost, typically, three to four times as much as all of topmaking. Yarn breaks are so expensive in terms of labour cost and lost productivity that it is common for less than one break every 40 km to be allowed (Lamb and Yang, 1996). For a fine yarn being produced at 1 km/hour/spindle this equates to a maximum of 50 ends-down per thousand spindle hours (50 EDMSH).

In order to improve the predictability of wool processing performance CSIRO has introduced a yarn and spinning prediction program – Sirolan-Yarnspec™ (Lamb and Yang, 1996). The program aims to predict what a good modern mill can expect to achieve using a particular wool top for a given yarn under the specified spinning conditions. This is a powerful and necessary tool for a closed quality control system that enables ongoing improvement and reduces error margins on cost and performance.

Sirolan-Yarnspec™ incorporates theory and algorithms derived from fits to experimental data. However, theory shows that all mills run up against the same limits so that expected yarn properties can be predicted without the
need for a mill-dependent correction factor (once measurement systems are uniformly calibrated).

### 4.4  Worsted spinning

#### 4.4.1  Spinning technology

At the spinning frame twin rovings are pulled off freely suspended packages, separated, and enter the drafting zone at each spindle position. Drafting control is via two synthetic aprons (top and bottom) driven by rollers of which the top rollers are recessed so that a light pressure is exerted on the drafting strand. Drafts around 20 are typical. Upon emerging from the delivery nip, twist is inserted by the rotation of a spindle. Because worsted yarns are generally fine, the ring diameters are of the order of 45 to 55 mm in diameter, and the spindle speeds are of the order of 8000 to 12,000 rpm. The twist inserted at the worsted spinning frame is usually in the Z-twist direction and depending whether knitting or weaving yarns are being spun, the delivery speeds are of the order of 12 to 20 metres per minute.

Because of the random positioning of fibres along the yarn inherent to the process, it is impractical to spin yarns having much fewer than 35 to 40 fibres on average in the yarn cross-section. Worsted spinning is principally a balance between the maximum mean fibre diameter that can be used to spin a yarn of a designated count while achieving satisfactory spinning performance and yarn quality. Beyond this, the next most important parameters in order of importance are hauteur, fibre strength, CV of diameter and sometimes crimp.

Apart from automation and electronic control, there have been a number of advances in long staple spinning technology based around ring spinning. These advances include the development of weavable singles yarn directly from the spinning frame namely Sirospun (Plate and Emmanueller, 1982a,b; Plate and Lappage, 1982; Plate, 1983; Plate and Feehan, 1983), Solospun (Prins, et al., 2001) and Compact (Krifa and Ethridge, 2006; Salhotra et al., 2003) spinning.

Taylor (1988) noted that in the manufacture of worsted weaving yarns, the reason for the two-folding stage is that single worsted yarns will not weave. They are too hairy, and their surface abrasion resistance is not high enough to enable them to survive the abrasion forces they experience on the weaving machine. The poor abrasion resistance arises because fibre on the surface of the yarn has a high probability of lying on the surface for a substantial part of its length, and thus can be readily abraded away. Two-folding overcomes the problem by twisting two yarns together in such a way that the surface fibres are trapped between the two yarns. The twofold yarn then has sufficient abrasion resistance to enable it to be woven. An important
point to note here is that, to achieve trapping of the surface fibres, the two component yarns must not only be twisted about each other, they must also individually contain twist. Two-folding of two untwisted yarns gives a structure in which the surface fibres are not trapped, but are on the surface of the twofold yarn for its entire length.

CSIRO researchers (Plate and Emmanuel 1982a,b; Plate and Lappage, 1982) recognised the requirements outlined above for the structure of such a yarn and undertook a study of the mechanisms needed to impart individual strand-twist while concurrently folding two strands together. By feeding two separated strands together on to one spindle, they showed that if the twist equilibrium at the point at which the two strands converge was disturbed, it was possible to trap small amounts of alternating twist in each of the strands while the strands were twisted together. This produced in one operation a yarn, Sirospun™, with some characteristics of a single yarn but one in which surface fibres are adequately trapped to withstand the abrasive forces on a weaving machine.

Sirospun™ is a technology that can be retrofitted to existing ring spinning frames to produce a two-strand weavable yarn. Sirospun yarns are spun from two drafted strands of roving, spaced about 14 mm apart in the drafting zone, that are allowed to combine in the twisting zone just below the front draft rollers. To avoid spinning a single strand, each Sirospun yarn passes through a breakout device mounted above the ring rail. Because Sirospun yarns do not require any further two-folding or twisting, the splices made in these yarns needed to have sufficient strength and abrasion resistance to survive the weaving process. This requirement lead to the development at CSIRO of the Twinsplicer™ and Thermosplicer™ technologies.

During 1998 a new spinning technology, Solospun™, was released and subsequently displayed at the 1999, Paris ITMA. This technology was developed in collaboration between CSIRO, the Woolmark Company and 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 (Solospun Technical Manual; Anon., 1998) 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 (Fig. 4.1). 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. The benefit of producing a fine, weavable singles yarn is the ability to manufacture lightweight pure wool and wool blend fabrics that
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would not ordinarily be achievable via the conventional singles followed by folding (twisting) route.

In an interesting combination, Shaikhzadeh Najar et al. (2006) investigated the benefits of combining the Sirospun and Solospun spinning technologies and dubbed it the Solo-Siro spun process. Wools with two different fibre diameters were spun to a single yarn count of 40 Tex (1/25 N m) over a range of twist levels. The authors found that in comparison with a conventional singles and a Sirospun yarn, the yarn hairiness of the Solo-Siro spun yarn was significantly less. The Solo-Siro and Sirospun yarns recorded similar yarn strengths with both being stronger than the conventional singles yarn. The Solo-Siro spun yarn did not exhibit any advantage in yarn evenness. Although at the time of writing the combination may be of academic interest, it remains to be seen whether this has any practical application.

The Compact spinning system has been recognised by some authors as a revolution in ring spinning. The benefits claimed for Compact spun yarns are increased strength (at the same twist), increased elongation and reduced hairiness. This technology was primarily developed for the short staple system, but companies such as Cognetex and Zinser offer Compact systems for the long staple sector. Using an SKF-developed system, Hechtl (1996) compared conventional and Compact spun long staple yarns. This study showed that in comparison with conventional ring spun yarns both yarn tenacity and elongation for Compact yarns were significantly increased at the same twist level and that yarn hairiness was significantly reduced. It was also noted that greater

4.1 Solospun rollers.
production for Compact yarns could also be achieved by reducing the yarn twist level while retaining yarn strength, therefore eliminating the need to increase spindle and traveller speeds. In a study by Basal and Oxenham (2006), using 100% Pima cotton yarns and 50/50 cotton/polyester, the indication was that the rate of fibre migration as well as the amplitude of migration is higher in Compact spun yarns. These findings were attributed respectively to the minimised spinning triangle and the resultant greater fibre density associated with Compact yarns. Further discussions of these spinning technologies can be found in Simpson and Crawshaw (2002).

It is quite often desirable or necessary to impart particular yarn and hence fabric characteristics at the spinning frame because of the impracticality of blending the components prior to spinning. The most common example today is the production of stretch wool knitting and weaving yarns by the introduction of elastane filament in the core of the yarn during spinning. The introduction of a filament core is known as core spinning. For core spinning with elastane, the filament must be positively driven to provide a known tension (Invista, 2006). Typically, the core component is guided through a series of rollers and stationary guides and introduced into the drafted fibre strand immediately behind the top front draft rollers. Core spinning may involve the introduction of a wide range of filaments and even pre-spun staple yarns to impart aesthetic or technical attributes. The core component can provide strength and integrity through components such as high-strength aramid filaments. Staple fibres can also be used as the core by wrapping filament around them, providing strength and cohesion. This system is generally referred to as wrap spinning, although for many, wrap spinning may refer to the hollow spindle system whereby a twistless drafted fibre strand passes through a hollow spindle on which is mounted a filament package. As the spindle rotates the filament is unwound and wrapped around the staple fibres, imparting strength to the resulting yarn. Other methods for achieving filament wrapping are the Selfil™ and Sirofil™ systems. Selfil is based on the Self-Twist principle and Sirofil is based on the Sirospun system. Self-Twist yarn is spun by inserting alternating twist into each of two fibre strands and immediately bringing them together so that, in trying to untwist, they twist about each other. For Selfil spinning, one strand of staple fibre feed usually used in Self-Twist spinning is replaced by two continuous synthetic filaments. These are then self-twisted using two consecutive twisting systems and produce a fine, strong, torque-balanced single strand yarn at 300 m/min. In Sirofil spinning, one of the two roving strands is replaced by a filament, with the filament being introduced immediately behind the top front draft roller in much the same way as that used in core spinning. However, the spacing between the filament and single roving strand is maintained at the standard Sirospun spacing of about 14 mm prior to emerging from the front draft rollers. The drafted fibre strand and filament are allowed to combine in the
twisting zone; because the filament is typically the lighter of the two components, it wraps around the staple fibre strand.

Robinson and Marsland (1984) briefly describe five variations of core spun and wrapped core spun based on the Sirospun principle using wool rovings and synthetic filaments. The five variations can be spun on conventional spinning frames and were given the following names:

1. double rove wrapped core spun;
2. double rove double core spun;
3. double rove wrapped spun;
4. single rove wrapped spun;
5. single rove wrapped core spun.

The authors concluded that these yarns showed considerable potential for knitting and weaving and that it would also be possible to spin finer yarns.

Open-end (OE) spinning, air-jet spinning and friction spinning systems are available for wool but have not to date found wide adoption. Short wool (40 to 45 mm) has been 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.

4.4.2 Winding and clearing

The yarn on the spinning bobbin is ‘twist lively’ which means that, if wound off the bobbin under moderate to low tension, it will tend to wind around itself and snarl. The bobbins are therefore steamed to impart temporary set.

Once spinning has been completed, the yarns are wound at high speed from their spinning bobbins onto larger packages for further processing. During this procedure the faulty sections of yarns are removed and the fault-free yarns are rejoined, either by knotting or splicing. If knots are used, they may fail in subsequent processing, may 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 from the parent yarn, and knotting has been generally superseded by splicing. CSIRO has been involved in the development of splicing technology suitable for wool yarns, partly motivated by earlier work on Sirospun.

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 inconspicuous) 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 (Fig. 4.2), the yarn ends to be joined are sandwiched
4.2 Mechanical splicer operation.
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.

The Thermosplicer for worsted yarns (Fig. 4.3) 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, inconspicuous 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.

During the winding operation, the opportunity is taken to monitor the yarns for faults. Traditionally, the yarns were monitored for thick and thin

4.3 Thermosplicer.
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 thin fault sensor to monitor the colour of the ecru yarn being wound; (Fig. 4.4). Both Loepfe Brothers Ltd (http://www.loepfe.com) and Uster Technologies AG (http://www.uster.com) incorporated sensing technology for the detection of polypropylene (undyed) in ecru yarn. The Loepfe technology is based on a triboelectric detection principle whereas Uster appears to have combined a capacitance detector with an optical detector. Keisokki Kogyo Co. Ltd (http://www.tmgoogle.com/en/Keisokki-Kogyo-Co.-Ltd.html) has also introduced an optical foreign fibre detector into their yarn clearing 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.

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 S.r.l, (http://www.loptex.it)) is typically incorporated in the fibre opening line after scouring. Recently, Loptex introduced polypropylene detection into their sorter by incorporating an acoustic reflection measurement system. Another contaminant detection system developed by Jossi Systems AG (http://www.jossisystems.ch) uses an ultraviolet light/fluorescence detection system in their sorter for the same application.
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.

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 to 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.

4.4.3 Twisting

Yarns for weaving, particularly warp yarns, are usually twisted or plied, although it is not uncommon to use singles yarns in the weft. Knitting yarns are almost invariably plied; however, there is a trend now for lightweight knitwear to use singles yarns. The purpose of plying is twofold. Plied yarns are much more resistant to abrasion than a singles yarn of the same count, so they will more easily resist the torture test of weaving. Knitting yarns are plied to create a balanced yarn which is not twist-lively and which will not cause spirality in the resulting knitwear.

Twisting (Simpson and Crawshaw, 2002) is now almost universally carried out using two-for-one twisters, which can take either two packages of singles yarn, or an ‘assembly-wound’ package which is formed by winding two yarns together. Twist is inserted by continuously looping the pair of yarns together around the package thus inserting two turns of twist for each rotation of the loop.
Plying twist is usually in the opposite direction to the singles twist, so two singles yarns of Z-twist will be plied in the S-direction. This has the effect of trapping the singles yarns’ surface fibres in the structure while increasing the yarn bulk and rendering the fibres in the singles components parallel to the yarn direction. For knitting yarns the ply twist in turns per metre will be between a half and two-thirds that of the singles twist. There are variants on this for weaving yarns and, for some fabrics, even twist-on-twist yarns may be made where the ply twist is in the same direction as the singles. These are very hard, lean yarns of high density and are typically used in crepe fabrics. The two-fold yarns again require steaming to give set to the new fibre configurations and eliminate twist liveliness.

4.5 Future trends

4.5.1 Air-jet spinning

The air-jet spinning principle involves the use of high-speed rotating air in one or more chambers to impart differential twist into a fibre stream. The air jets mainly operate on the surface fibres, creating a fasciated yarn. As a result 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 (Fig. 4.5). This system imparts a greater degree of fasciation 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 MVS system has three zones: drafting; spinning; and winding. 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 required to spin the yarn (typically between 70 and 100 for fine yarns). 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 ‘A’ as shown in Figure 4.6(a).
4.5 Murata Vortex Spinning system.

The yarn appearance and production speed have obvious appeal for the worsted sector and interest has been shown worldwide to adapt the MVS system to spin wool (Gordon et al., 2005).

Little work has been undertaken to characterise wool MVS yarns, but a study undertaken on cotton MVS yarns (Soe et al., 2004) has shown that the core fibres in MVS yarns are highly ordered and parallel and have almost no
4.6 MVS twist insertion principle.
twist. In comparison with ring spun and rotor spun yarns, MVS yarns have the greatest proportion of wrapper fibres and these encircle the core fibres. In comparison to ring spun yarns, MVS yarns appear to be more uniform, bulkier and stiffer, while having a lower tenacity. Whether the properties of short staple (cotton) MVS yarns will transfer to wool MVS yarns is still to be determined, but in general MVS yarns have been shown to have good pill resistance and good dimensional stability. The yarn count range for MVS yarns is typically 1/20 Nm to 1/66 Nm and the fabric handle, particularly for coarse count yarns, tends to be stiffer and harsher than equivalent fabrics produced from ring spun yarns. The high production rate, however, can be quite attractive with MVS yarns, being up to 30% cheaper than equivalent short staple ring spun yarns.

4.5.2 New generation self-twist spinning

To address the knitting industry’s demands for greater yarn production rates and lower input costs, the Oerlikon, Allma Volkman Company (Oerlikon) recently released a long staple yarn manufacturing technology called WinPro™ based on the self-twist principle. The WinPro™ system produces four-ply knitting yarns from conventional rovings in the yarn count range of 4/10 to 4/120 Nm. WinPro™ is a two-stage system with the first being WinSpin™ which is a high-speed spinning system based on the self-twist principle and the second stage is WinTwist™ which is high-speed, two-for-one twisting. Each WinSpin™ spinning position consists of a three roller drafting system:

1. a pair of oscillating rollers to impart alternate S and Z twist;
2. a set of six idler rollers to combine the four individual yarns; and
3. yarn wind up onto a parallel-sided package.

The draft system is of sufficient width to accommodate the four roving strands which are kept separated while alternating S and Z twist is inserted into each strand. The alternating twist direction interval is about 110 mm. At the immediate output of the oscillating rollers, the fibre strands are initially combined into two-ply yarns followed by the four-ply combination by three pairs of idler rollers. It is claimed that production speeds of 250 m/min are possible. Each pair of idler rollers is offset such that the twist reversals do not coincide, improving yarn strength and appearance. The WinSpin™ operation is followed by a tailored two-for-one operation with claimed production speeds of up to 120 m/min. It is claimed the higher work to break of the 4-ply WinPro™ yarn makes it suitable for whole garment knitting due to improved knitting efficiency. With up to 50% less twist than conventional ring-spun yarn, WinPro™ is said to result in softer handle knitwear.