6

Mechanical processing for yarn production

L HUNTER

6.1 Introduction

The mechanical processing stage in the wool pipeline commences with the clean scoured wool and ends with the yarn ready for the fabric manufacturing stage. The main objectives of this stage are to disentangle the fibres, remove vegetable matter, mix (blend) the fibres, form a uniform coherent strand of fibres (sliver or slubbing) and then attenuate the fibre strand and impart cohesion to form a yarn of the desired linear density (count), quality and character. Other operations that can also take place during the mechanical processing stage include short fibre and residual vegetable matter removal (combing), dyeing (loose stock, sliver/top or yarn) and shrink-proofing (loose stock or sliver). Folding (plying), winding, clearing, waxing, etc. are final operations that may be required to produce a yarn and yarn package suitable for the fabric forming stage. All the above need to take place with the maximum efficiency and quality and with the minimum cost, fibre breakage and fibre loss.

The mechanical processing of wool can be divided into the following three main stages:

- *Sliver or slubbing formation* – Involves disentangling (individualising) and mixing the fibres, removing vegetable matter and forming a continuous web, sliver or slubbing, this being accomplished by carding.
- *Preparing the carded sliver for spinning* – Entails fibre alignment (parallelisation), evening (doubling), drafting and the removal of short fibres, neps and vegetable and other contaminants – Accomplished by gilling, combing and drawing
- *Yarn formation* – Drafting and imparting cohesion, usually through twist insertion, this being the spinning stage.

The middle, or intermediate stage (i.e. preparing for spinning) is omitted from the woollen processing route and it is the differences in this stage (namely combing and the associated additional gilling operations) that also essentially distinguish the worsted from the semi-worsted processing route.

There are basically three different routes or systems used in the mechanical processing of wool (Fig. 6.1), namely worsted, semi-worsted and woollen.[1] The essential differences in the products of the three systems are the levels of short fibres and the alignment of the fibres in the yarn, the fibres in worsted yarns being far more parallel than those in either semi-worsted or woollen yarns, resulting in a far leaner (less bulky) and less hairy yarn. Close on 90% of Australian and South African Merino type apparel wools are processed on the worsted system while some 80% of New Zealand wool is processed on the woollen system.

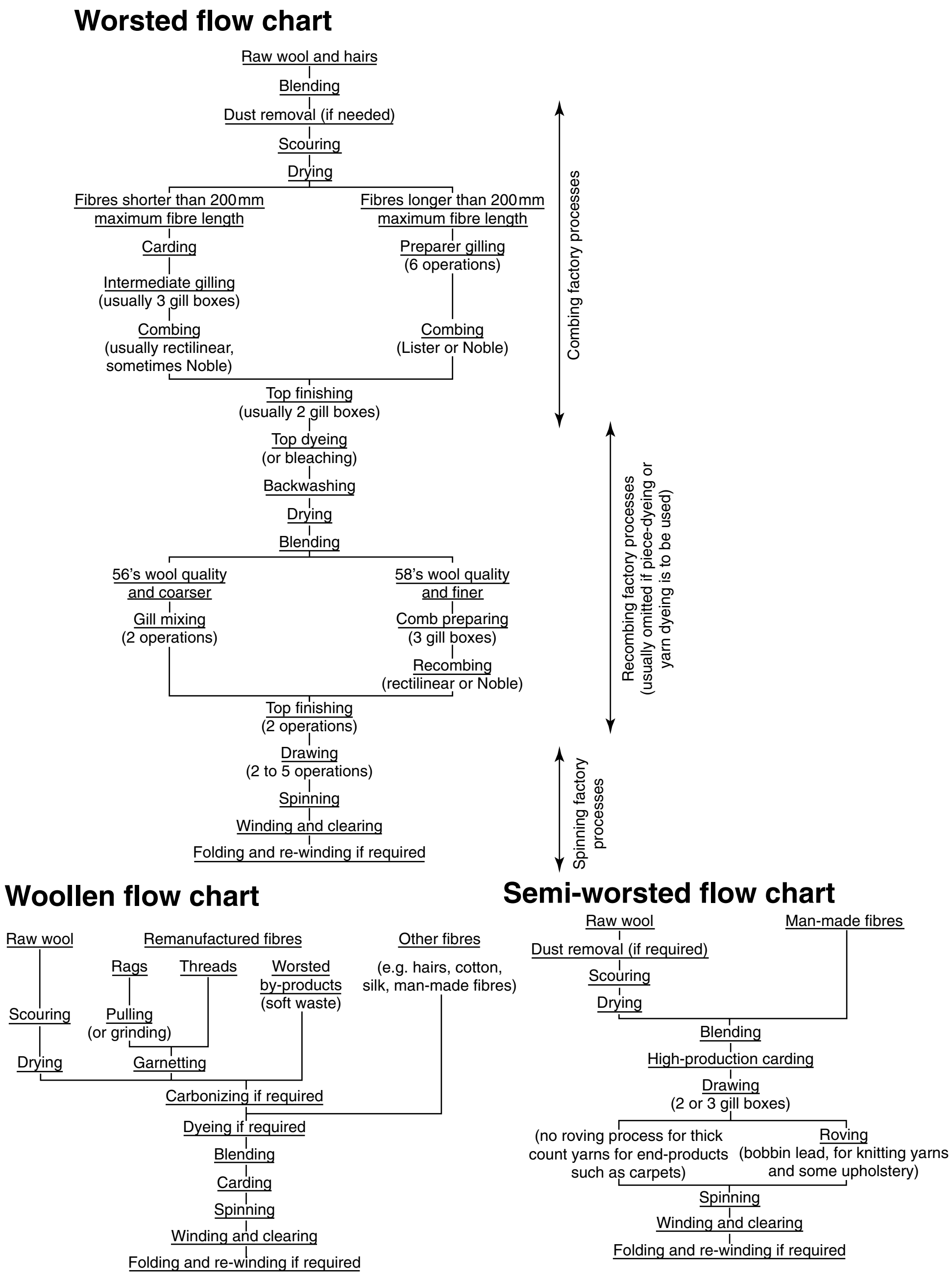
It should be mentioned that short wools, mainly in blends with either cotton or polyester, are also processed on the cotton (short staple) system, being occasionally rotor-spun (open-end) rather than ring spun. Wool with a mean fibre length around 40 mm can generally be processed without any major alteration to the cotton machinery, while wool with a mean fibre length of around 50 mm generally requires slip drafting at the drawframe, speedframe and ringframe. Iype *et al.*[2] have reviewed the processing of wool and wool-rich blends on the cotton system and this processing route will not be dealt with in this chapter.

6.2 Worsted processing system

6.2.1 Introduction

The name 'Worsted' is a slight corruption of 'Worstead', the name of a village in Norfolk where expert cloth-workers who entered England in the early fourteenth century, introduced novel methods for the production of superior and finer cloth than was previously produced in Britain.[3] As already mentioned, the essential and differentiating element of the worsted system is combing. Generally, only virgin wool, typically ranging in length from about 40 to 100 mm, is used in manufacturing worsteds, the term worsted-spun yarn, as opposed to worsted yarn, being used for the yarns in those cases where man-made fibres are processed.

Virtually since the start of worsted processing, two main systems have been used, namely the English (oil combed or Bradford) system, involving Noble combing, and the French or Continental (dry-combed) system, involving Rectilinear combing. The former was primarily developed and used for longer wools and the latter for shorter wools. Nevertheless, Noble (and also Lister) combs, employed in the Bradford system, are no longer being manufactured and the industry has moved almost entirely to the Rectilinear or French combing route. Essentially, the latter route entails carding followed by Intermediate or Preparer Gilling, then Rectilinear



6.1 Processing routes for wool. [*From Oxtoby.*[1]]

Combing (very occasionally Noble combing) and then Top Finishing, which usually comprises two Finisher Gilling operations. The stage from greasy wool to top is referred to as the 'early processing' or 'topmaking' stage. Papers at the *Top-Tech '96 Conference* in Australia[4] dealt with various aspects of topmaking, including the potential and merits of automation in topmaking, cost and flexibility being important aspects in this regard.

The Worsted Flow Chart is shown in Fig. 6.1.[1]

6.2.2 Carding

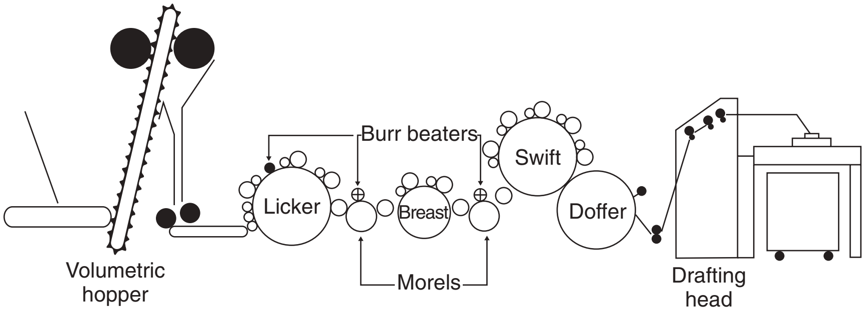
Carding generally represents the first stage of the mechanical processing of scoured wool, worsted cards typically being available in widths between 2.5 and 3.5 m. If any opening is applied prior to carding, care must be taken not to entangle the fibres, particularly for fine wools. Lubricants (generally 0.4 to 0.5%) are applied prior to carding to provide a well-balanced static and dynamic fibre-to-fibre and fibre-to-metal friction, and cohesion and anti-static properties.[5] Best results are generally obtained with boundary layer lubrication for carding, the main effect being at the swift. The lubricants should be emulsifiable and preferably bio-degradable, and often also contain bactericides/fungicides, complexing agents and anti-odourants.

The worsted, semi-worsted and woollen cards entail similar carding principles, although the last has more carding elements as well as an intermediate feed. Automatic linkages between carding, intermediate gilling and combing have also been developed. In essence, carding is aimed at opening up or disentangling the scoured wool staples (clusters or tufts), individualizing the fibres, mixing the fibres, removing residual dirt and vegetable matter, such as burrs and seeds, and forming the wool fibres into a continuous form (web); this is then condensed into a card sliver, and, in the case of worsted carding (Fig. 6.2), delivered into a ball or can. These actions need to be carried out in such a way that fibre breakage is minimised and as even a web and sliver as possible are produced. In the case of the worsted route, the wool is virtually always carded in the undyed state.

The card essentially consists of the following separate mechanical sections, each playing a different part in the process:[7]

- Feeding
- Licker-in, including burr removal etc.
- Swift-worker-stripper section
- Fancy doffer section

The exact configuration of the card (Fig. 6.2) depends upon the nature of the fibre being processed, notably the level of vegetable matter. For example, when wools of relatively high vegetable matter levels are carded, the card could have more morels and burr-rollers.



6.2 Worsted Card. [*From Harrowfield.*[6]]

The feed system plays a critical role in the uniformity of the card web and sliver. Examples are continuous flow volumetric feeders or gravimetric feeders, incorporating automatic monitoring and regulating devices (autolevelling).

The card essentially consists of rollers with surfaces covered in pins (card clothing). There are two main types of card clothing, flexible steel wire mounted into a firm foundation and rigid (non-flexible) metallic wire. The latter is a continuous steel ribbon with saw teeth which is wound around the card rollers, and this form of card clothing is presently the most popular.

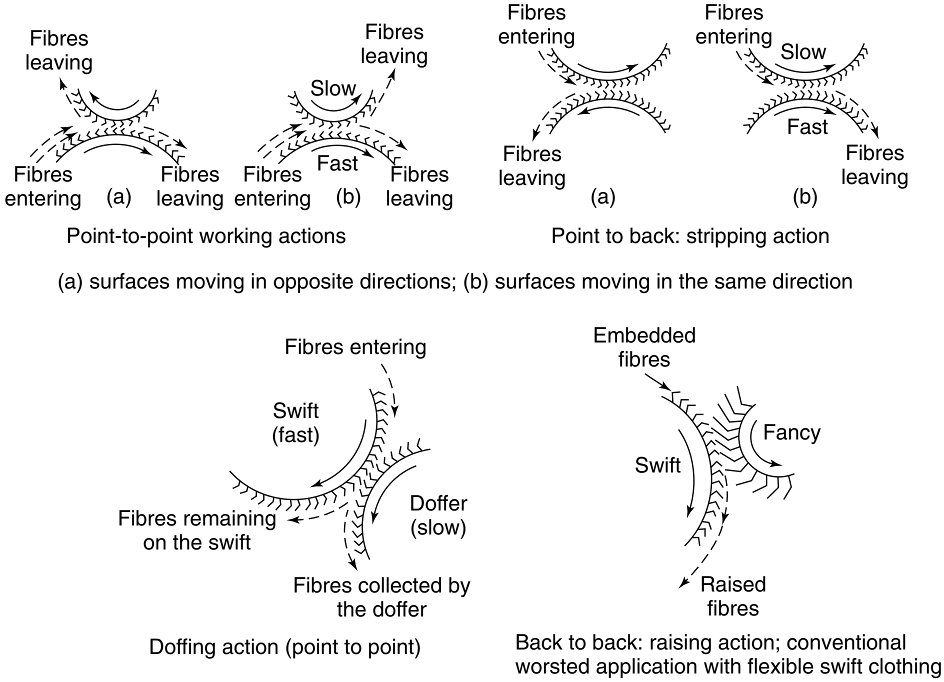
The following carding actions take place (Fig. 6.3):

- Carding (working)
- Dividing
- Stripping
- Doffing
- Brushing or Raising

The action on the fibres present between the pins of two adjacent rollers on a card is determined by the following factors:[1]

- Relative speed and direction (i.e. same or opposite) of the movement of the roller surfaces
- Direction of inclination of the pins, i.e. points leading or backs leading
- Distance (setting) between points on the adjacent rollers

The intensity of the carding action can be altered by changing one or more of the above factors. Increasing the overall speed of the card generally does not increase the carding action (or fibre breakage) as such, although it can increase fly waste and air currents. There are three pin relationships in carding, namely point to point, point to back and back to back[1] (Fig. 6.3):



Point-to-point working actions

Point to back: stripping action

(a) surfaces moving in opposite directions; (b) surfaces moving in the same direction

Doffing action (point to point)

Back to back: raising action; conventional worsted application with flexible swift clothing

6.3 Carding actions. [*From Oxtoby.*[1]]

Point to point, when used to open and disentangle the tufts of fibres, is called working or carding (e.g. at the licker and divider). This action always results in some fibres being retained on both surfaces. It is also used by the doffer to collect fibres from the fast moving swift, normally following the action of the fancy.

Point to back provides a stripping action, i.e. transfers all the fibres from the one surface to the other.

Back to back results in a raising action, which moves the fibres carried by the swift towards the tips of the pins by the action of the long fancy wire pins as they intersect with the pins on the swift.[1]

Burr beaters are used to remove burrs and other vegetable matter. They have steel blades and are usually run at the highest feasible speed in the opposite direction to the card roller surface. They are at their most effective during the earlier stages of the carding process, before the burrs have been opened out, and when they are used in conjunction with Morel rollers. Morel rollers are clothed with rigid wire clothing that cause the fibres to bed into the wires (assisted by the action of brush rollers) whereas the vegetable matter particles protrude from the surface and are knocked off into trays by fast revolving burr beaters, sharp blades offering certain advantages.[8] A modern card with two Morels typically removes over 90% by weight of burr and close on 90% of shive.

The full width web from the doffer, which can be monitored and corrected for evenness, is condensed into a sliver as it passes through a funnel and between a pair of pressure rollers, the latter running at a slightly higher speed than the doffer. Card sliver linear density monitoring and autolevelling (open and closed loop) take place at this stage, a drafting head at the delivery end of the card allowing the sliver linear density to be controlled.

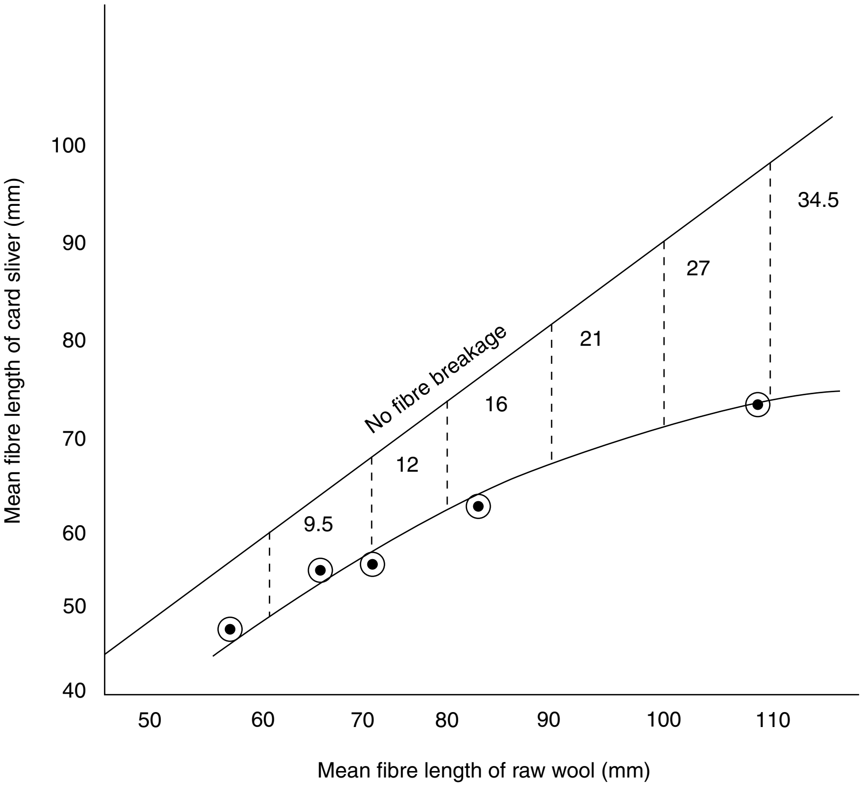
When carding with rigid metallic wire clothing, wool regain should not exceed 25%,[1] and ideally should be between 20 and 25%. Residual grease content of the wool should not exceed 0.6%.[1]

Carding is a fairly severe action, typically breaking between about 20 and 40% of the fibres, with an average breakage rate of about 30%; as much as 90% of the fibre breakage that takes place in converting scoured wool into top takes place during carding.[9] The card also breaks about 90% of the weathered wool tip. These short degraded fibre fragments either fall from the web as carding waste or are taken out of the sliver when subsequently combed. The level of fibre breakage is influenced by the degree of fibre entanglement developed during scouring, the fibre fineness, strength, length (Fig. 6.4)[10] and friction (lubrication), as well as on the thickness of the fibre layer on the swift, an increase in fresh fibre density on the swift increasing fibre breakage. It is perhaps worth noting that storage and pressing of scoured wool to high density, lead to additional fibre breakage during subsequent processing. Table 6.1 illustrates the potential effects of changes in certain parameters on fibre breakage during carding, summarising results obtained during various experimental studies (some on processed wool) at SAWTRI.[11]

The disentangling and opening processes may be inadequate to the extent that small tangled balls (tight clusters) of fibres, described as neps, are present in the card web. Poor carding, often indicated by increasing nep content, can be due to damaged or inadequately ground (blunt) card clothing and incorrect settings. Card wire should not be blunt, bent over, flattened or damaged in any other way. Incorrect setting of burr-beaters and crushing rollers may also lead to unacceptable levels of vegetable matter. Reducing the 'fresh fibre density' by increasing swift speed, reduces neps and combing waste.[12]

The quality of the carding operation can be assessed in terms of the following web characteristics:

- Degree of individualisation of the fibres.
- Uniformity in weight per unit area.
- Uniformity of blending.
- Degree of alignment of the fibres.



6.4 Mean Fibre Length of Card Sliver after 3rd Gilling vs Mean Fibre Length of Raw Wool. [*From Aldrich et al.*[10]]

Table 6.1 Summary of breakage results obtained in various experimental carding studies at SAWTRI[11]

Parameter*	Change in value of parameter	Change in fibre breakage
Style	Spinners to Inferior	6% to 36%
Length	57 mm to 109 mm	19% to 43%
Vegetable impurity	0.5% to 2.0%	10% to 19%
Temp. of scouring	45 °C to 70 °C	12% to 18%
pH of scour liquor	3.4 to 10.8	10% to 24%
Residual grease	0.4% to 1.6%	26% to 40%
Lubricant added	0.4% to 2.1%	2% to 10%
Worker settings	26 gauge to 30 gauge	27% to 42%

* Only one parameter changed in each case.

- Level of hooks (most hooks occur at the trailing ends of the fibres as they leave the card).
- Level of neps and vegetable matter.

Although the card can remove pre-existing neps resulting from fibre entanglement in the scoured wool it also forms new neps and fibre structures that tend to form neps during subsequent gilling. The number of neps decrease with an increase in the number of workers, sharpness of card wire, closer worker settings and with a decrease in recycled fibre density/swift load.[12] The number of neps also increase with increasing scoured wool entanglement and with increasing fibre fineness, crimp and length. Neps generally increase from the card to the comb (i.e. during gilling), affecting the amount of noil. Reducing neps by 50% could reduce noil by some 25%.

The basic principles of carding remained virtually unchanged for the entire 20th century, probably the most notable changes taking place in the last two decades of the 20th century. These include the development of Very High Speed Carding (VHSC) by the CSIRO (Australia), the IWS and G H Michell (Australian topmaker) in collaboration with Thibeau (France), and the high speed *Hercules* card by Octir. The former development virtually doubled the carding speed and resulted in the *Thibeau CA7 Card*, which was exhibited at the 1995 *ITMA*, a compact version being shown at the 1999 *ITMA*. On such a card (2.5 m wide), typical production rates achieved are 220 kg/hr for 22 µm wool and 160 kg/hr for 19.5 µm wool. This substantial increase in speed was brought about essentially by two breakthroughs. The first was the development of tandem burr beaters, which overcame the speed limitations of the single burr beater and enabled much higher carding speeds without any sacrifice in vegetable matter removal efficiency. The second innovation involved the use of two doffers at the swift, which maintained the transfer efficiency from swift to doffer (traditionally about 50%) at the higher carding speeds used.

Overall, the increase in production speed was achieved by:

- Increase in swift speed and diameter.
- Increase in the number of carding points.
- Optimising speed ratios between different rollers and fibre diameters.
- Improved vegetable matter removal.
- Double doffer.
- Efficient suction systems to keep the environment clean.

For superfine wools to achieve the longest Hauteur* and lowest noil, the ratio of swift worker pinning density to fibre density should be as high as

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* Hauteur is the mean fibre length of a top, based upon a length biased distribution.

possible; this can be achieved by increasing pin density or reducing fibre density, but it is not sufficient to reduce fibre density at some stage before the final swift.[13]

Developments that have helped to reduce the number, frequency and time required for setting and maintenance include:

- Centralised read-out and control of the different production parameters from the operator console.
- Variable-speed motor drive to allow operational changes of sliver weight, rate of production and carding intensity.
- Automatic doffing of full cans.
- Remote card (gap) settings.

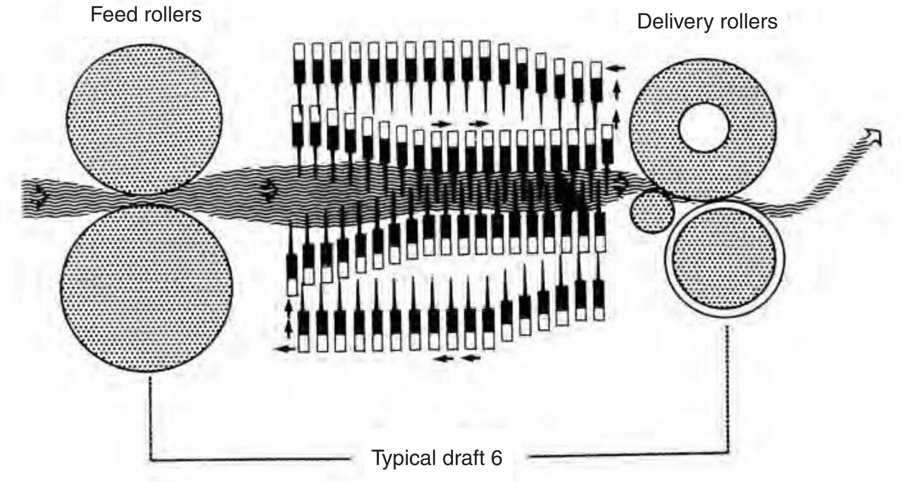
Meng *et al.*[14] critically reviewed the studies undertaken on fibre distribution and movement on the various carding elements, these governing carding efficiency, fibre mixing and levelling, productivity and web quality. They noted the pioneering work of Montfort[15] in mathematically modelling the fibre transfer process in a roller-top card as a finite Markov chain, this having been extended by other workers to cover other stochastic features of carding. They concluded that, according to theory, fibre mixing and equalising are improved by increasing the collecting power of workers and decreasing doffer transfer efficiency, but that the theory was not always supported by experimental work. Work has also been done to measure the fibre density on the various carding elements, one example being the optical system developed by Rust and Koella.[16]

The combined carding and combing operations remove some 99.5% of the vegetable matter present in the scoured wool.[17] Particularly troublesome, however, is contamination by polypropylene fibres from twine and by polyethylene wool pack fragments; the latter can be avoided by the use of nylon packs.

6.2.3 Preparer (intermediate) gilling

Generally, three preparer (intermediate) gilling operations follow carding (i.e. precede combing), coarser pinning generally being used for preparer than for finisher gilling.

The purpose of gilling the card sliver prior to combing is to remove hooks, align, straighten and blend the fibres and improve sliver uniformity (by doubling) so as to reduce fibre breakage and noil during combing as well any excessive extensibility of the card sliver. The more aligned the fibres and the fewer the fibre hooks, the lower the chances of fibre breakage during combing. Significant fibre breakage, however, can occur on high-speed intersecting gill boxes when using close front-roller settings.[18] Gilling tends to increase neps from fibre structures formed during carding. The gilling



6.5 Intersecting Gill Box. [*From Harrowfield.*[6]]

operation mostly removes trailing hooks, hence the need to reverse the direction of the sliver in subsequent operations. Gilling also creates some hooks.[19]

It is generally recognised that, in terms of the gilling operations, intersecting pins are necessary to ensure the proper drafting of wool. Intersecting (or intersector) gills (Fig. 6.5) generally have either screw-driven or chain-driven fallers or pinned rollers and rotary gills, and can have either single or double heads. Very few screw gills are now manufactured, chain gills dominating the market. The latter are versatile and have a production rate around double that of the screw gills, the pin paths being similar. Screw gills are, however, still preferred for very short fibres and where high loads are required. There are essentially four gilling machine manufacturers, namely NSC Schlumberger, OKK, Cognetex and Sant' Andrea Novara.

Gills can be equipped with either mechanical or electronic autolevellers and also can be fitted with spraying devices. Adding moisture during high speed gilling, e.g. by spraying, is important for achieving the desired regain for subsequent processing. A lubricant (0.1 to 0.3%) can also be sprayed onto the sliver during the first or second gilling operations, to assist in maintaining or increasing regain, minimising static and modifying static fibre-to-fibre cohesion.[5] Integrated suction and blowing systems keep the heads clean.

Okamura *et al.*[20] investigated the competing effects of draft and doubling on sliver evenness, evenness improving with doubling up to 12 slivers, after which it remains largely constant.

Direct linking of the card to the first gill and the third gill to the comb was found to reduce Hauteur but did not affect noil, neps, vegetable matter or fibre length distribution.[19] Introducing a fourth gilling operation in such a set up had a beneficial effect on Hauteur and noil.

6.2.4 Combing

Combing enables finer, stronger more uniform and less hairy yarns to be spun at better efficiency. Combing aligns the fibres and removes, as noil, fibres generally shorter than about 20 to 30 mm, vegetable matter and neps. Typically, Hauteur is increased by 10 to 15 mm and its coefficient of variation (CVH) is reduced by 10 to 20%,[21] while more than 95% of VM and neps are generally removed. Most of the short fibres removed by the comb as noil arise from fibre breakage during carding. Noil removed during combing has a market value about 40% of that of the top and is mainly utilized by the woollen industry.

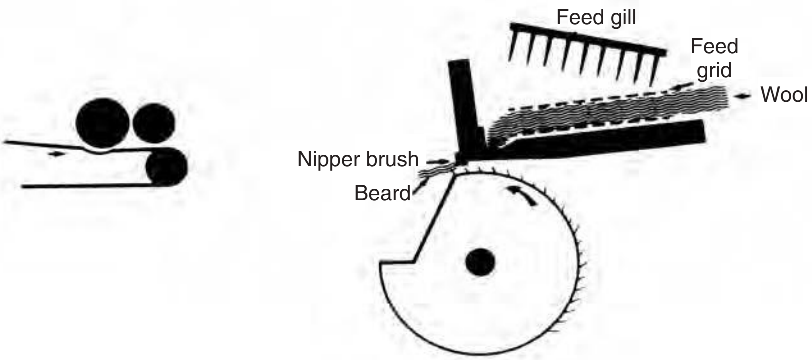
Originally, four types of combing machines, namely Noble (circular), Rectilinear (intermittent), Lister (nip-motion) and Holden (square motion), were used, but today combing is largely done on the rectilinear comb, also called a Continental, French, Heilmann or Schlumberger comb, the other types of combs no longer being manufactured. The move to rectilinear combing is mainly due to the increasing use of dry-combed as opposed to oil-combed tops and the shorter mean fibre lengths of the wool typically being processed nowadays. Rectilinear combing is the only type described here.

The principles of combing introduced during the mid 1800s were so good that they are still used today. The rectilinear comb was invented by Heilmann around 1845 and there are now two main manufacturers of wool combing machines, namely NSC Schlumberger and Sant' Andrea Novara. Examples of modern rectilinear combs are the *Sant' Andrea P100* (production 1.2 to 1.6 kg/μm) and the *Schlumberger PB33*, combing speeds being as high as 260 nips/min and visual readout providing instant information on virtually all aspects of the combing operation.

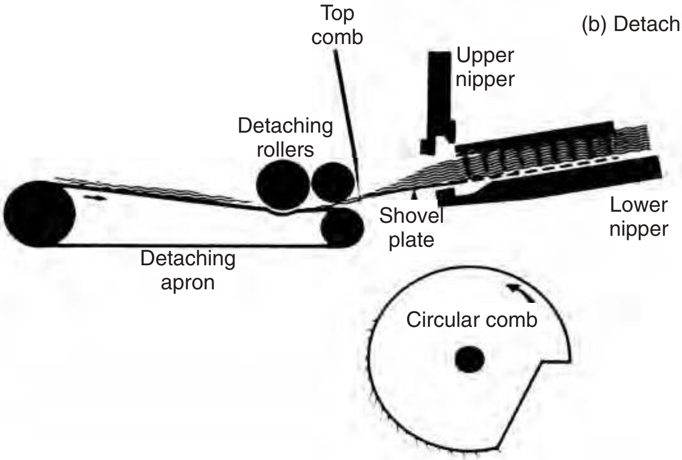
The basic operations of a combing machine are:[1]

- Feeding the slivers, typically 24 to 32, from balls or cans into the machine.
- Holding the fibres and combing the free fibre ends by means of a cylinder covered with progressively finer pins, any fibres not held being combed out as 'noil', along with neps and vegetable matter (Fig. 6.6).
- Gripping, by means of detaching (drawing off) rollers, and detaching the combed fringe of parallel fibres (which is now free of short fibres and entanglements), holding it, inserting the top comb, and pulling the

(a) Circular combing



(b) Detaching phase



6.6 Two phases of Rectilinear Combing. [*From Harrowfield.*[6]]

fibres through the pins of the top comb, which consists of a single row of pins, thereby removing any ungripped fibres as noil as well as neps and vegetable matter (Fig. 6.6).

- Laying the combed fringe on the previously combed fringes and forming a continuous 'combed' sliver from the tufts that have just been combed.

Brushes play an important role in combing; for example, in cleaning the circular and top combs and drawing-off cylinder, and pressing the fibres into the circular comb. Automatic adjustment of brushes, such as the nipper and circular brushes, and the simplified reversal and removal of the latter represent important developments.

A good measure of combing quality for Merino type wools is the percentage of fibres shorter than 15 mm in the top, which should preferably be below 1.8 to 2.0%.[22] It is affected by the total fatty matter content of the sliver (minimum 0.6 to 0.7%), the relative humidity (ideally 70 to 75%) and temperature (ideally 20° to 24 °C) of the combing shed, as well as by the regain of the wool (ideally around 20%) and the comb setting. The comb also breaks fibres, the breakage rate decreasing with decreasing fibre length, friction, combing intensity and with increasing fibre alignment and fibre strength. Fibre breakage during combing can range from around 17 to 31%.[23] Trailing hooks in the sliver fed to the comb are less likely to be broken during combing,[19] hence the importance of an uneven (odd) number of gilling operations between carding and combing, assuming cans are used.

The percentage of fibres shorter than 30 mm and of noil are influenced by the following factors:[24]

- Raw wool characteristics (e.g. fineness, staple length uniformity, staple strength, character or style, including levels of vegetable matter and other impurities).
- Quality of scouring and associated processes (greasy wool opening, wool felting. etc.).
- Quality of carding (card production, setting, speed).
- Quality of combing (comb setting, maintenance).

The amount of noil removed during combing may be expressed either as percentage noil or Tear (ratio) as follows:

$$\text{Noil } (\%) = \frac{\text{mass of noil} \times 100}{\text{mass of (noil + comb sliver)}} \qquad [6.1]$$

$$\text{Tear ratio} = \left(\frac{\text{mass of comb sliver}}{\text{mass of noil}} \right) : 1 \qquad [6.2]$$

It follows that:

$$\text{Noil } (\%) = \frac{100}{(\text{tear} + 1)} \qquad [6.3]$$

6.2.5 Backwashing

Backwashing is the process of treating wool slivers and tops in an aqueous detergent solution to remove any remaining unwanted impurities, such as residual grease and lubricants, and also to straighten the fibres (i.e. reduce fibre crimp). A lubricant is added at the end of the process, and also a fugitive tint to produce a temporary improvement in the colour (whiteness) of the wool. Typically, 36 slivers are fed to the backwashing machine, which consists of two scouring bowls and one rinse bowl followed by a suction drum dryer. A gilling process normally follows the backwashing process. Backwashing can either precede or follow the combing process, the former option normally being used for oil-combed tops (e.g. to remove dirt prior to Noble combing) and the latter for dry-combed tops (e.g. to reduce residual fatty matter and improve the appearance of the top). Top shrink-resist treatment (e.g. chlorine-Hercosett) is carried out in a machine similar to a backwashing machine except that there are extra bowls for chlorine and resin application (i.e. a total of five bowls) and an extra dryer to cure the resin.

6.2.6 Recombing

Recombing was originally introduced for dyed tops, in order to separate and align fibres which became entangled during dyeing and also to remove neps and slubs formed during dyeing, as well as any other remaining short fibres and neps; the neps in the top are generally reduced by over 80% (small neps by 70 to 80% and larger neps by 90 to 95%). A crimping box was introduced at the comb delivery to improve the cohesion and crimp of dyed tops and it is today often also used in first combing, particularly if chain gills are to be used subsequently.

Recombing is carried out after top-dyeing, when fibre blends are involved and also when producing high quality tops, and is particularly important when spinning fine high quality weaving yarns (25 tex and finer). In fact, recombing is increasingly being regarded as a cost-effective means of improving spinning and weaving efficiencies and improving fine yarn and fabric quality in terms of yarn faults (neps and slubs).

In the case of pure wool, a recombing line typically has four operations, two preparatory gillings preceding combing (often three in the case of dyed tops and four where different fibre types and colours are involved). Combing is followed by two finisher gillings, the chain gill increasingly being preferred. Six operations are typical for wool/polyester blends.

The two gillings prior to recombing are aimed at improving fibre alignment, thereby reducing noil, as well as achieving the correct fibre regain and sliver linear density (weight). The first finishing gill after recombing needs to randomize the fibre ends, which have been aligned at the comb, so as to facilitate subsequent drafting.

On modern combs, recombing production (kg/hr) for ecru wool is around 2.3 times the mean fibre diameter of the wool being processed. Noil produced during recombing varies from about 2 to 5%, depending upon factors such as the degree of entanglement of the top.

6.2.7 Top finishing (finisher gilling)

Top finishing refers to the 'finisher' gilling operations (generally two) subsequent to combing. Combing aligns the leading ends of the fibres, which adversely affects the sliver cohesion and subsequent processing. One of the main objectives of finisher gilling is to again randomise the leading fibre ends by drafting. Additional objectives are further blending, straightening and aligning of the fibres, the addition of moisture (and oil) according to the trade allowances and producing a top of the required linear density and evenness. A sliver (top) that is uniform in its linear density (weight per unit length) is produced and formed into a ball or bump top of specified size and weight. The main actions are drafting and doubling with pin control. Normally, the first finisher operation (gill box) has an auto-leveller unit. The first gilling operation generally involves up to 30 doublings and drafts of between 5 and 10, with the second only involving around 4 or 5 doublings.

6.2.8 Prediction of top properties

A quality specification for tops could include the following:[25]

- Mean fibre diameter
- Fibre diameter distribution (e.g. CV and Coarse Edge)
- Minimum (or mean) fibre length (Hauteur)
- Fibre length distribution (e.g. Max CV and Short Fibres)
- Oil (extractable or total fatty matter) content (IWTO value is 1%, but normally around 0.7% for dry-combed tops)
- Moisture content (18.25% IWTO)
- Colour
- Maximum coloured (dark) fibres (e.g. 100/kg)
- Neps and vegetable matter content
- Linear density
- Evenness
- Ash content
- pH

Considerable experimental work has been done at the CSIR in South Africa[26] and the CSIRO in Australia to quantify the effects of raw wool properties on top properties. These studies have led to empirical equations (e.g. CSIRO TEAM formulae) being derived that quantitatively relate the top properties, such as Hauteur, to those of the raw or greasy wool. Two examples are given for purposes of illustration:

CSIR (SAWTRI)[27]

$$\text{Hauteur (mm)} = 1.89 \times SL - 0.075 \times D \times Cr + 0.085 \times St \times D - 0.0048 \times SL^2 - 0.127SL \times Cr + 7.44 \times Cr - 39.7 \quad [6.4]$$

where SL = Staple Length (mm)
D = Mean Fibre Diameter (μm)
Cr = Staple Crimp Frequency (No/cm)
St = Style Index

CSIRO TEAM Formula[28,29]

$$H = 0.52 \times SL + 0.47 \times SS + 0.95 \times D - 0.45 \times VM - 0.19 \times M - 3.5 \quad [6.5]$$

$$CV(H) = 0.12 \times SL - 0.41 \times SS - 0.35 \times D + 0.20 \times M + 49.3 \quad [6.6]$$

$$\text{Noil (\%)} = -0.11 \times SL - 0.14 \times SS - 0.35 \times D + 0.94 \times VM + 27.7 \quad [6.7]$$

$$\text{Barbe (mm)} = \text{Hauteur}\left\{1 + \left(\frac{CV(H)}{100}\right)^2\right\} \quad [6.8]$$

where H = Hauteur (mm)
CV(H) = CV of Hauteur (%)
SL = Staple Length (mm)
SS = Staple Strength (N/ktex)
D = Mean Fibre Diameter (μm)
VM = Vegetable Matter Base (%)
M = Adjusted Percentage of Middle Breaks, which is given the value of 45 when M < 45% and the actual value when M > 45%
Noil = Romaine

The constant of 3.5 in eq. [6.5] can be adjusted according to the mill specific conditions.

Also $$H = \frac{1.17 \times SL}{1 + p} \quad [6.9]$$

where $$p = \frac{e^Y}{1 + e^Y} \quad [6.10]$$

$$Y = 0.561 - 0.113 \times D + 0.0276 \times SL - 0.0331 \times SS + 0.0125 \times M \quad [6.11]$$

and 1 − p is the probability that a fibre will not break during processing.

Another formula, requiring a computer program, also provides a measure of fibre length distribution.[28,29] The work carried out at the CSIRO led to the development of the *Sirolan-TOPSpec* processing prediction software,[30] which allows Hauteur, CV(H), Noil, short and long fibres and the shape of the fibre length distribution graph to be predicted from the raw wool test results for mean fibre diameter, VM base, staple length, staple strength and the position of staple break. A *Topmaker* System software was also developed; this also includes a *Topmaker* Data Management Program.[31] These have now been combined in the *Topspin* computer program, which can be used to predict and model an infinite array of performance and costs for greasy wool, tops and yarn. It is PC-based and can be configured for network. The Internet-based program can be licensed (desk-top licensing model).

Generally, Merino type tops for the pastel trade are expected to have fewer than 100 dark fibres per kilogram to be deemed 'commercially free from dark fibre'. Longree and Delfosse[32] reported on the latest results obtained with the *Optalyser* measurement of dark fibre and other contaminants, including neps, in wool tops. The *Optalyser* is an instrument that automatically measures and grades into different classes, coloured fibres, neps and vegetable matter particles in wool tops.

6.3 Preparation for spinning (drawing)

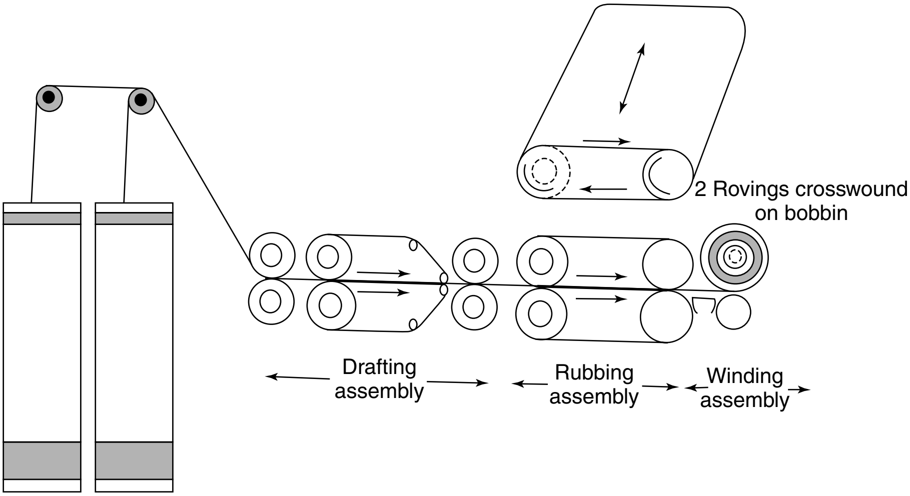
Although direct spinning of sliver into relatively coarse yarn is carried out on the semi-worsted system, thereby eliminating intermediate stages such as the roving stage, this requires high drafts, precise drafting and also good fibre control. Nevertheless, it is not yet possible to spin good quality and relatively fine yarn in this manner, partly because it eliminates the beneficial effects of sliver feed reversal and doubling. A sequence of processes, called drawing, is required to gradually and in a controlled manner, through a process of drafting, reduce the sliver linear density while controlling the movement and alignment of the fibres and the sliver linear density and evenness. This enables a roving (twisted or twistless) to be produced, of the linear density and evenness required for the efficient spinning of a yarn of the desired linear density and quality. Worsted drawing is the process of converting the top into a roving suitable for spinning, this also being referred to as 'preparation for spinning'. Within the present context, drawing can be defined as the series of operations involving doubling and drafting, the machines which work together for this purpose being called the 'drawing set'.[1]

Drafting essentially involves two sets of rollers that run at different surface speeds, the surface speed of the front rollers (delivery) being higher than that of the back (feed) rollers. The ratio of the surface speed of the delivery rollers to that of the feed rollers represents the numerical draft. The difference in surface speed causes the fibres to slide past one another, thereby reducing the number of fibres in the sliver cross section and its linear density correspondingly. It also helps to align the fibres. The distance between the nips of the front and back rollers is termed the ratch. The amount of draft which can be applied at any one stage is dependent upon the degree of fibre control, and can vary from as low as four to over 25, there generally being an optimum draft, depending upon the fibres and type of system used.

The fibres that are not held by either the front roller nip or the back roller nip are called floating fibres; these fibres are not positively controlled, being controlled only by the frictional forces of adjacent fibres. It is these uncontrolled floating fibres that prevent perfect drafting (i.e. where the random fibre arrangement is preserved). Various techniques are used to improve control over the floating fibres, including additives to increase interfibre friction, pins, twist and direct pressure (e.g. double aprons) and certain combinations of these. Most commonly, pins are used to control the fibres during the early stage of drawing and aprons during the final stages, pinned drafting systems generally being able to handle heavier loads and delivery than apron drafting systems (whereas the latter can handle higher drafts). Accurate settings on apron drafting systems are generally also more critical than on pinned drafting systems because the latter tend to be a more ‘tolerant’.

Although drafting is an effective means of aligning the fibres and reducing sliver linear density, it increases sliver unevenness. This problem is overcome by combining the actions of doubling and drafting. Doubling is the action of combining (feeding) two or more slivers into a drafting zone, which results in a more even output sliver. If no draft is applied, the irregularity of the output sliver equals that of the input sliver divided by the square root of the number of input slivers, assuming all input slivers have the same linear density. Nevertheless, to achieve the main objective of drawing, namely to reduce the sliver linear density, the overall draft needs to exceed the number of doublings. Typically, four operations, more for finer yarns and for finer and shorter wools, are used – for example, three gillings (e.g. screw or chain gills) and one roving. Factors, such as lower drafts, individual fibre movement, parallel fibres, fibre control, good lubrication and fewer short fibres, contribute towards good roller drafting and evenness of the drafted material. The reversal of the slivers, and consequently also the direction of fibre hooks, improves fibre randomisation during roller drafting and the removal of fibre hooks. This reduces the short-term irregularity of the sliver.

Autolevellers, introduced in the early 1950s, are used to improve the evenness of slivers by measuring the sliver thickness/linear density variation and then continuously altering the draft in such a way that more draft is applied to the thicker than to the thinner sections. Autolevellers, using



6.7 Rubbing Frame. [*From Grosberg and Iype.*[33]]

either mechanical or electronic measurement and draft control systems, can correct short, medium and long term variations, including the mean sliver linear density.

The final stage of spinning preparation is the roving or finisher stage. The roving is given the required cohesion, either by inserting low levels of twist (flyer) or, more commonly, by a twistless rubbing action (rubbing-frame), illustrated in Fig. 6.7.[33]

In the case of the production of twisted rovings, the sliver is generally drafted using an apron drafting system, after which twist is inserted by means of a flyer that inserts one turn of twist per revolution. The twisted roving is then wound onto the bobbin, which rotates with a higher surface speed than the flyer. The flyer also avoids balloon formation and any adverse effect on the fibre assembly due to air currents. Electronic flyer roving frames with integrated automatic doffing are amongst the latest developments.

In the case of the rubbing-frame, two slivers are normally fed to each drafting head, the strands remaining separate as they are consolidated and given cohesion by means of the oscillating rubbing action of the aprons. The pairs of consolidated rovings are cross-wound onto a double-meche package which is then used to feed two spindles on the spinning frame. In some cases, e.g. for automatic spinning frames, it is also possible to produce a single meche package from a single sliver. Horizontal and vertical rubbing frames are available. High-speed finisher rubbing frames can now also incorporate automatic bobbin doffing (and ticketing) and have spiral guides after the rubbing zone that improve roving cohesion and enable high-speed winding and also trouble-free unwinding on the spinning frame. Electronic contactless stop motions between the rubbing aprons and winding rollers can be fitted. Suction systems achieve good cleaning. Speeds of up to 275 m/min can be achieved on vertical rubbing frames with one rubbing zone (single pair of aprons), and up to 220 m/min on horizontal rubbing frames. Different drafting systems are also interchangeable.

Flyer rovings and rubbed rovings essentially produce yarn of virtually equivalent quality, although the former generally enable higher drafts, fewer end breakages and higher speeds in spinning. However, the capital investment costs for rubbing-frames are considerably lower than for flyer frames and the production higher, while fibre breakage also tends to be lower. The flyer roving frame, which can accommodate heavier packages (bobbins), has certain advantages over the rubbing-frames when processing fibres with low cohesion and crimp, such as mohair and certain coarse wools, and in some cases also when using spinning frames with broken end detectors or automatic pieceners.

6.4 Semi-worsted processing system

The semi-worsted system, developed in the first half of the 20th century mainly for synthetics and blends, essentially consists of carding, gilling and spinning, and, when spinning medium and fine yarns, also a roving process prior to spinning. Raw wools are scoured and dried, opened, blended and lubricated prior to carding. The machinery used is very similar to that employed in worsted processing. This system has production and economic advantages over both the woollen and worsted system, but generally cannot produce yarns of the same fineness, character or quality. The character of semi-worsted yarns is somewhere between that of the worsted and woollen yarns, being bulkier, weaker and less regular than worsted yarns.

A flow chart for the Semi-Worsted System is shown in Fig. 6.1, the absence of a combing operation being the main feature that distinguishes it from the Worsted System. The absence of combing and the very high production levels make it economically attractive and suitable for producing relatively coarse yarns (about 50 to 500 tex) destined for certain end-uses, particularly carpets but also upholstery and hand-knitting yarns. Best results are generally obtained with between about 80 and 120 fibres in the yarn cross-section, the latter being more typical. The Semi-Worsted System is used for medium to long, relatively coarse wools and man-made fibres, and it handles fibres with finenesses between about 9 and 16.5 dtex and with mean fibre length ranging roughly between 150 and 75 mm (but generally not shorter than 60 mm, and with 15% or fewer of fibres shorter than 30 mm).

The semi-worsted system does not offer the opportunity to remove post-carding short fibres and neps, making the carding operation a very critical one, nep removal increasing with increasing carding power. The subsequent gilling operations can reduce vegetable matter slightly but can also create neps. The configuration of the high-production semi-worsted cards, which are generally covered with rigid metallic wire, depends upon fibre type and characteristics, such as length and fineness, as well as upon the production rate required. A semi-worsted card typically has only one swift, with four or five sets of workers and strippers and usually twin doffers to ensure high production rates.[1] Depending upon applications, they can be supplied with morel rollers, a burr roller on the licker-in, with a fancy, with an intermediate doffer and with one or two delivery doffers.

Carding is followed by two to three drawing operations, mostly using chain gills, preferably three if no roving operation is involved, so that a majority of trailing hooks enter the spinning frame as leading hooks. The first and/or second passages can be autolevelling. The sliver is then either attenuated further into roving or spun directly on a ring frame, where drafts can be as high as 300 in a multiple (e.g. three) drafting zone, the main drafting taking place in the final double apron drafting zone.[34]

Correct fibre lubrication, for low fibre-to-metal dynamic friction, good fibre-to-fibre static friction and antistatic properties, is important. The optimum fatty matter content lies between about 0.7 and 1.2%.[35] A regain of about 19.5% appears acceptable for carding. Atmospheric conditions of 23 to 24°C and 70 to 75% RH can be regarded as suitable for the processing of wool, while for spinning it is 21 to 25°C and 55 to 60% RH.[35]

Elliott *et al.*,[35] building upon the work of Richards and Batwin to develop the concept of 'Total Carding Power', describe a computer model based upon published empirical and theoretical studies, for simulating the semi-worsted processing of wool, which predicts how changes in scoured wool properties and processing variables affect yarn irregularity, breaking strength and bulk, spinning performance, card waste and card mixing power. They assumed that most fibre breakage occurred when fibres were withdrawn from tufts during opening. Maddever *et al.*[36] reported on an Expert System which can be used to determine a suitable objective blend specification for the manufacture of wool carpet yarn by the woollen or semi-worsted routes, the fibre property specification depending upon the processing route, product specification and technical data.

6.5 Woollen processing system

6.5.1 Introduction

The woollen system represents the shortest processing route for staple fibres, essentially entailing only two primary stages, namely carding and spinning, although there is an important preliminary stage involving blending, opening and lubrication. Yarns ranging in linear density from about 30 to 2000 tex can be spun on the woollen system. A woollen yarn is defined[37,38] as a yarn made from any fibre processed on a card with at least two parts, and at least one intermediate feed, a condenser dividing the card web into slubbings or rovings, which are subsequently spun at drafts of up to 1.6 (or at most 2). Because spinning follows immediately after carding, the fibres are not very well aligned, and woollen yarns tend to be characterised by their bulkiness, low density, less orientated fibres, softness, low twist and hairiness. A 'woollen yarn' would normally refer to 100% wool, whereas a 'woollen-spun yarn' would refer to a yarn spun on the woollen system but which contains other fibres.

Virgin wool represents a relatively low proportion of the total fibres processed world-wide on the woollen system, the bulk being materials such as noils, re-used and reprocessed wools, man-made fibres, cotton etc. It is a very versatile system and represents one of the major systems for processing noils and other forms of fibre waste and recovered fibres into yarn, although capital and labour costs relative to its productivity impact negatively on its competitive position, particularly for medium to fine yarns. The continuing trend towards lighter-weight fabrics has also impacted negatively on the woollen system, although the move towards a more informal or casual form of dress favours it. Purely from an economic point of view, woollen processing compares unfavourably with semi-worsted processing. Nevertheless, these systems generally process widely different fibres and also produce yarns very different in character. The advantage of the woollen system is that it can handle natural and man-made fibres of almost any type, fineness and length, it being stated that any fibre can be processed, 'provided it has two ends'. In the case of wool, the woollen system handles from lambswool, 19 μm or even finer, to Shetland and crossbred wools 35 μm and coarser. In the main, fibres ranging in mean fibre length from about 25 to 80 mm[33] are processed on the woollen system. The wool processed on the woollen system is also referred to as carding wools (e.g. crutchings, locks, lambs and skirtings), generally having staple lengths ranging from about 30 to 50 mm. Woollen carding generally requires a low level of vegetable matter, vegetable matter adversely affecting carding and spinning, and it is important that only wool with little, if any, vegetable matter is processed on this system. This can be achieved by carbonising, a large proportion of wool processed on the woollen system being carbonised. Atmospheric conditions of 65% RH and 20°C are normally acceptable for processing wool on this system.

6.5.2 Pre-carding

Good opening and cleaning of the wool prior to carding are beneficial, the pre-carding operation generally involving blending, opening (willeying) and lubrication (oiling and antistatics). The blending operation, crucial for achieving quality woollen yarns and products, can be either manual or automatic, generally employing 'sandwich' (horizontal) layers and 'vertical slice' removal. Bin blending is still widely used for wool although various improved feeding and bin-emptying methods (e.g. automatic and continuous) have been introduced, with continuous inclined step blenders of increasing importance. It is vital that the components of the blend be similar in their degree of openness, composition and density. WRONZ applied the concept of linear programming (computer blending) for optimising wool blends for spinning carpet yarns, taking into consideration the relevant wool characteristics, such as diameter, length, bulk, medullation, colour and vegetable matter content.[39]

The *Fearnought* (coarse metallic toothed roller) type of machine, automatic or hand-fed, for example, is widely used for opening and blending, particularly at the final willeying (opening) stage prior to carding. It imparts a carding (fibre working) action, tufts being partially opened by the action of the fast moving cylinder and slower moving worker teeth, there often being four workers. Some fibre cleaning also takes place. Oiling/lubrication, generally takes place here, preferably at the exit, which is more effective, does not lead to the contamination of the *Fearnought* and does not interfere with its cleaning efficiency.

6.5.3 Lubrication (oiling)

The effectiveness and efficiency of woollen carding, and in particular fibre breakage, are dependent upon various factors, notably fibre lubrication. It is critically important that the wool is optimally lubricated prior to carding in order to minimize fibre breakage, fly waste and static electricity, provide additional fibre cohesion and facilitate drafting, condensing and spinning. Between about 5 and 10% of oil is usually applied, either as a straight oil or preferably a 50/50 oil/water emulsion, the card generally being key in the even distribution of the lubricants/additives.

Lubricants are used to:[40]

- Reduce static, fibre breakage and friction against the condenser rubber
- Lubricate the fibres for drawing and twisting
- Increase fibre cohesion
- Control the rate of build-up of trash on the card.

The essential requirements of a wool lubricant are as follows:

- Must have good lubrication and anti-static characteristics in carding and spinning within the temperature ranges experienced
- Should not discolour the wool
- Should not impair the strength of the fibre

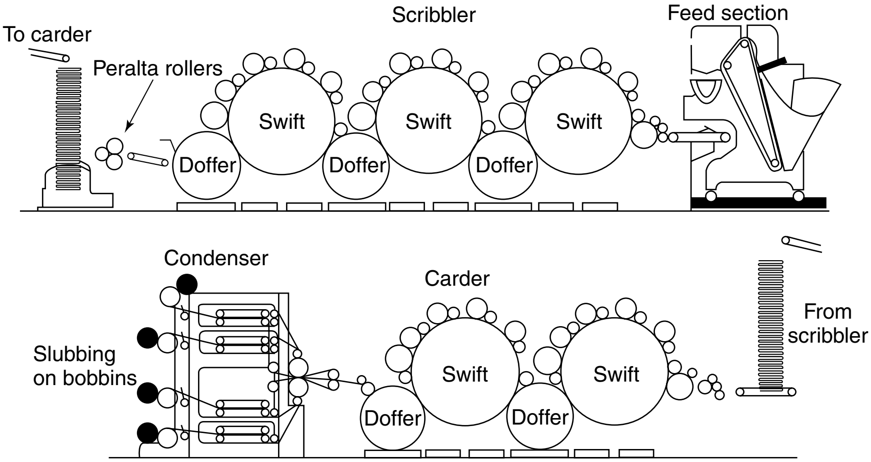
- Must not cause rusting or corrosion of the clothing (surfaces) with which it comes into contact
- Should not reduce the life-span of the leather aprons or condenser tapes
- Should form a stable and uniform emulsion with soft or moderately hard water
- Must remain stable in storage under various conditions of temperature
- Must be easily removed by scouring
- Should not cause or support spontaneous combustion
- Should not have or create an objectionable odour.

A further requirement today is that the lubricants should be environmentally friendly (e.g. bio-degradeable).

6.5.4 Carding

Because of the very shortness of the woollen processing route, the carding stage is critical and the woollen card is very sophisticated, particularly when relatively fine yarns are being produced. The card web needs to be uniform, both in terms of fibre blend and density (mass), across its width and along its length. The card needs to separate (individualise) and mix the fibres and this requirement largely determines the number of carding units.[42] The production of a woollen card is greatly dependent upon its width, which can vary from 1 to 4 m (typically around 3 m), and the fineness of the fibre being processed, increasing the card production rate tending to cause a deterioration in slubbing and yarn quality and neppiness. Neps increase as the wool becomes finer, carding rate increases and number of swifts decrease. Over the years there has been little real improvement in the basic productivity of the worker, stripper, swift and doffer actions, increased production largely coming from the increased width of the card.

Uniform feed, by a feed hopper, to the card is very important in terms of productivity and web and yarn quality, notably evenness. Feed can be manual, semi-automatic or automatic. The hopper feeds the tufts of fibres to the card, the aim being as uniform a feed of fibres as possible (in terms of both composition and weight), often achieved by weighing or otherwise monitoring and controlling the tufts and their rate of supply to the card. Automatic hopper feeds can provide either ‘weigh’ (gravimetric) or volumetric ‘chute’ delivery, with or without control systems, the latter entailing monitoring, correcting and controlling. There has been a significant move to chute feed-hoppers, hopper-fed via spiked lattice or automatically from a bin. Examples of advanced feed control systems are the *Tathams Microweigh 2000* system for a weigh hopper feed and the *Microfeed 2000* and *HDB Servolap* for volumetric chute hopper feeds. Double hoppers, microprocessor-controlled hoppers and volumetric feeds with autolevellers



6.8 Woollen card. [*From Grosberg and Iype.*[33]]

provide good long-term evenness, although some medium- and short-term variation remains.[41]

The composition of the woollen card (Fig. 6.8) depends upon the type of fibres to be processed, as well as the range of yarn linear densities to be produced, the card generally consisting of between two and seven units, typically four, each with a swift. The two-card set, with an intermediate feed, is becoming increasingly popular.

The major differences between woollen carding sets are as follows:

- Number of Sections
- Number of Swifts
- Number of Workers per Swift
- Type of Intermediate Feed
- Type of Condenser
- Type of Card Clothing

As shown in Fig. 6.8, a typical woollen card essentially consists of two parts or sections, namely the scribbler (breaker card) and carder (finisher card), there typically being two or three cylinders (swifts), each with a doffer (and four or five pairs of worker and stripper rollers each) in each section. The density of card clothing pinning increases along the machine, thereby increasing the opening of the fibre tufts correspondingly. Typically, the carding unit is made up of a breast section clothed with metallic wire with two workers and strippers; this is where the opening and disentangling of tufts commences. From the scribbler the sliver is fed, crosslapped (cross-fed) to improve blending, to the next section, i.e. to the carder. Various combinations of metallic and flexible card wire are supplied with woollen cards, the combinations depending upon the nature of the fibre being processed. Because of the high levels of oil used, flexible wire clothing, as opposed to metallic wire, was traditionally used on woollen cards, but there has been a significant move towards rigid metallic wire (garnett) clothing, the early part of the card (feed and breast sections) having been metallic for many years. Metallic wire is used extensively for synthetics and well-scoured coarse wools, semi-rigid or fillet wire being more popular for relatively 'greasy' and fine wools, although even in the case of fine wools there is a move towards metallic wire, particularly for the scribbler section (A G Brydon, private communication).

After the scribbler, the fibrous web can be passed through crush ('Peralta') rollers. The Peralta hardened steel rollers (precision ground and perfectly set) at the end of the scribbler section, crush vegetable matter, such as burr, in the open fibre web, the smaller crushed particles being easier to remove. The much finer fibres are not damaged to any significant extent.

On a woollen card there are typically around 15 to 30 positions where a carding or working action (closely set point-to-point) takes place, which breaks down the tufts into individual fibres, a typical fibre passing through such an action between 100 and 300 times.[42] Fibre separation (working) generally takes place where two card-clothed surfaces, set closely to each other and the teeth pointing towards each other, move at different speeds. The stripping action occurs when a faster moving roller, with the clothing tips pointing in the direction of movement, removes all the fibres from the backs of the teeth of a slower moving roller.

Fibre opening takes place at the interfaces between the feedrollers and licker-in, the swift and the workers, and the doffer and swift, being completed when the fibre reaches the last swift of the scribbler section. The main opening at the swift–worker interface is due to the combing action of the swift wires on the tufts of fibres held by the slower moving workers. Work by WRONZ[43,44] has modelled fibre breakage on the basis of fibre tensile properties and the mechanics of tuft opening. In addition to fibre separation, during which process significant fibre breakage takes place, the carding operation is also crucial for blending (mixing) the fibres, the collecting power of the doffer playing an important role in this respect. According to Richards,[45] the Delay Factor (D), or time constant, which is a measure of the average time that fibres take to pass through a part (excluding time on doffers), may be calculated as follows:

$$\mathrm{D\ (Delay\ Factor)} = 1/\mathrm{f}\left(1 + \sum \mathrm{np}/1 - \mathrm{p}\right) \qquad [6.12]$$

where

f = collecting fraction of the doffer
p = collecting fraction of the worker
n = number of swift revolutions during which the fibre spends on a worker, stripper and swift from when it is picked up until it is released again.

In the case of four workers this becomes:

$$D = 1/f\left(1 + \frac{4np}{1-p}\right)$$

$$C \text{ (Carding Power)} = 1/f\left(1 + \sum 1/1 - p\right)$$

C, a measure of the card–opening ability and determined by the average number of times a fibre passes through the setting region between swift and workers and swift and doffer, is the same as the average number of workings (t) received by a fibre as derived by Montfort.[46] Carding power increases as the delay factor increases.

The Intermediate feed (intermittent or continuous) transfers the output of the one carding machine (section) to the next, the objectives being:

- to convert the fibres emerging from the one carding section into a convenient form for transfer to the next carding machine or section
- to reduce irregularities in the rate of flow of fibres through the card
- to improve fibre blending
- to produce a uniform shade where fibres of different colours are involved

Examples of the different types or combinations of feeds are:

- Pull-away Centre-Draw and Cross Feed
- Wide Side-Draw and Cross Feed
- Pull-away Centre-Draw
- Scotch Feed (finer yarns)
- Parallel-Fibre Feed (bulkier fibre and coarser yarns)

The pull-away centre-draw, reciprocating overhead and Scotch feed is considered to offer a simple, yet effective, operation. The Scotch feed is popular as it is simple, versatile and convenient for small lots. The wider cards have resulted in a move away from the side-draw Scotch feed system to centre-draw cross-feed and broad-band or parallel-fibre feed systems.

The Condenser divides the web of fibres emerging from the last (final) carding machine into a number of continuous ribbons, consolidates these ribbons into cylindrical, twistless slubbings and winds the slubbings onto individual cheeses positioned side by side on condenser bobbins (positioned in a creel) for transfer to the spinning frame. There are two different methods of condensing, namely by Ring Doffers or by Tape Condensers, the latter being more common. Ring Doffers (single or double) separate the web into ribbons by a carding action, producing strong, straight and uniform slubbings while Tape Condensers (Series or Endless) separate the web into ribbons by a tearing action. Tape condensers can be offered with single (fine yarn), tandem/double (medium yarns), or triple (coarse yarns) rub arrangements. Tape condensers are generally manufactured with four or six heights (tiers), the latter increasing the production and number of ends, or the end spacing, and package size. Condenser rubbing leathers, used for condensing the narrow strip of materials, are made in various designs; leather aprons have largely been replaced by either grooved or smooth fabric/rubber/ synthetic aprons. A well-rubbed slubbing has good cohesion and wraps onto the condenser bobbin well and unwinds easily and cleanly during spinning, different creel assemblies being used for mule spinning and ring spinning creel assemblies including Ordinary, Traverse and Tandem. Doffing of the condenser bobbins can be either manual or automatic, being one of the most costly operations in woollen processing. Automatic doffing can increase card productivity by up to 12%.

Two systems are available to increase the length of slubbings (by up to 50%) on the condenser spool, thereby extending the time cards, and spinning frames can run between creel changes. They are the *Tathams Denspak Creel System* and the *High Density Spooling (HDS) System*. The latter was first shown at *ITMA* in 1987, utilising friction in a groove and a difference in the surface speed of the bobbin/spool and the rubbing apron to create controlled tension and drafts (about 6% actual), enabling increased card production. It also has a beneficial effect on spinning performance and yarn properties.

Optical- and capacitance-based devices are used to automatically monitor the evenness of the slubbings or rovings at the output of the card, between the rub apron and the package. One such system (*Rovingtex*), using a capacitance measuring system, has an alarm should the values exceed preset limits. Open and closed loop automatic controllers are used to correct variations in card web mass per unit area. Automatic setting of the machine when changing slubbing weight (linear density) is also available. The use of electronics for control and automation has been one of the main areas of development, it now being possible to electronically programme and control the main functions of the woollen card.

Significant fibre breakage takes place during carding, the amount of fibre breakage depending upon factors such as fibre entanglement, fibre lubrication (friction), fibre strength, fibre length, fibre crimp, fibre regain and the severity of the carding action.

6.5.5 Woollen spinning*

Although ring frames dominate woollen spinning, the mule frame still occupies an important position. The ring frame produces about 2.5 times per spindle more than the mule frame and occupies about a third of the floor-space per spindle. The mule can, however, spin lower twist, bulkier, softer, more even and less hairy yarn, and can handle more difficult fibres and blends than the ring frame. Mule spinning enables finer yarns to be spun than ring spinning, due to the lower tensions involved and the advantages of spindle drafting over roller drafting, drafts often being about 5% higher. Mule spinning, however, is more labour intensive and requires greater operator skills than ring spinning.

It is generally accepted that commercial woollen spinning limits are about 100 fibres (125 being more typical) in the yarn cross-section, compared to 40 for worsted spinning, Lee[22] suggesting a minimum of 120 per strand for two-ply yarn and 200 for singles yarn. In woollen spinning, draft (normally at least 1.2 but less than 1.6, with a maximum of 2) is usually effected against twist, its main function being to straighten rather than to relatively displace the fibres.

6.5.5.1 Ring spinning

A false twist device in the drafting zone close to the front rollers, inserting about 80 to 160 turns/m (typically 40% of the spindle speed), reduces the strand irregularity by preferentially drafting thick places with low twist, since twist generally runs into thinner places thereby increasing inter-fibre cohesion. Drafting is affected by the orientation of the hooks in the slubbing, best being when the slubbing is fed with the majority of hooks trailing, a draft of around 1.5 appearing to be desirable. Collapsed balloons (e.g. using a spindle top extension probe or finger or else a modified spindle top) have become popular and rings with diameters of up to 300 mm are used, traveller speeds peaking at around 40 m/s.

Automation in ring spinning, e.g. automatic doffing of full packages, fitting of new tubes, replacing slubbing packages, joining of slubbings, underwinding, stopping and restarting, represent notable developments.

Automatic doffing reduces labour and improves productivity, and so have end-break detectors and monitors that allow rogue spindles to be identified, 3 to 4% of such spindles often being responsible for 30 to 40% of end breaks. Information on traveller, roller and spindle speeds enables yarn production and twist to be determined by monitoring systems, such as the *Uster*

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*Note: See also Section 6.6 Spinning

Ringdata. Electronic console adjustment of the various spinning operations and parameters is also possible.

6.5.5.2 *Mule spinning*

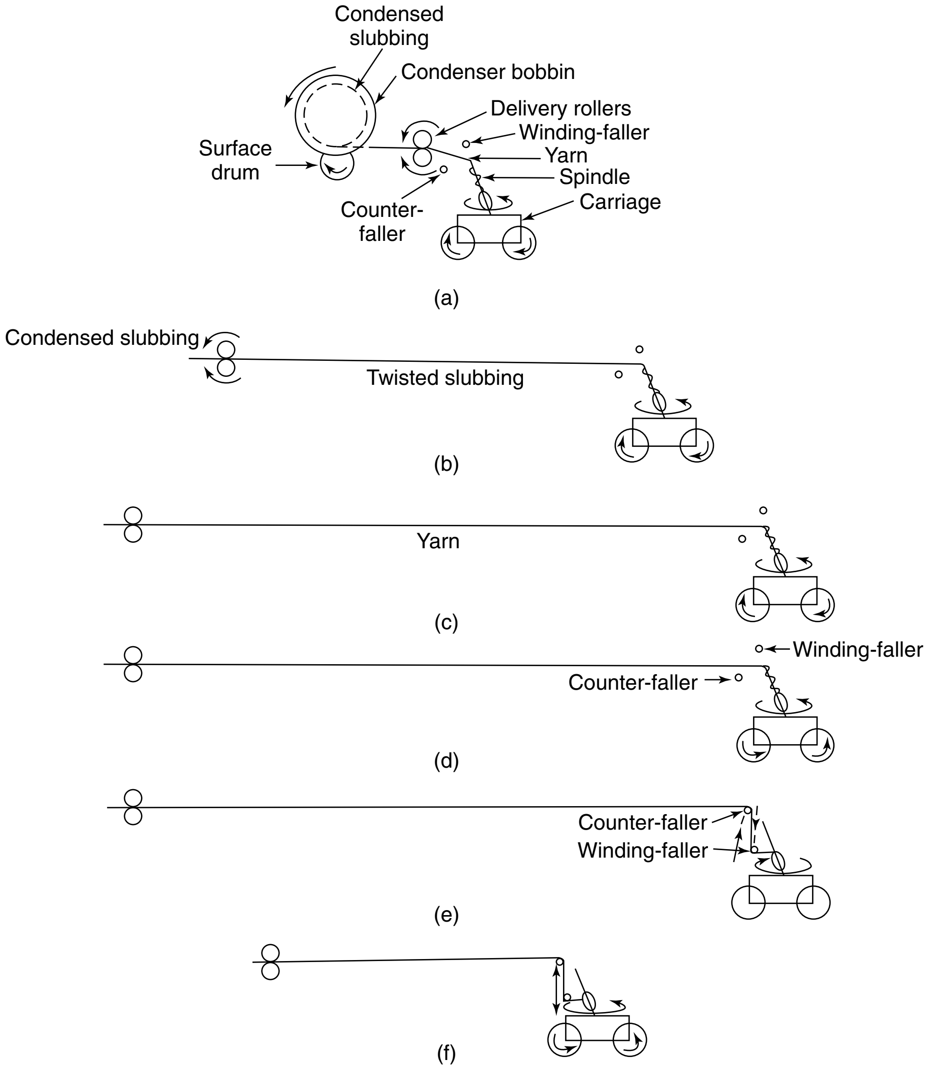
This system of intermittent spinning was invented by Samuel Crompton in 1774, the self-acting mule being patented by Roberts in 1825, and is now virtually only used for spinning fine woollen yarns (woollen mule) from woollen slubbings. The mule frame, utilising draft-against-twist, comprises two parts: a fixed part (headstock) and a moving part (carriage) that moves backwards and forwards on rails (although in some cases, the carriage remains stationary while the headstock moves, while in others, both systems move). The operation of the woollen mule consists of the following five stages (Fig. 6.9):

i) Slubbing Delivery: The carriage moves forward at approximately the same speed as the slubbing is delivered and the spindles rotate at a slow speed to insert twist into the slubbing.
ii) Drafting: At this stage the delivery rollers stop but the carriage continues to move and the spindle continues to rotate at the same speed, thereby causing a draft-against-twist of the twisted slubbing.
iii) Final Twist Insertion: At this stage the carriage is stationary at its most forward position but then moves slightly towards the stationary delivery rollers to compensate for yarn shortening due to the twist, and the spindles are now rotating at full speed to complete twist insertion (the faller wires out of operation).
iv) Backing-off: With the carriage stationary, the spindle now rotates in the opposite direction, thereby unwinding the yarn remaining on the spindle when twisting stopped. The winding faller is lowered and the counter faller raised so as to take-up the slack in the yarn, the winding faller being level with the nose of the cop.
v) Winding-on: The carriage returns towards the rollers to assume its original position at the start of the cycle; the spindles rotate to wind the yarn onto the cop under the guiding of the winding faller.

Today, electronic (computer-controlled), totally-automated self-acting Mule spinning frames are produced, modern examples attaining speeds of 15 to 18 m/min and featuring automatic doffing, fitting of empty tubes, yarn tension control, slubbing replacement and piecening, the complete cycle taking less than four minutes.

6.5.5.3 *General*

Woollen yarn properties can be predicted from the wool fibre properties, very much as is the case for worsted yarns.[47,48,49] On the basis of their



6.9 Mule Spinning [*From Octoby*[1]].

processing trials on 68 wool lots, and using multiple regression analysis, van der Merwe and Gee[47] established empirical relationships between on the one hand, carding and spinning performance and yarn and knitted fabric performance, and on the other hand, fibre properties. They showed that mean fibre diameter and its CV were the most important fibre properties influencing processing performance and yarn and fabric properties. The next most important property was fibre bulk resistance to compression followed by mean fibre length. An increase in either mean fibre diameter or

CV of diameter, more specifically the former, in most cases had an adverse effect on carding performance and yarn properties. An increase in bulk resistance to compression had an adverse effect on yarn and fabric strength, fibre breakage during carding, fabric abrasion resistance and spinnability but had a beneficial effect on yarn extension, bulk and hairiness and on cross-card variation. An increase in mean fibre length, within the ranges covered, generally had a beneficial effect. A 'length after carding' test has also been developed in which a small scale card and double draft gill system are used to convert the scoured wool into a sliver suitable for Almeter fibre length measurement.[50] It correlates well with actual results.

6.6 Spinning

6.6.1 Introduction

The ultimate aim of spinning is to produce yarn (i.e. a coherent and cohesive fibre strand) of the required linear density (count) and which has good evenness, tensile properties and a minimum number of faults.

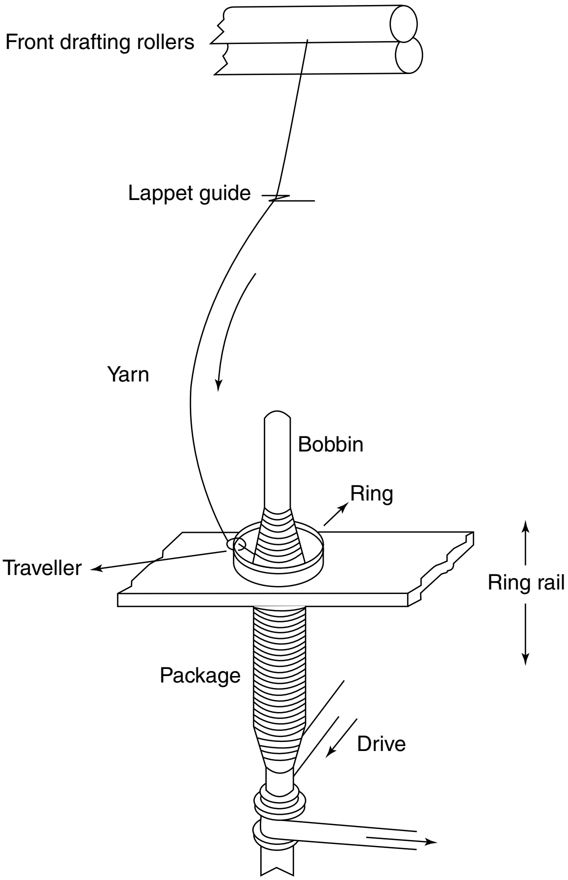
Spinning can be divided into the following three basic operations:

i) Attenuation (drafting) of the roving, sliver (semi-worsted) or slubbing (woollen) to the required linear density.
ii) Imparting cohesion to the fibrous strand, usually by twist insertion.
iii) Winding the yarn onto an appropriate package.

Spinning machines can be divided[1] into two main groups, namely intermittent (e.g. mule) and continuous (e.g. ring, flyer, cap, open-end, self-twist, twistless, wrap-spinning). It should be noted that wool is not commonly spun on the open-end (rotor) spinning system, although a recent paper[51] indicates progress in this direction, 42 tex to 111 tex yarns being spun successfully from 20.5 µm wool at speeds of around 100 m/min. Nevertheless, the wool has to meet very strict requirements in terms of residual grease levels (0.1 to 0.3%) and fibre length; for example, an average fibre length of 30 to 40 mm is required for a 46 mm rotor diameter, with the longest 1% of fibres not exceeding about 60 mm.

6.6.2 Ring spinning

Because of its versatility in terms of yarn linear density and fibre type, and also the superior quality and character of the yarn it produces, ring spinning (Fig. 6.10) remains by far the most popular system for spinning wool, particularly for fine yarns, there being some 16 million long-staple ring spindles installed worldwide. It includes two-strand and compact/condensed type spinning.



6.10 Ring Spinning [*From Grosberg and Iype*[33]].

The input into the ring-frame can be twistless (rubbed) or twisted (flyer) rovings in the case of the worsted and semi-worsted system, slivers in the case of the semi-worsted system, and slubbings in the case of the woollen system. Double apron drafting, draft typically 20, is generally used in modern ring-frames, except in low-draft woollen spinning and some of the high-draft spinning systems.

The yarn production of ring-frames is limited largely because of limitations in the speed of the traveller on the ring (around 40 m/s maximum), due to excessive wear and heat being generated by the traveller at high speeds, as well as by the yarn tension and tension variability (peaks) generated during spinning. The maximum spindle speed is normally around 13 000 r/min and yarn production 40 m/min. The tension on the yarn can be controlled by the traveller, largely depending upon the frictional resistance of the traveller against the ring, which in turn is largely determined by the rotational speed. Requirements of the traveller include good heat dissipation, sufficient thread space, matching of traveller size and shape to the ring flange and good sliding properties.[1]

Yarn spinning tension is affected by the length and diameter of the balloon, the use of balloon control or suppression devices (e.g. rings, and spindle attachments) enabling the yarn tensions in the balloon to be reduced by reducing (semi-collapsing) or collapsing the balloon, thereby allowing spinning speeds and/or package sizes to be increased and power consumption to be reduced. Traveller speeds as high as 45 m/s become possible when, for example, using sintered rings and nylon travellers. The use of collapsed balloons is particularly important for the larger packages used in woollen and semi-worsted spinning systems.

Rotating rings were explored as another way to overcome traveller speed and yarn tension limitations, but they have not yet found wide application.

According to Oxtoby[1], about 85% of the total power requirements of a ring-frame is consumed in driving the spindles (depending on yarn density, package size, spindle speed, etc.), the balance being consumed by the drafting and lifter mechanisms.

The following factors have the main influence on spinning conditions:[1]

- Ring diameter (affects package size, yarn tension, traveller and spindle speeds, power consumption, capital costs, floorspace and doffing costs).
- Balloon height (affects power consumption, capital cost, floorspace, doffing costs, balloon collapse). Longest balloon height without balloon collapse is the most economical.
- Spindle speed.
- Traveller mass.

Spinning production and cost are related to the level of twist inserted, which in turn is related to spinning efficiency (end breakage rate) and yarn properties (notably tensile, bulk, hairiness and stiffness). The minimum twist required to produce acceptable spinning performance and yarn properties is normally selected.

It is generally held that surface fibres have the same angle of inclination to the yarn axis when yarns have the same twist factor (turns/cm $\sqrt{\text{tex}}$), and that such yarns therefore have a similar geometry. Fibre migration (variable helix angle at different positions along the fibre length) determines the yarn structure, and properties and can be characterised by:[1]

- Mean fibre radial position
- Migration amplitude
- Mean migration intensity (i.e. rate of change of radial position)

Modern ring frames can incorporate automatic doffing, sliver/roving stop motions, thread break indicators, electronic speed and package building programs, and automatic piecening, data collection, ring cleaning. They can also be linked to the winders, with a cop steamer stage between spinning and winding.[52]

Turpie[53] developed the MSS accelerated spinnability test while Huang *et al.*[54,55] developed a model for predicting end breaks in worsted spinning. Yarn strength variation, followed by mean yarn strength and spinning tension were the main factors in the model. They found that the spinning tension varied considerably, the CV being typically 15 to 20%. End breaks are caused either by the yarn spinning tension exceeding the yarn strength (more particularly that of the yarn weak places) or by flaws, such as neps, vegetable matter and short fibres, in the input material.

Various studies,[26,56] have shown that mean fibre diameter is by far the most important fibre property in terms of spinning performance and limits, and yarn quality, this largely because of its effect on the number of fibres in the yarn cross-section when yarn linear density is constant. It is followed in importance by mean fibre length (a 10 mm change in mean fibre length having approximately the same effect as a 1 μm change in mean fibre diameter), then fibre length distribution (CV and short fibres), fibre crimp (lower crimp generally beneficial), fibre strength and CV of diameter (a 5% absolute change in CV having approximately the same effect as a 1 μm change in mean fibre diameter).

For worsted ring spinning, spinning limits are normally taken to be 35 fibres in the yarn cross-section although commercial spinning limits range between 40 and 50 fibres, generally 50 for dyed fibres. Normally, around 40 to 50 end breaks per 1000 spindle hours represent the maximum acceptable limit for commercial spinning of wool.

The average number of fibres (n) in the yarn cross-section can be calculated as follows:

$$n = \frac{972 \times \text{yarn linear density}}{D^2\left\{1+\left(\frac{CV_D}{100}\right)^2\right\}} \qquad [6.13]$$

where

yarn linear density is in tex units,
D = mean fibre diameter (μm),
and CV_D = CV of fibre diameter (%)

For a fairly typical CV_D of 24.5%, equation [6.13] becomes:

$n = 917\,\text{tex}/D^2$.

According to Martindale,[57] the limiting (or ideal) yarn irregularity (CV_L) assuming completely random distribution of fibres, can be calculated as follows:

$$CV_L(\%) = 100\sqrt{\frac{\left\{1+4\left(\frac{CV_D}{100}\right)^2\right\}}{n}} \qquad [6.14]$$

which becomes

$$CV_L = 3.208D\sqrt{\frac{\left\{1+5\left(\frac{CV_D}{100}\right)^2\right\}}{\text{tex}}} \qquad [6.15]$$

or

$$CV_L = \frac{3.208Fe}{\sqrt{\text{tex}}} \qquad [6.16]$$

where Fe is the effective fineness as termed by Anderson.[58]

$$Fe = D\sqrt{1+5\left(\frac{CV_D}{100}\right)^2} \qquad [6.17]$$

Fe illustrates the relative effects of D and CV_D on yarn irregularity as well as on yarn and fabric stiffness.[59,60]

An irregularity index (I) for yarns and slivers is also often used to provide a measure of the yarn unevenness relative to the fibre used.

I can be calculated as follows:

$$I = \frac{CV(\%)}{CV_L} \qquad [6.18]$$

If $CV_D = 25\%$ this becomes:

$$I = \frac{CV(\%)\sqrt{n}}{112} \qquad [6.19]$$

where CV(%) = actual or measured yarn or sliver irregularity and n = the number of fibres in the yarn (or sliver) cross-section, calculated according to eq. [6.13].

I = 1.2 is regarded as very even for worsted yarns and 1.4 for fine woollen yarns.[22]

Bona[61] gave the following empirical relationship, based upon an important worsted spinning mill in Biella, which enables the optimum fibre fineness (diameter) to be calculated if the desired yarn linear density is known, and the optimum yarn linear density to be calculated for a given fibre fineness or diameter:

$$\bar{n}_s = \frac{150}{\sqrt[3]{Nm}} = 15(\sqrt[3]{tex}) = 15(tex)^{0.33} \qquad [6.20]$$

where $\bar{n}_s$ = optimum average number of fibres in the yarn cross-section.

Comprehensive empirical studies have been carried out at the CSIR in South Africa[26] and the CSIRO in Australia to relate ring spinning performance and yarn properties to top fibre properties and to derive empirical relationships that quantify the various effects and enable prediction. The following are examples[26] of the empirical relationships derived in South Africa on the bases of the results obtained on more than 1000 wool worsted yarns.

$$\text{Irregularity (CV\%)} \ \alpha \ D^{0.8} L^{-0.2} \text{Compr.}^{0.1} \text{tex}^{-0.4} \qquad [6.21]$$

$$\text{Tenacity (cN/tex)} \ \alpha \ D^{-0.8} L^{0.4} \text{Compr.}^{-0.2} \text{tex}^{0.2} \qquad [6.22]$$

where D = Mean fibre diameter (μm)
Compr. = Resistance to compression (mm)
L = Mean fibre length (mm)

The general empirical relationship between Irregularity and number of fibres (n) in the yarn cross-section and mean fibre length (L) was found to be:

$$\text{Irregularity (CV\%)} \ \alpha \ L^{-0.2} n^{-0.4} \qquad [6.23]$$

The CSIRO work has led to the *Sirolan Yarnspec* prediction software,[62] which has been superseded by the *Topspin* computer program that combines top prediction from greasy wool and prediction of spinning performance and singles worsted yarn properties, also including commercial costing details. It also enables the spinning mill to benchmark itself against 'best commercial practice'.

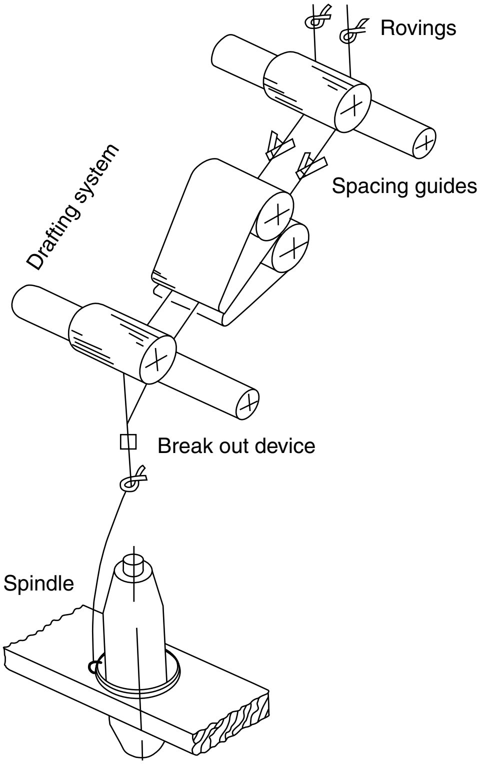
According to the work of Gore *et al.*,[63] the fibre tensile properties do not significantly affect processing performance, from re-combing to yarn and fabric, until the fibre extension at break falls below about 28 to 32% (corresponding to a bundle tenacity of 7 to 9 cN/tex), after which a significant deterioration in performance may be found. Nevertheless, some work[64] indicates that a 10% change in fibre bundle strength has approximately the same effect on spinning end breaks as a 6 to 9 mm change in Hauteur.

Cheng *et al.*,[65] applied Neural Networks to successfully predict spinning performance and yarn quality.

6.6.3 Two-strand spinning (Twin-spun)

Considerable efforts have been directed towards eliminating two-folding (plying) in the production of weaving yarns, the ultimate aim being to produce as fine a yarn as possible on the spinning frame, which can be woven without resorting to either two-plying or sizing. In the main, two approaches have been followed, namely: Two-strand spinning (e.g. *Sirospun* and *Duospun*) and Compact (condensed) spinning.

Two-strand spinning, also referred to as spin-twist or double-rove spinning, involves two rovings being fed separately to the same double apron drafting system, each strand receiving some twist before they are combined at the convergence point after the front rollers. Two examples are *Sirospun* (Fig. 6.11)[68] and *Duospun*, the former using a mechanical break-out device and the latter suction and automatic repiecening to prevent spinning when one strand breaks. It is also possible to include a filament (flat, stretch or textured). In the case of *Sirospun*, the only modifications required to the ringframe are the following:



6.11 Two strand (*Sirospun*) spinning. [*From Plate.*[68]]

- New rear roving guide to feed the two rovings separately to the rear rollers
- Central roving guide, fitted behind the aprons, which controls the strand-spacing
- A front zone condenser with two condensing slots at the correct strand spacing
- Break-out device
- Provision for double creels

The strand length (thread length between the convergence point and the nip of the front rollers) should be a minimum, it being related to the strand spacing. The strand spacing needs to be optimal, as large strand spacing beneficially affects yarn hairiness and abrasion resistance but adversely affects spinning performance. Spinning limits are about 35 fibres per strand cross-section, a low short fibre content being important. A minimum of 0.8% lubricant prior to combing is required, and 4 drawing passages are desirable. A draft of 20 appears optimum.[67] *Sirospun* reduces spinning costs by some 55% on average but increases weaving costs by about 1% because of slightly higher yarn breakage rates.

Maximum yarn strength occurs at a tex twist factor of between 38 and 41, increasing to about 44 for very fine yarns.[67] The recommended tex twist factor for a *Sirospun* yarn is around 38 (α m = 120).[67] Typically, the tenacity of the two-strand yarn is equal to, or slightly greater than, that of the corresponding two-ply yarn, its extension 10 to 30% greater, its irregularity slightly greater, its hairiness slightly less and it contains more thin places. It also produces a more streaky fabric. Its abrasion resistance falls between that of two-ply yarn and that of a singles yarn of similar tex and twist.[68] Compared to a two-ply yarn, however, it is twist-lively (similar to a singles yarn). It is also more circular and less easily deformed. Yarn joint quality is very important, splicing (thermal and pneumatic) generally being preferred, particularly for medium and coarse yarns. Z/Z Fisherman's knots also give good performance, particularly for fine yarns.

Approximately 2% of a suitable lubricant (e.g. anionic) in the final rinse of the package dyeing cycle reduces yarn-to-metal friction and improves warping and weaving efficiencies. The application of a suitable lubricant during beaming also improves weavability.

Double-rove spinning of woollen slubbings (lambswool) on a woollen ringframe has also met with some success.[69]

6.6.4 Compact (condensed) and related spinning systems

6.6.4.1 Compact (condensed) spinning

Following upon the two-strand spinning developments, further work has been undertaken to produce ring-spun singles yarns with superior properties (notably tensile, hairiness, abrasion and pilling). The ultimate aim was to be able to weave the yarn without plying or sizing. Considerable success has been achieved, although it is not yet possible to produce, in one operation, ring-spun wool yarn with the same weaving performance as the traditional two-ply yarn. It has been stated, however,[70] that such yarns are not necessarily a direct substitute for the traditional yarns but that the fabric structure may have to be adapted to the new yarns.

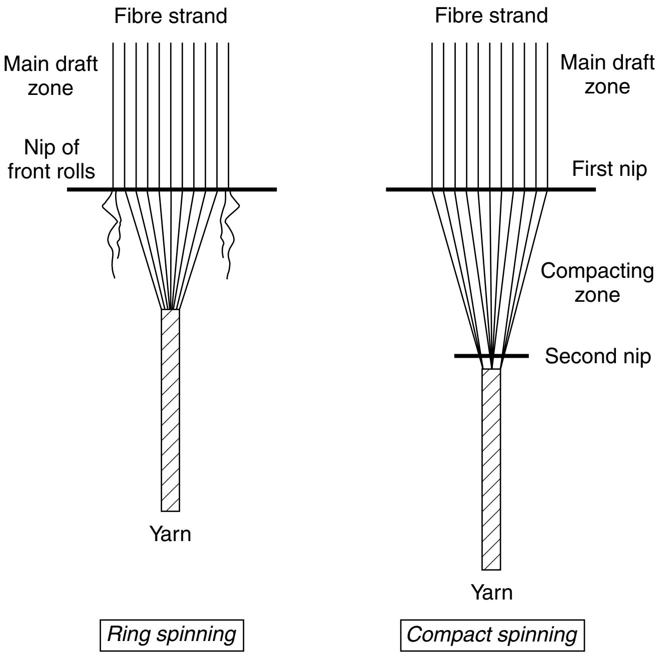
A number of papers[70–74] at the *2000 International Wool Textile Research Conference* in Aachen dealt with Compact and related spinning techniques.

The width of the spinning triangle (fibre beard) has been shown to be related to the spinning tension as well as to the hairiness and imperfect integration of the fibres into the yarn.[75] Considerable effort has therefore been directed towards narrowing (condensing) the spinning triangle at the exit of the front rollers. Most of the resulting systems, also referred to as condensed spinning, involve a condensed, narrow spinning triangle at the front roller nip (Fig. 6.12),[76] and better control of the fibres at the exit of the front roller nip and their integration (binding) into the yarn, eliminating peripheral fibres. This has been done by introducing an intermediate (condensing) zone between the front roller delivery and the yarn formation (twist insertion) point, in which the fibrous ribbon width and spinning triangle are reduced, giving improved spinning efficiencies, fibre alignment, smoothness, hairiness, tensile properties and compactness in the yarn, as well as less fibre waste. The condensing systems used to accomplish this, and which are generally easily attached to, and dismantled from, the spinning frame, generally involve pneumatics (vacuum), applied, for example to a perforated front roller, lattice or apron.

Examples include the *EliTe* spinning system of Suessen, *ComforSpun (Com4)* of Rieter, and *Air-Com-Tex* of Zinser.

6.6.4.2 Solospun[73,74]

Solospun (developed by WRONZ, CSIRO and IWS) merely entails the clipping of a pair of grooved plastic rollers to the drafting arms of the spinning frame, in front of the delivery rollers. These split the fibre ribbon emerging from the front rollers, and do not permit twist to reach the front roller nip, allowing the fibres (substrands) to twist and recombine in such a way as to increase the localized twist (cohesion) and compactness of the

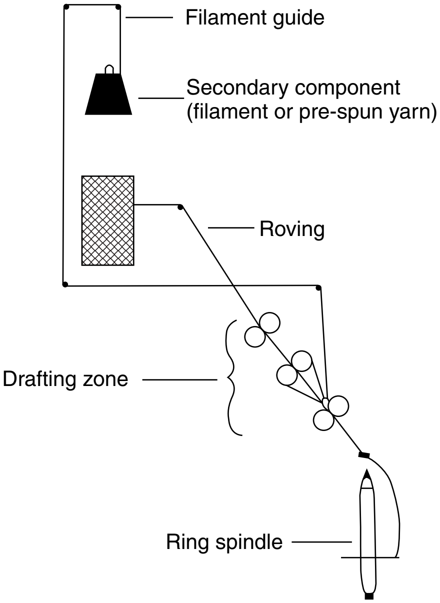


6.12 Compact spinning. [*From Hill and Brayshaw.*[76]]

substrands and yarn, as well as the fibre integration into the yarn. Thermo-splicing (hot air) is recommended, the average splice strength should be 80% that of the yarn. Relatively even yarns of 25 tex to 50 tex and tex twist factors from 33 to 43 (at least 38 for weaving yarns) can be spun, and coarser fibres utilised (65 fibres in yarn cross-section), longer fibres being preferable. Compared to two-fold yarns, yarn production costs can be reduced by up to 50%.

6.6.5 Bicomponent spinning

Bicomponent yarns, also referred to as bound yarn, have found a niche in the market, these generally combining pre-spun continuous filament yarns with staple fibres to provide improved properties, such as stretch (e.g. *Lycra*) and strength. Bicomponent spinning[77] (see Fig. 6.13)[66] normally involves twisting together either a filament (sometimes water-soluble) or pre-spun staple yarn and a conventionally drafted staple (wool) strand during the spinning operation. It is particularly attractive for the cost-effective production of superior yarns, which can, for example, be woven or knitted without any further operations (i.e. eliminating plying, sizing and

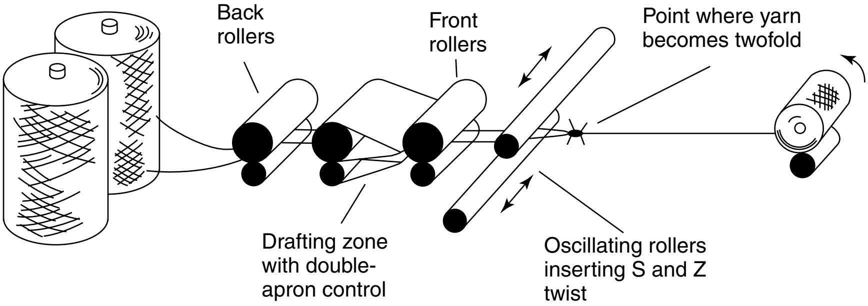


6.13 Bicomponent spinning. [*From IWS.*[66]]

steaming). It also enables coarser fibres to be spun into finer yarns, reduces spinning end breakages, allows higher winding speeds and enables yarn and fabric properties to be engineered by suitable selection of the two components and the way in which they are combined. On the negative side, bicomponent yarns are generally not pure wool or torque-balanced and produce fabrics that are generally more streaky and air permeable and have more conspicuous joints. A suitable type of 'break-out device' can be used to prevent the production of a single component yarn. Steam setting at 80 to 85 °C is recommended (55 to 60 °C if a water-soluble filament is used).

6.6.6 Self-twist spinning

On the *Repco* self-twist spinning machines (Fig. 6.14), S and Z twist is inserted alternately into each of a pair of strands, which are then brought together, out of phase, along their length to wrap around each other, thereby forming an alternating twist two-ply structure (22 cm total cycle length) in which the torque of the two strands is balanced by the folding torque of the pair. The drafting zone is a modified double-apron system (back rollers, aprons and front rollers), optimum draft being around 25 for wool. Twistless or lightly twisted (maximum twist in turns/metre = $644\,\text{tex}^{-0.5}$) rovings can be used.



6.14 Self-twist spinning. [*From Grosberg and Iype.*[33]]

When the pair of strands leave the drafting zone, they pass between a pair of synthetic rubber covered rollers which cooperatively rotate and axially oscillate in opposition.[1] The self-twist yarn that is produced is wound directly onto cheeses (yarn tension in cN = 0.3 × tex). This system circumvents the limitations associated with package rotation and balloon formation that apply in ring spinning. The self-twist is dependent upon the tension applied to the yarn. Such self-twist wool yarns can withstand tensions of up to 60 mN/tex but need to be up-twisted for weaving, giving what is termed twisted self-twist (STT) yarn.

Some useful definitions and concepts follow:

$$\text{Self-Twist-Factor (STF)} = \text{Average self-twist per half cycle (t/m)} \times \sqrt{\text{tex}}$$

$$\text{Generally STF} = 1550$$

Pairing twist (PT) is the minimum amount of uni-directional twist required to make all the ply twist either zero or unidirectional. It is proportional to the average self-twist per half cycle.

$$\begin{aligned}\text{Pairing Twist Factor (PTF)} &= \text{pairing twist (t/m)} \times \sqrt{\text{tex}}\\ &= 1.55 \times \text{STF} \qquad \text{on average}\end{aligned}$$

For twisted self-twist (STT) yarn the uptwist factor or added twist factor (ATF) may be calculated as follows:

$$\text{ATF} = \text{PTF} + 880$$

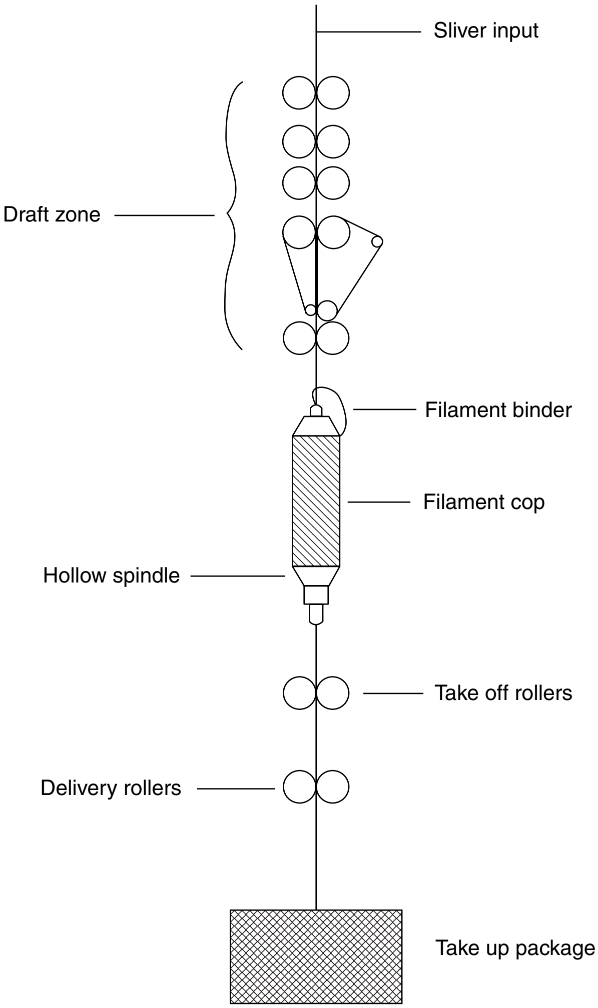
The above twist factors can be converted to tex twist factor (i.e. t/cmx $\sqrt{\text{tex}}$) by dividing them by 100.

In addition to the original self-twist (ST) yarn, a number of other versions of self-twist yarns exist, including the use of one filament (STm) or two filaments (STm)m, as well as their uptwisted and plied versions.[79]

Although self-twist spinning has many advantages over ring spinning, such as production rate, floor space, waste levels, cleanliness, spinning limits (35 fibres per strand), noise levels, power consumption, it is not used much today for spinning wool, but rather for spinning high bulk acrylic for knitting.

6.6.7 Wrap (hollow spindle) spinning

Hollow spindle wrap-spinning (Fig. 6.15)[66] shown at the 1975 Milan *ITMA*, in which continuous filament yarn, on a hollow spindle, is wrapped around



6.15 Wrap spinning. [*From IWS.*[66]]

an untwisted wool core (the latter accounting for typically 80 to 95% of the yarn composition), has also found some application for wool.

In plain yarns, the number of wraps required per unit length is generally very similar to the number of turns (twists) per unit length used for the equivalent ring-spun yarns. The economics tend to favour wrap-spinning for yarns coarser than about 50 tex. Such yarn is not twist lively and has a soft handle, the yarn being more suitable for coarse count knitting than for weaving. Wrap-spun yarns tend to be less hairy and bulky and equal to, or better, in strength and evenness, and can be spun finer than the ring yarn equivalent. Spinning limits generally lie between about 30 and 60 fibres in the yarn cross-section. The fine filament wrapper is expensive, however.

Nunes *et al.*[80] established empirical equations relating wool core/nylon wrapper yarn properties to the yarn structural parameters, separating the effects of the staple fibre from those of the filament wrapper. Naik and Galvan[81] also empirically related wrap yarn properties to spinning machine variables. Xie *et al.*[82] showed that the strength of a wrap yarn was largely due to lateral pressure generated in the staple core by the binder helix. Choi[83] also presented a yarn model that accurately predicted how wrapping pitch affected the yarn load – extension properties. In a study on woollen wrap-spun yarns, Cheung and Cheng[84] found that wrapped yarn elongation was higher than that of ring yarn, increasing with wrapping density and also with yarn linear density, being higher without than with a false twister.

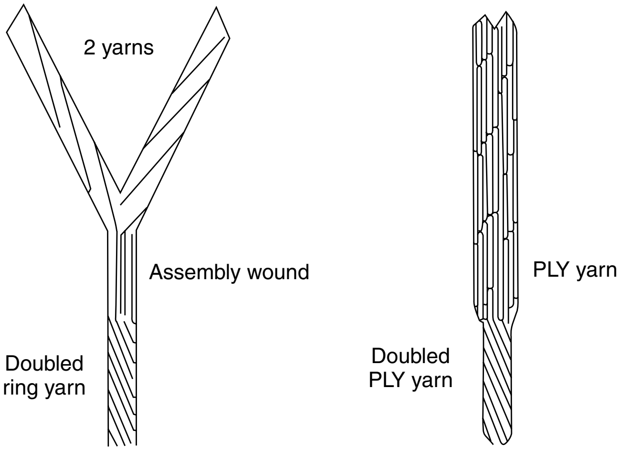
6.6.8 Other spinning systems

6.6.8.1 *Treotek*

Treotek is a WRONZ developed variation of the *Sirofil*, adding two filaments, which can be water soluble (or one filament plus a pre-spun yarn), to staple wool fibres. The number of wool fibres in the yarn cross-section can be as low as 20 (or even 15).

6.6.8.2 *Cerifil*

The *Cerifil* (Bigagli) system replaces the traditional ring and traveller with an inverted funnel-(cone)-shaped winder, resembling a cap, which is rotated by the yarn itself. It performs two basic functions, namely retarding the winding of the yarn and acting as a rotary balloon limiter, reducing yarn tension (which is adjustable) and end-breakage rate. The *Cerifil* system, which also eliminates the balloon break, can be incorporated into both semi-worsted and woollen ring frames.



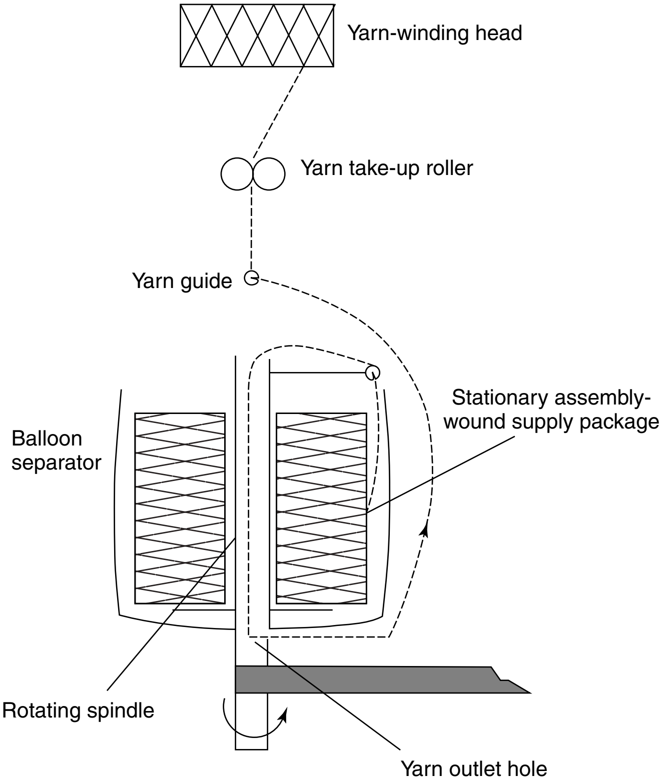
6.16 Plyfil. [*From Fischer.*[85]]

6.6.8.3 *Plyfil*

The *Plyfil* (Suessen) system (Fig. 6.16), first unveiled at the 1987 *ITMA*, consists of a five-roller, two pairs of apron drafting system, with drafts of up to 400, being fed by slivers. The *Plyfil* machine has been referred to as a 'spin assembly winder'. Yarns are consolidated by a sheath of helically wound fibre ends, wrapped around the fibre core in one direction by air-spinning jets behind the drafting system. The two twistless yarns produced on the *Plyfil* machine are wound onto each cross-wound package, assembly wound fashion. Generally, two-for-one twisting follows, the folding twist being in the opposite direction to the wrapped fibre sheath but lower than that for conventional two-ply yarn. It can also be used for the worsted spinning of wool, preferably using combed sliver.

6.7 Twisting

The twisting operation, also referred to as plying or folding, is the process where two (sometimes more) yarns are twisted to form a two-ply (or multiply) yarn. Traditionally this was done on a ring-frame (ring-twister) but today it is almost exclusively carried out on a two-for-one twisting machine (Fig. 6.17),[33] three-for-one twisting systems having also been developed. Assembly winding is used to assemble two ends of yarn on one package in preparation for two-for-one twisting. It is particularly important to ensure that the two yarns are wound at the same tension. The assembly wound package remains stationary, the yarn passing through a guide mounted on a rotating arm which can freely rotate, through the hollow rotating spindle,



6.17 Two-for-one twisting. [*From Grosberg and Iype.*[33]]

then through an eyelet (outlet hole) and from there, via a yarn guide and yarn take-up rollers, to the yarn winding head. One revolution of the spindle inserts one turn of twist into the yarn while the rotating eyelet simultaneously inserts a turn of twist in the yarn in the balloon. Thus two turns are inserted per spindle revolution. (For a detailed description of twisting technology relevant to various textile products see Section 9.2.)

6.8 Winding, clearing and lubrication

Winding (re-winding as it is sometimes called) is aimed at transferring the yarn from the spinning packages (referred to as tubes, cops or bobbins), which normally hold relatively short lengths of yarn, into packages (cones, cheeses, etc.) that can hold considerably longer lengths of yarn more suitable for the subsequent processes, such as yarn preparation, weaving, knitting, package dyeing, etc. The winding process also provides an opportunity for unwanted yarn faults (e.g. slubs and thin or weak places) to be removed (yarn clearing) and the yarn to be lubricated. The latter is often referred to as waxing in the case of knitting, since it entails the use of a solid wax disc for lubricating the yarn. Clearers may be either of the capacitance or optical types, or even a combination of these. (Other aspects of winding and related technology are described in Section 9.3.)

Splicing, notably pneumatic, is widely used today, giving joints of acceptable strength and appearance, thermal splicing being considered particularly suitable for wool. On-line monitoring of winding is carried out mainly to provide exact length measurement and control, yarn path control and winding speed control, as well as to provide the necessary management information. On-line monitoring of yarn quality (e.g. hairiness) has also been introduced.

Automation (package changing, yarn jointing, etc.), higher speeds, and yarn monitoring and clearing systems characterise modern winders. Automatic linkages between spinning machines and winders, together with in-line steaming (setting) of yarn, are also increasingly being used. Maintaining yarn tension also enables twist-lively (i.e. unsteamed) yarn to be wound.

6.9 Yarn steaming (setting)

Yarn is steamed (heat set) in an autoclave after spinning so as to reduce or eliminate the twist liveliness (torque) and snarling tendency of the yarn and thereby facilitate the subsequent winding and twisting (folding) of the yarn, and to avoid fabric distortion (e.g. spirality in knitted fabric). Some modern winders do, however, enable twist-lively yarn to be wound.

Different steaming conditions can be employed to achieve the desired effect but it is important to regulate the setting temperature and time, particularly the former, in order to avoid yellowing of the wool. The following is an example of steaming conditions that can be used:

- Evacuate to 88 kPa (26 inch Hg)
- Steam at 80 °C for 5 mins
- Evacuate again to 88 kPa
- Steam at 80 °C for 15 mins
- Evacuate to 88 kPa for 15 mins

Longer steaming times, rather than higher temperatures, are preferred if the setting effect is not adequate.

In-line steaming on conveyers has also been introduced.

6.10 Top dyeing

Top dyeing is described in Chapter 8. Suffice it to say that it can adversely affect the fibre properties and subsequent processing performance. Work by Gore *et al.*[86] indicated that the fibre tensile properties do not significantly affect subsequent processing performance until the fibre extension falls below about 28 to 32%. Recombing improves winding and spinning performance significantly.

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