9
Manufacture of wool products

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9.1 Introduction

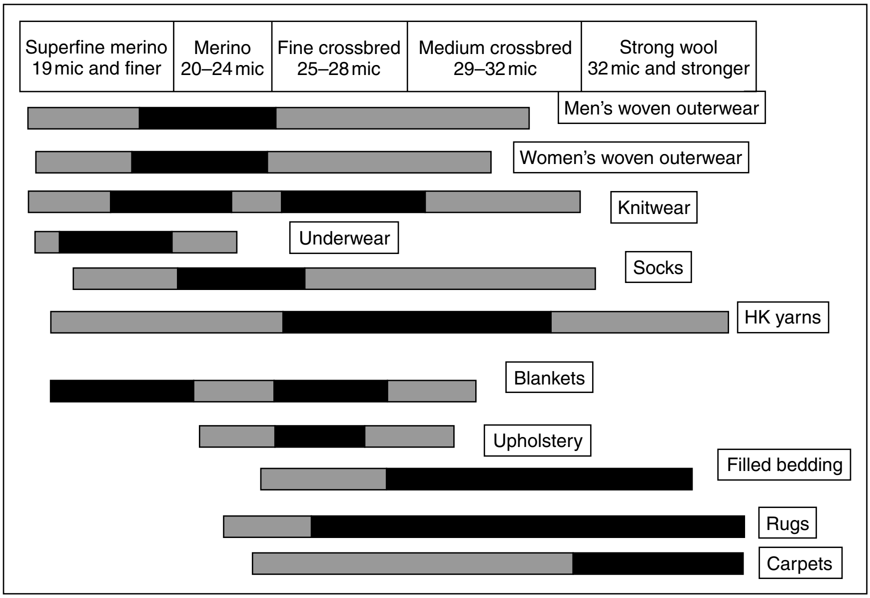
Opportunities for introducing variety into wool products are provided by the fact that wools of different origin vary considerably in terms of mean fibre diameter, distribution of diameter, fibre length, crimp and medullation. Such extensive variations result from the fact that many different breeds have evolved over the years, either through natural selection or through the efforts of man. Different breeds have adapted to particular habitats, and the wools from each breed have their own characteristics and physical properties.

In textile processing, wools of different types may be blended together or with other fibres to create special product features, but usually within a fairly narrow average diameter range. Figure 9.1 illustrates the typical usage of wools of different diameters in 11 broad product areas. The darker colour in each band indicates major usage and the lighter areas in the bands indicate some usage.

Most apparel products are made by weaving or knitting, although carpets and felts may use other processing methods (see Chapter 10). Chapter 6 covers the processing of wool fibre into singles yarns. This chapter now outlines the machinery used when processing from singles yarns into woven and knitted materials. The various processes are applicable to all fibres, but some are more suited to wool than others, and special conditions appertaining to wool may sometimes be required to ensure production of a satisfactory wool product.

9.2 Twisting

Yarn twisting or folding is a relatively expensive and non-productive operation but for weaving yarns it was, until relatively recently, the only way to produce a final yarn that could withstand the rigours of the weaving process and provide fabrics that exhibited good performance in wear.



9.1 Allocation of wool by fibre diameter in 11 broad product areas. [*Source: The Woolmark Co.*]

Since the mid-1980s, considerable efforts have been made to eliminate the need to twist yarns together and several methods have evolved that have taken a small but significant share of the market (see Chapter 6 Yarn Production).

9.2.1 The need for twisting

Yarns are twisted together for the following reasons:

i) To improve quality (regularity). As with the doubling of slivers (see Chapter 6), twisting two or more yarns together improves regularity. Good regularity is essential to produce fabrics with non-streaky appearance and good physical properties.

   When one yarn is brought alongside another, chance dictates that it is highly unlikely that a thin place in one yarn will coincide with a thin place in another, or that a thick place will coincide with a thick place, so that such variations are reduced by twisting.

ii) Design. Twisting yarns of different colour, count, fibre type or twist can give interesting design opportunities for marl and fancy textural fabrics that, because of the relatively late stage of implementation, can be attractive in terms of delivery options.

iii) To improve the efficiency of later processes. Twisting usually improves the strength (tenacity and elongation) of a yarn but the vast majority of single yarns have sufficient strength to withstand the forces of later processes. However, in the case of weaving, single warp yarns often lack the abrasion resistance that is required to withstand the loom motions such as the reciprocating action of the reed and the rubbing action of the healds which, when coupled with the flexing action of the loom, can lead to yarn failure. The yarn breaks because the weaving process disturbs and then removes the surface fibres, exposing deeper and deeper layers of fibre until the yarn becomes weaker than the operating tensions of the loom. Additionally, relatively small levels of surface disturbance at the reed lead to entanglement of raised fibre from adjacent ends of yarn. This entanglement ('buttoning') can affect loom efficiency and can escalate into a situation where the loom can not operate.

Yarn twisting enhances abrasion resistance by trapping the fibre ends and increasing the general security of individual fibres within the yarn structure, both the single and twisted elements. Splices or knots in the single yarn are also to some extent protected from failure by twisting.

Yarn performance in knitting (Chapter 9) or tufting (Chapter 10) requires elasticity as well as strength. Twisting can improve the elasticity (elongation) of a yarn compared to that of a single yarn. However, many singles yarns are used for tufting and knitting, the required elasticity being achieved by selection of raw materials and twist levels.

Because wool is generally used in high value products that have a quality image, and because yarn twisting tends to improve quality, the economic advantages of using single yarns in worsted products have not yet gained widespread acceptance. By contrast, many yarns produced from short staple fibres such as cotton are woven without twisting, size being applied to the single yarns to improve abrasion resistance at weaving.

Although sizing is a long established technology, it has evolved in a way that favours large process lots. These are usually found in markets for short staple products but very rarely in the long staple process areas where wool is used. However, the pressure to reduce the fabric weights and costs of long staple worsted products have resulted in the use of single wool yarns that have waxes or lubricants applied to the warp to enable efficient weaving to take place in specific fabric designs. Also, spinning developments such as *Plyfil*, *Duospun*, *Sirospun* and *Solospun* have evolved that provide greater fibre security within the yarn without the need for a separate twisting operation. However, as with conventional single yarn, the regularity may not be as good as that of plied (twisted) yarns. For this reason, and despite the acceptance of *Sirospun* yarns for worsted suitings trousers, jackets, etc., these types of yarn have not yet taken a major share of the market for wool yarns, although they do provide effective routes to producing lightweight fabrics that have good performance in wear.

9.2.2 Twisting machinery

Three main methods are used to twist yarns together: ring, two-for-one, and two-stage twisting, with some other systems being used in a small way.

9.2.2.1 Ring twisting

The oldest of the three main methods uses a ring and traveller system to insert yarn twist and to wind the yarn onto a spindle. It is relatively slow but is versatile and flexible. Ring twisting machinery is available in different guises, some of which use prepared feed packages in order to maximise efficiency, and others which can twist several single yarns together. Some simple machines have only a creel, feed roller system, spindles and ring; while other more complex machines have individual end detectors and stop motions to halt the spindle for ends to be repaired.

Although less productive than other methods, ring twisting tends to produce yarns with low twist variation and is still used for quality reasons and when very fine or very heavy count yarns are required.

A few ring machines use assembly wound packages in order to reduce creeling time, thus increasing efficiency and productivity.

9.2.2.2 Two-for-one twisting

Two-for-one twisting (TFO) has taken the major share of yarn production since its introduction in the 1960s and is used in all production areas, apart from perhaps the very heavy yarn count market. The system is ideally suited for the production of two-fold yarns in the mid-to-fine count area (a high volume area for wool worsted yarns).

A hollow spindle inserts two turns of twist for each rotation of the spindle, thus doubling the production compared to ring twisting. The system is usually fed from cone or PSP (parallel-sided package) and also delivers onto cone or PSP, enabling the machine to run for extended periods without stops for donning or doffing.

There is little positive control of feed rate and this tends to result in higher twist variation than from other production methods. Variation may be controlled within acceptable limits for weaving yarns but may be considered too high for some knitting yarns.

Generally, but not exclusively, the system uses assembly winding to prepare the yarn for twisting.

In an alternative procedure, two special cones are clipped together and the yarn taken from each package in the normal way. Unfortunately, this 'Clip Cone' system suffers from two disadvantages: variation in tension between the two ends, which can create quality problems, and the possibility of one package emptying before the other, which creates waste. Despite these problems, the system has gained some market share, not least because of the improvements to yarn length measurement during winding, which has reduced variations to a few metres in feed cones that may contain more than 30 km of yarn.

9.2.2.3 Two-stage twisting

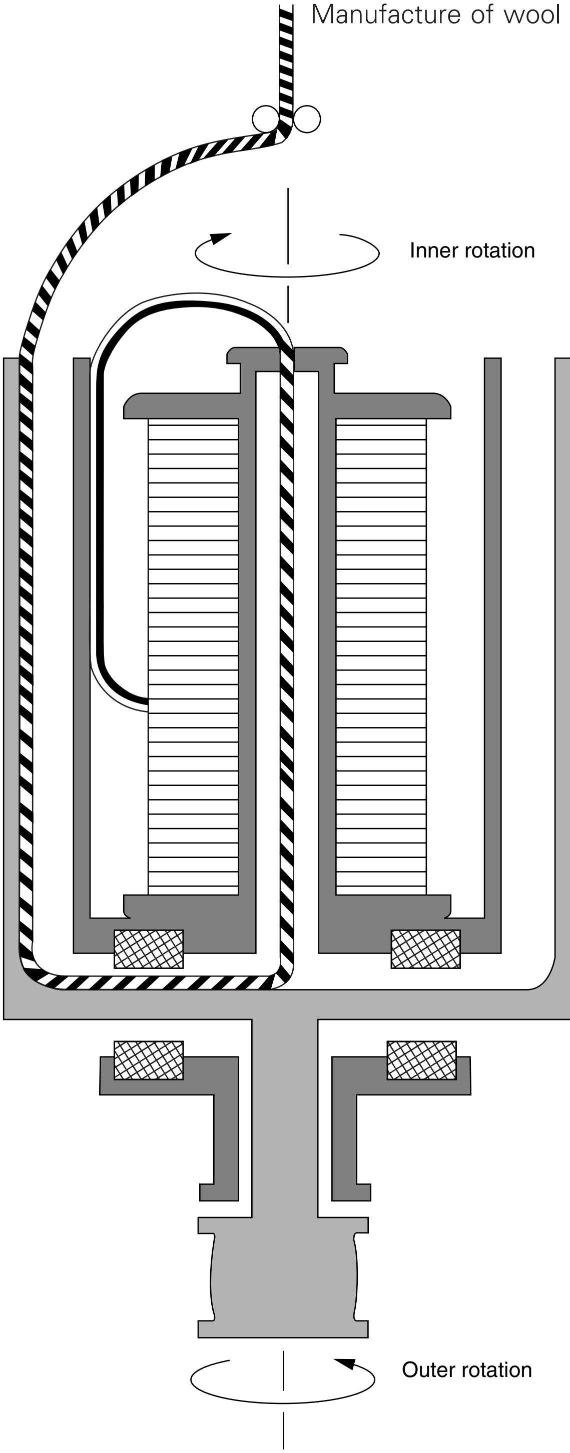
Two machines are used. The first prepares the feed package, imparting a small amount of twist to the two single yarns as they are assembled. The second machine brings the total twist to the required level. The system arguably provides the lowest twist variation of any twisting method, and is used for product areas where twist variation is critical, e.g. hosiery yarns.

9.2.2.4 Other twisting systems

Fancy twisting. The production of 'fancy' yarns is a significant area. By definition, such yarns offer the textile designer a virtually limitless range of possibilities to introduce textural and colour effects into a fabric. As a consequence, machines can be very complex mechanically and are often controlled by computer in order that they can be quickly and easily set up. The machines use multiple feed systems that can stop, feed or overfeed yarns and filaments in many combinations. Some machines have one or more drafting units at each spindle so that slub and flame effects can be introduced into a yarn.

Tritec. Tritec technology augments two-for-one technology by adding a further yarn loop into the spindle area to produce three turns of twist for every rotation of the spindle (see Fig. 9.2). Although much more complex mechanically and technically than TFO, the system has spindle components revolving at relatively low speed, and it is claimed that this reduces the stress placed on the yarn.

Parafil. The *Parafil* system combines spinning and twisting. It delivers an untwisted fibre stream from the draft zone, which is wrapped as it leaves the draft roller by a filament that gives the strength and abrasion resistance for weaving. This yarn method seems to have been accepted by the industry as more suited to knitted products.



9.2 Principle of the *Tritec* twisting system for inserting three turns of twist for each rotation of the spindle. [*Source: The Saurer Group.*]

Other systems for incorporating filament yarns during spinning, e.g. *Sirofil* or *Bi-component*, have a small niche market in lightweight wool blend fabrics for suitings, trouserings etc., that have good abrasion performance.

9.2.3 Yarn structures

Conventions on yarn structures become blurred when styling takes precedence over technical performance, so that rules on twist levels cannot be formulated. However, there is a general difference between knitting yarns and weaving yarns. Knitting yarns are usually required to be bulky so that twist factors, both singles and folding, are relatively low. To avoid twist liveliness, folding twists may be selected so as to provide torque balance, or twist imbalance may be corrected by setting. Weaving yarns can be more compact, and the essential requirement for low hairiness can be met by using high levels of twist, especially folding twist, and controlling twist liveliness by steam setting. Some spinners provide special high twist yarns for fabrics that are variously claimed to provide good wrinkle resistance and comfort properties.

9.3 Winding

9.3.1 Objectives of winding

The various aims of winding include the following.

- *To provide the size and form of package required for subsequent processing or handling.* For example, fine yarns may be spun on 50 g cops but may be wound into 1 kg packages for twisting; twisted yarns may be wound onto cones for knitting or parallel-sided packages (PSP) for weaving; packages may be required to withstand the rigours of packing and transportation.
- *To improve yarn quality by clearing faults.* Sophisticated optical or capacitative devices detect yarn mass (or colour) outside the pre-set limits and activate a cutter. The fault is removed and the yarn is joined using a knot or splice.
- *To provide packages suitable for dyeing.*
- *To re-wind dyed packages or hanks for further processing.*
- *To assemble two or more yarns for twisting.*
- *To apply processing aids such as size or wax.*

Often, several of these requirements may be satisfied in one winding operation. Winding is sometimes linked with other processes, e.g. automated spinning on one side and twisting on the other. Some machines such as open-end spinning frames or TFO twisters often have sophisticated winding equipment at each production point and can provide a variety of quality packages suitable for subsequent processing.

9.3.2 Manual winding

Manual winding machines are still used because they are flexible, easy to operate and adjust, and simple to maintain and repair.

The tasks of the operative are to:

- load feed packages and remove empties
- remove delivery packages and replace formers
- tie or splice yarns that break or have been cut by clearers
- clean and provide general housekeeping

After the yarn leaves the feed package it is tensioned, often by a dual disc system, to control package density in a uniform way. Lubrication, usually required for knitting yarns, is by controlled contact with a wax disc. The take-up package is supported and surface-driven by a drum that has a helical groove so as to traverse the yarn onto the package. Alternatively, the drum may have a plain surface, and a small guide in front of the drum is then used to traverse the yarn.

9.3.3 Automatic winding

For this operation, fully-automatic winding machines take over the tasks of the operative and require only a container of feed packages at one end of the machine and the removal of pallets loaded with delivery packages from the other.

Automatic winding machines usually wind and clear spun yarns onto cone ready for twisting. They are less flexible than manual machines.

9.3.4 Yarn jointing

Yarn jointing is now mostly by pneumatic splicing. A refinement is thermal splicing, which uses heated compressed air, resulting in reduced variability between splices as well as improving the appearance of the splice.

Spliced joints have been widely accepted since their introduction in the late 1970s and have almost replaced knots, except in the fine count area around 13 tex (Nm 80) and finer, and also in some knitting applications, especially for products having a plain smooth surface where the visual appearance of a splice may be unacceptable. In such cases, a knot may be pulled to the back (knitwear) or be replaced by a mend (woven fabrics).

Knots are usually weaver's (paradoxically for knitting) or fisherman's (for weaving).

9.3.5 Twist setting

Weaving yarns are usually subjected to a mild steam-setting process to stabilise the twist and prevent snarling in later processes. Setting is carried out in an autoclave, ideally using a multiple steam/vacuum cycle to achieve uniform penetration of steam. Generally, temperatures not exceeding 85 °C are used for wool, to avoid yellowing the wool and losing yarn strength.

In-line autoclaves have been developed for setting yarn in linked spinning/winding systems.

9.3.6 Package types

Since 1970, the variety of yarn packages used in the wool textile industry has been rationalised from more than 30 to about 10, only five of which are in widespread use. Parallel-sided packages and cones are used for dyeing. The most common knitting package has a conicity of 4° 20′, although 5° 57′ is becoming the preferred package for knitting. The traverse length of these packages is usually 150 mm (6 inches) although 125 mm (5 inches) is still used by some companies. A small (70 mm traverse) cone is used as a clip cone for feeding two-for-one twisters.

Packages may be random wound (constant winding angle and variable traverses per revolution) or precision wound (constant traverses per package revolution and variable winding angle). Because of the relationship between package diameter and traverse length in random winding, the yarn layers tend to create intermittent diamond shaped patterning or ribboning (local areas of high density) that can be detrimental to uniform dyeing in dye packages and unwinding performance. Precision winding does not give such local variations in density but gradually changes density from the inside to the outside of the package as the yarn build up. 'Step' precision winding uses an electronic system to change the traverse angle in a series of small steps to obviate the problem of inside to outside density variation.

9.4 Warp preparation for weaving

Good warp preparation is an essential requirement to reach optimised efficiency and wool fabric quality from high-speed weaving machines.

The two main types of warping systems used for wool and worsted yarn preparation are section warping and beam or direct warping.

9.4.1 Sectional warping

Sectional warping is the most commonly used system for producing woollen and worsted warps. It is a very flexible system that not only allows for full warp preparation from an individual yarn, but also can allow warps to be made with a combination of yarns of different count or colour.

In sectional warping, a given number of warp threads, known as sections, are wound side by side onto a cylindrical drum (see Fig. 9.3). One end of the cylindrical drum is conical in shape and may be either a fixed angle (usually 11° or 14°) or variable angle type.

To commence warping, the yarn packages required to form the section band are mounted onto pegs in the creel. Each thread is passed through its tensioning unit, leasing device and finally through the warping reed where the threads are dented to the required sectional width.

Using as an example a warp with a total of 3400 ends and a width of 68 inches (172.7 cm), this gives 3400/68 = 50 ends per inch, and the warp is made as follows:

With 200 warp packages, 17 full sections are required to complete the warp, each section being 1727/17 = 4 inches (approx. 10.2 cm) wide.

9.3 The *Ben-tronic* sectional warping machine and creel. [*Source: Benninger.*]

All relevant data, such as total warp ends, ends per section, warp width required, yarn counts in d/tex, warp density, and warp length, are entered at the input station, and the machine positions itself for winding the first section. During winding, the section band is traversed unidirectionally so that the warp threads build-up along the incline of the cone. Subsequent sections are built-up on the angled platform provided by the previous section.

Quality requirements are accurate build-up of each section, precise fit of the different sections, and equal length and tension of all warp ends.

The sectional warp is then beamed-off onto the weaving machine's warp beam. Optional waxing/cold sizing may be performed at this stage.

9.4.2 Beam warping

Beam warping is occasionally used in the preparation of single-count wool warps for lightweight, plain, piece-dyed fabrics, and may be associated with sizing. Usually, a number of individual warp beams (back beams) with an equal number of warp ends are produced. The back beams are then mounted in the beam creel at the rear of the sizing machine. The total contained number of warp ends from the back beams are then run together through the sizing and drying units, and the required warp length wound onto the weaver's beam.

This volume type of warp preparation is common in the cotton industry, but, as stated above, may be used for worsted warps requiring sizing as a means to improve weaving efficiency and quality, e.g. single or fine count yarns.

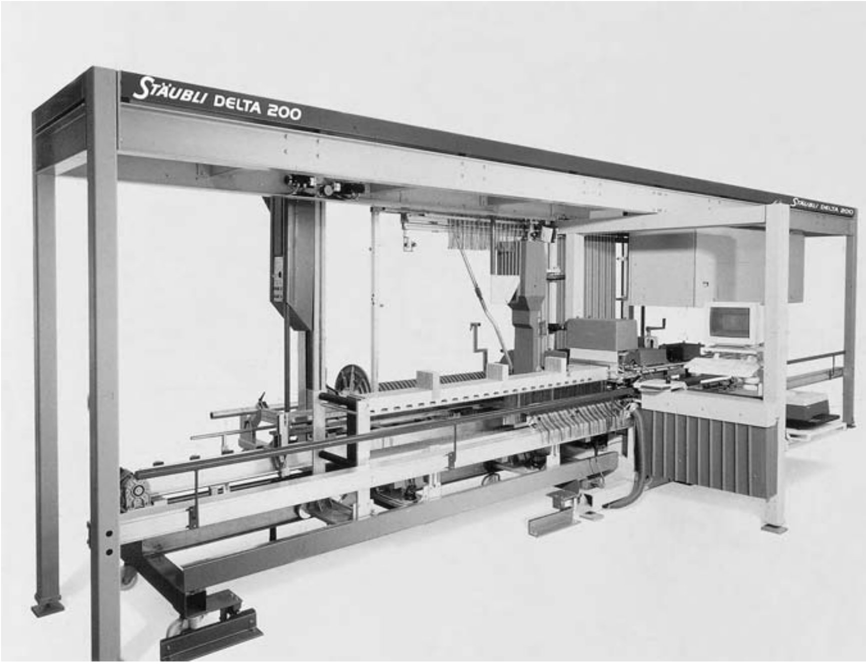
9.4.3 Drawing-in of the warp threads

Different circumstances in weaving dictate three different ways in which warps are drawn in for weaving:

Follow-on warp. When the warp is identical in quality (total number of ends, width and pattern repeat) to the one previously woven, it is tied in at the weaving machine with the aid of a knotting machine.

Prior preparation. The warp is knotted into a previously prepared harness set, off the loom.

Empty loom. Each individual yarn end is drawn through an eye of a heald wire (or jacquard harness) in the sequence required by the design, and then through the weaving reed. Automatic machines are available that accomplish the entire drawing-in operation reproducibly under computer control, facilitating short runs (see Fig. 9.4).



9.4 The Uster *Delta 200* automatic drawing-in machine. [*Source: Staubli.*]

The reed is selected according to the cloth construction: it determines the spacing of the warp threads, guides the shuttle and beats up the weft. There may be two (plain weave), three (2 × 1 twill) or four (2 × 2 twill) yarns in each dent space.

9.5 Weaving yarns

Warp yarns. Warp yarns need to be strong, elastic and of low hairiness. As a consequence of this, twofold yarns having high levels of folding twist are usually used (e.g. single twist factor 85–90; folding twist factor 110–120). Some single yarns may be used for lightweight fabrics, but their hairiness should be reduced by waxing or sizing. Crepe yarns are usually single yarns with very high levels of twist (e.g. twist factor 200) and are used for specialised fabrics.

Weft yarns. The requirements for physical properties are a little less stringent than for warp yarns, so that singles yarns are more often used (for reasons of economy).

9.6 Fabric design

Patterns are produced in the cloth by passing each weft yarn under or over a varying number of warp threads, forming the weave. Most simple weaves, which repeat over a small number of ends and picks, are drawn up using squared paper (point paper). The squares marked by a cross (×) indicate where a warp thread should be raised over the weft pick at that point of the design weave. From the design weave, the drafting plan is created, indicating the order that the warp threads should be drawn into the heald harness frames. Where two or more warp threads have the same weaving or interlacing order throughout the design repeat, they can be drawn onto the same heald frame. During weaving, the heald shafts are raised and lowered, alternately, and opposed to each other, after each successive weft pick insertion.

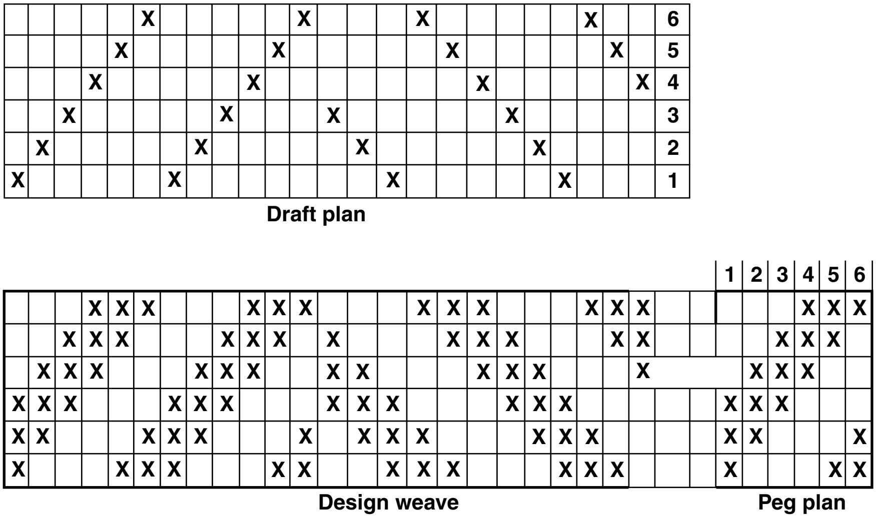
9.6.1 Plain weave

In Fig. 9.5, the first and third warp threads of the plain weave design 'A' are the same, so they can, if desired, be drawn into the first heald frame. The second and fourth warp threads of the design also have the same order of interlacing as each other, but opposite to the interlacing order of threads 1 and 3, so must be placed into the second heald shaft, as at 'C'.

Design plan 'D' illustrates that all four yarns can alternatively be placed onto four separate heald frames. In this instance is necessary to have frames 1 and 3 working as one unit, being raised and lowered together, and to have frames 2 and 4 working together but in the opposite direction.

												4		
											3			
				2		2				2				
			1		1				1					
				C							D			
4				X		X				X		X		
3			X		X				X		X			
2				X		X				X		X		
1			X		X				X		X			
			1	2	3	4			1	2	3	4		
					A						B			

9.5 The same plain weave designs 'A' and 'B' may have alternative design plans, 'C' and 'D'.



9.6 Herringbone 3 × 3 weave.

9.6.2 3 × 3 twill herringbone effect

The herringbone effect is achieved by simply reversing the diagonal direction of the twill line, as illustrated in Fig. 9.6, periodically across the width of the fabric. The warp threads are drawn 12 to right and 12 to left alternately across the whole warp width, and the design weave is complete on 6 picks.

9.6.3 Colour and weave effects

A combination of colour arrangement and design weave provides patterns in two or more colours.

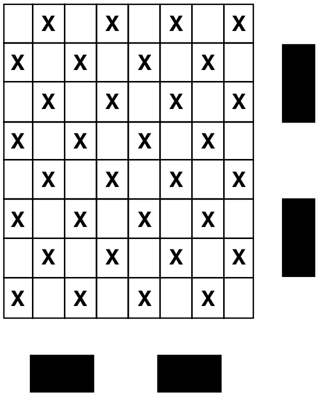
In Fig. 9.7 a plain weave design in one colour is shown at 'E'. The same structure, woven with black and white yarns in the order 2 and 2 in both the warp and weft directions, produces the well known crows foot check pattern shown at 'F'.

A specification of any fabric pattern requires:

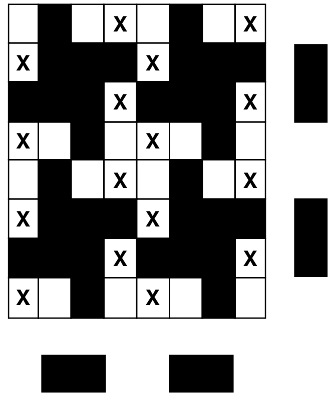
- the colour arrangement of warping
- the colour or sequence of weft insertion
- the draft, peg plan, and design weave

9.6.4 Fabric structure (sett)

The main parameters that influence the structure of a woven fabric are the design weave, warp and weft yarn counts, and fabric sett. The term 'fabric



E



F

9.7 Left: A plain weave design in a single colour. Right: The same structure woven in two colours.

sett' is used to indicate the number of warp threads and weft pick density required during the warping and weaving process, to enable the fabric finisher to achieve the correct fabric firmness and cover, weight, handle, drape, and stability, etc. after final finishing.

There are many setting theories to enable designers to calculate weave density (ends and picks per cm) for the many different weave and yarn types. The first was by Thomas Ashenhurst in 1896. Others, such as Law, Armitage and Brierley, concentrated mainly on formulating setting/construction theories for woollen and worsted fabrics.

Brierley's setting theory postulates that maximum achievable sett with worsted yarns is 73.5% of the maximum geometric setting.

Brierley's formula for square set fabric (73.5% maximum sett of maximum density) is:

$$T = \sqrt{K \times C} \times F^m$$

where,

T = Threads per inch each way (warp and weft)

K = Constant depending on yarn count system (118.7 for metric count system)

C = Average count warp and weft

F = Average float of weave

^{m} = Constant according to type of weave.

^{m}	for plain weave	= 0.00
	for twill weaves	= 0.39
	for satin	= 0.42
	for hopsack	= 0.45

Example: A worsted fabric in 2 × 2 twill using 2/60 Nm yarn warp and weft yarn counts set to Brierley's formula would require:

$$\begin{aligned}\text{Max. sett} &= \sqrt{118.7 \times 30} \times F^m = 59.67 \times F^m \\ &= 59.67 \times 2^{0.39} \\ &= 59.67 \times 1.3 = 77.6 \text{ ends and picks per inch.}\end{aligned}$$

In practice this figure may be reduced slightly by the designer according to quality requirements.

Note that picks and ends are commonly specified per inch in the USA and UK, and that these figures are easily converted into yarns per cm, when applying the formula in other countries.

9.7 Weaving machinery

Woollen and worsted fabrics are mostly woven on rapier or projectile gripper machines, although shuttle looms are still widely used in some sectors and some countries. Air-jet looms are used for producing wool fabrics to a minor extent.

9.7.1 Projectile weaving

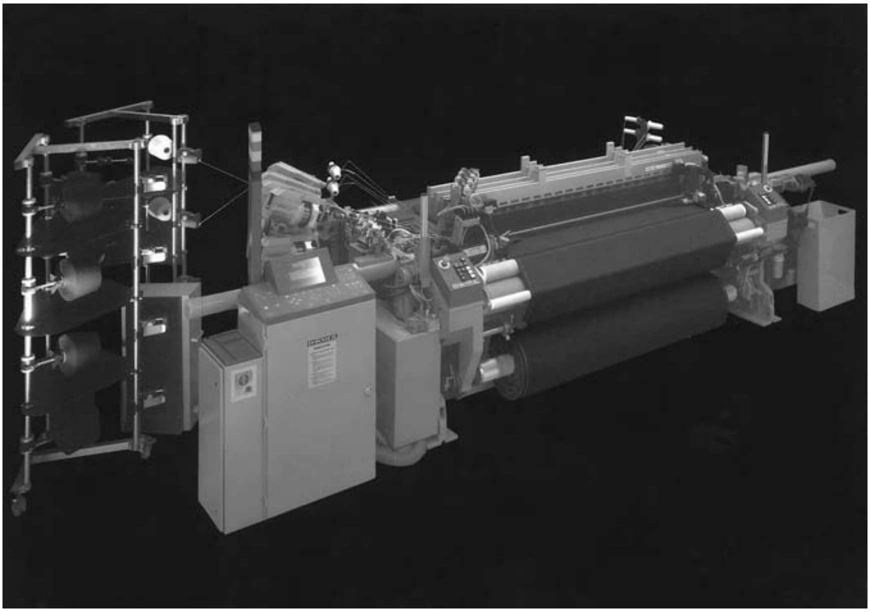
The multi-gripper projectile weaving machine, introduced by Sulzer Brothers in 1953, was the first system to begin to displace shuttle weaving. The company and its successors have remained the sole suppliers of projectile weaving machinery.

Pick lengths of weft yarn are drawn from large cones by a weft accumulator. The free end is held in the jaws of a weft carrier gripper (projectile), 88 mm long weighing 40 g, and the accumulated yarn is threaded to a sophisticated tensioning and braking system. The projectile is lifted to the picking position, and is propelled across the warp shed by a torsion bar system. At the other side of the loom, the projectile is received, the yarn is released and the projectile is ejected for eventual return to the picking side. The weft is cut at the picking side and is held at both sides by selvedge grippers during beat up and shed change. During the next machine cycle, tucking needles draw the outer ends of weft yarn into the fabric to form selvedges. Usually, 10–12 projectiles are associated with a single-width loom.

Picking rates are typically 380–420 ppm for worsted yarns and 250–300 ppm for woollen yarns.

9.7.2 Rapier weaving

Rapier weaving is offered by many loom manufacturers and consequently is in widespread use in the worsted and woollen industry. It offers the same

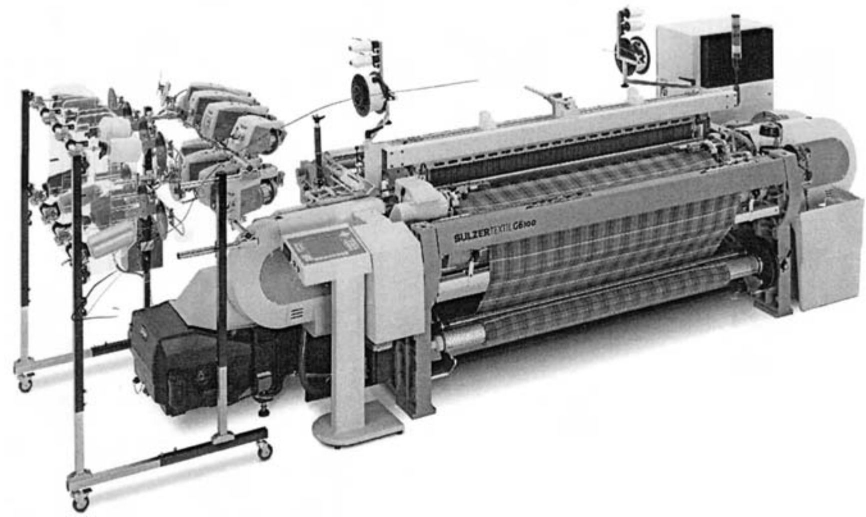


9.8 A rigid rapier weaving machine, *Type HTVS8/S20*. [*Source: Dornier.*]

advantages as projectile weaving in terms of large weft supply packages, linked on the creel for continuous operation, and supply of weft yarn at minimum tension.

Rigid rapier machinery (Fig. 9.8). This machinery employs a weft hand-over system having opposing carrier and receiver rapiers. The rigid rapier racks are driven via teeth cut to their undersides and carry heads that grip the wefts. In a typical machine, weft transfer is positive: cams activate the operation of clamp levers. Timing is such that the receiving rapier arrives at the central position slightly in advance of the carrier rapier and its clamp is opened to receive the yarn, immediately gripping it. Both rapiers begin to withdraw from the shed as the carrier clamp is released. The receiver rapier takes the weft just beyond catch threads to complete the insertion sequence.

Flexible rapier machinery (Fig. 9.9). As with rigid rapier weaving, a handover system is used, but weft transfer is achieved by a negative action. The gripper clamps are mounted on flexible tapes that are radiused at the sides of the loom to economise on floor space. Weft yarn stress is minimised by gentle acceleration of the rapiers during critical stages of the insertion cycle. Such looms operate reliably on virtually all types of yarn.



9.9 A flexible rapier weaving machine, *Type G6300*. Note the radiused rapier housing. [*Source: Sulzer Textil.*]

Operating speeds of 700 ppm have been achieved on 1900 mm rapier looms. Typical picking rates for worsted yarns are 450–550 ppm and for woollen yarns 300–350 ppm.

9.7.3 Air-jet weaving

Current systems for inserting weft by jets of air offer more rapid weft insertion than rapier or projectile systems, but are less flexible and have more stringent requirements for yarn. Because of the diverse nature of the woollen and worsted industry, air-jet weaving has not been accepted as widely as other systems.

Air-jet weaving of worsted fabric has been accomplished at 850 ppm. The technology may be expected to be improved in terms of performance, flexibility and energy saving, and could become more widely applied for weaving wool/synthetic blend yarns.

9.8 Knitting and knitwear

9.8.1 Knitting machine types

The knitting industry as a whole can be divided into four manufacturing sectors: fully fashioned, flat knitting, circular knitting and warp knitting. Within the wool industry both fully fashioned and flat knitting are widely used. Circular knitting is limited to certain markets and warp knitting is seldom used for wool.

9.8.1.1 *Fully fashioned machines*

Fully fashioned machines have been used extensively for producing plain classical wool knitwear such as sweaters and cardigans, and there are many machines of this type in existence today throughout the world. Such machines produce panels that are fully shaped and styled during knitting. After knitting, the front, back and sleeve panels are linked to form the garment.

The basic principle of loop formation is unique and has changed little since its invention. Fully fashioned machines are sometimes referred to as 'Cottons Patent' or 'Cotton machines' as a result of William Cotton's patents in the mid-1800s.

A row of bearded needles is set into a straight bar and the entire bar is reciprocated by rotary cams, causing the knitting action. The yarn is laid across the width of the needles and sinkers/dividers immediately push the yarn firmly against the stem of the needles, ready for loop formation.

Edge stitches can be transferred to narrow the panel, leaving 'fashion marks' and creating a shape.

Generally fully fashioned machines have only one set of needles and therefore can only produce plain knit fabric, making it necessary to produce the welts/cuffs on special ribbing knitting machines. The ribs are stored on 'running-on' bars and can either be transferred onto the needles of the fully fashioned machine by hand, or automatically.

Often, the ribs are knit wider than the body panel to compensate for the difference in characteristics between rib and plain knit. This results in a series of tiny pleats between the rib and the plain stitching, known as doublings, i.e. two rib stitches knitted to one plain stitch.

The patterning capability of fully fashioned machines is limited to plain knit fully fashioned panels with stitch transfer and intarsia capabilities. Wrap stitches or 'rakers' are also possible. These are usually one-needle-width diagonal lines in contrasting colours and may create diamond patterns (argyle styles).

Gauges range from a relatively coarse 9 gg (generally best suited to heavy yarns in the range 9/2–12/2 Nm) to super-fine 33 gg. Note that fully fashioned gauge is the number of needles per 1.5 inches. The machines are multi-sectioned and the number of knitting sections can vary from 4 up to 16 (normally) and all sections knit identical panels simultaneously. Figure 9.10 shows a section of a fully fashioned knitting machine.

Fully fashioned machines are used to produce high-quality wool knitwear: their gentle action allows delicate, fine count woollen spun yarns,

9.10 A section of a fully fashioned machine. [*Source: Monk Cotton, UK.*]

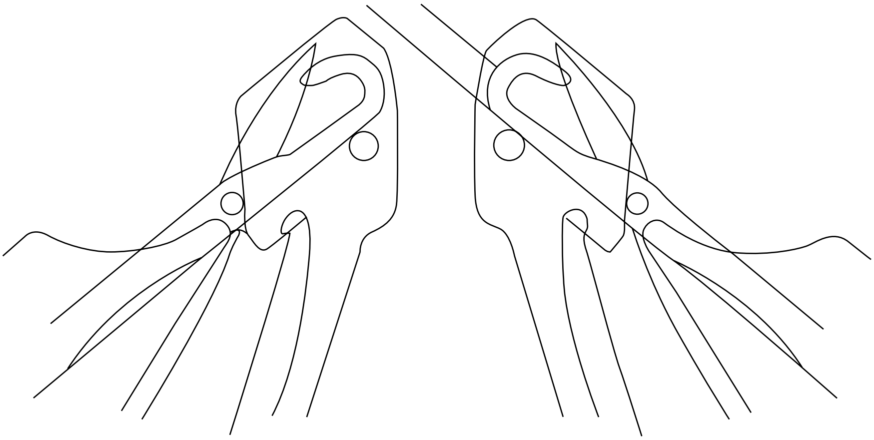
e.g. Merino lambswool, to be knitted. The gentle action also provides good knitting efficiency.

9.8.1.2 Flat knitting machines

Flat knitting machines ('Flatbeds' or 'V-beds') are the most versatile knitting machines available as a result of recent technological developments. Machines are ultra-compact (see Fig. 9.11) and are supported by impressive computer design stations. Gauge is the number of needles per inch.

Two opposing needle beds are positioned so that the upper ends form an inverted 'V' (Fig. 9.12). Needles slide down the beds in slots known as tricks. The carriage of the cam box traverses across the needle beds, selecting needles for knitting. Modern machines have variable traverse cam boxes that can travel only as far as the knitting width. The carriage effectively raises and lowers the needles on both beds simultaneously as it passes over them, depending on the desired pattern. Needle bed lengths can vary from 1.0 m to 2.2 m. They are designed for specific purposes.

9.11 Flatbed knitting machine with computer control facility. [*Source: Shima Seiko, Japan.*]



9.12 Needle bed layout of a flatbed knitting machine. [*Source: Shima Seiko, Japan.*]

It is possible to produce either shaped panels (fully fashioned) or body lengths of knitted fabrics, which are then cut to the required shape. The panels are then linked to form the garment.

Patterning. Stitches can be passed from one bed to the other, and the machines offer virtually unlimited patterning capability. The beds can be moved linearly in relation to each other, which not only allows panels to be shaped, but provides patterning possibilities using stitch transfer, as in Aran-style sweaters. The structured work can be combined with intarsia techniques similar to those produced on fully fashioned machines, although flat machines are limited as to the maximum number of colours and yarn carriers.

Servo-motors are increasingly used to drive the yarn carriers, enhancing the scope not only for intarsia but also for knitting of integral garment parts.

Integral knitting has closely shadowed machine developments. Garment parts such as pockets, collars, stolling, trims and V-necks can be knit as an integral part of the panel. Expertise devoted to programming and setting up a machine for such detailed work saves time at making-up.

Complete garment machines. Complete garments may be knitted on specialised machines, without the need for any making-up. There are two techniques: using an adapted V-bed, or using four needle beds (for finer options).

The two-bed machine is quite similar to the conventional machine, but uses coarser needles having larger hooks for the gauge (e.g. 5 gg needles in a 10 gg machine) so that heavier yarns can be knitted. The yarn is knit on every second needle leaving a needle available for transfer. Each stitch has an empty needle in the opposite bed to enable stitches to be transferred back and forth as required. The resultant effect is a 5 gauge fabric from a 10 gauge knitting machine.

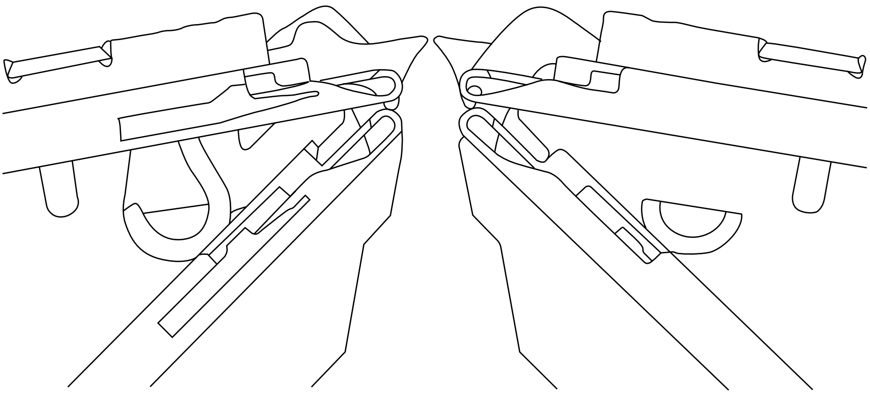
Two-bed complete garment machines are wider than single panel width to allow for the body and two sleeves to be knit side by side as tubes, which are shaped and linked as required.

Four-bed machines (Fig. 9.13) utilise two of the beds for stitch transfer and knitting of ribs. The gauges are the same as for conventional machines and hence finer options than on two-bed machines are available.

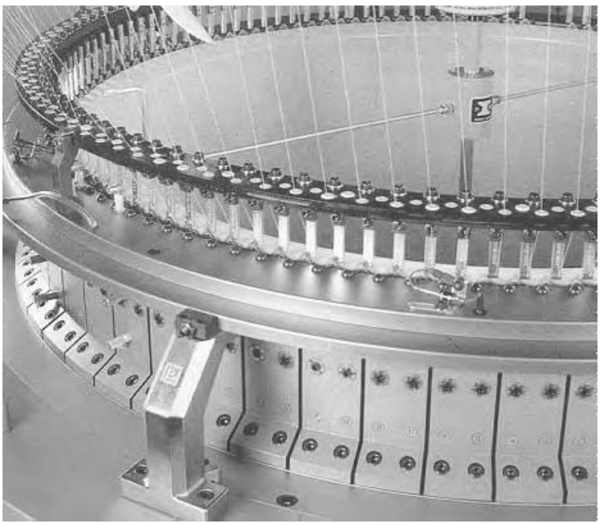
Complete garment technology is highly sophisticated and requires considerable skill.

9.8.1.3 Circular knitting machines

Circular knitting produces lengths of tubular fabric rather than panels or panel lengths. This method is less popular for wool than fully fashioned or flat bed knitting. Garments have to be made via the cut and sew route, which creates waste; and there are technical limitations in knitting, dyeing and finishing.



9.13 Layout of a four-bed knitting machine. [*Source: Shima Seiko, Japan.*]



9.14 A typical single jersey knitting machine, showing cylinder of needles. [*Source: Pailung, Taiwan.*]

Generally, circular knitting produces finer gauge products than the knitwear machines, although available gauges range from 5 to 32 gauge (needles/inch). Gauges suitable for wool jersey knitting are in the region 12–22 gauge, however.

Many types of circular knitting machine are dedicated to specific end uses, e.g. interlock or terry loop. There are models that are more versatile, i.e. that allow knit, miss and tuck selections at each feeder, and even stitch transfer, but none match the versatility of flat knitting machines.

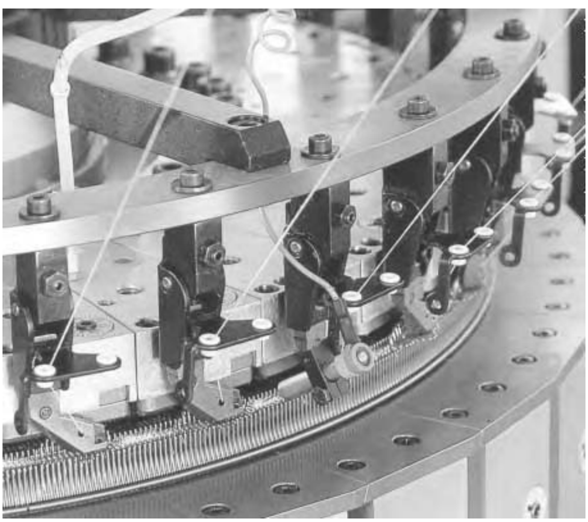
Single jersey machines. Single jersey machines are equipped with a single cylinder of needles (see Fig. 9.14) that produce plain fabrics (single thickness) and plain-knit-based derivatives such as float jacquards and piqués. Needle selection can vary from two-needle through to full electronic needle selection with knit-miss-tuck capabilities. The horizontal stripe depth of these machines is usually governed by the number of yarn feeders around the circumference of the cylinder.

Wool fabric production on single jersey machines tends to be limited to 20 gauge or coarser, as these gauges can utilise two-fold wool yarns up to 48/2 Nm, the balanced twist giving spirality-free fabrics. Finer gauges require single yarns which induce spirality and, although this can be partially 'set' during finishing, the garment may subsequently twist during laundering. Fabrics are used in cut-and-sew garment manufacture, and an inherent feature of wool single jersey fabrics is that the fabric edges tend to curl inwards after cutting.

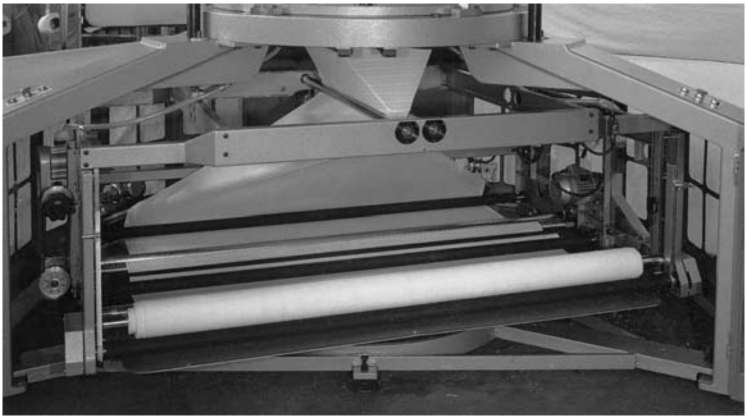
Terry loop is a basis for fleece fabrics and is produced by knitting two yarns into the same stitch, one ground yarn and one loop yarn. The loop yarn is controlled by sinkers which press on the stitch to create a large loop. These protruding loops are then brushed or raised during finishing.

Sliver knitting machines are single jersey machines that have been adapted to feed in a sliver of staple wool fibre. The drafted sliver is hooked over the raised needle via card wire rollers. The fibres are then held in place and laid by a jet of compressed air until locked in place by the stitches.

Double jersey machines. Double jersey machines have a dial of horizontal needles positioned adjacent to a cylinder of vertical needles (see Fig. 9.15). The pattern/structure possibilities are enhanced dramatically



9.15 A double jersey machine having a cylinder of vertical needles that interact with a dial of horizontal needles. [*Source: Terrot, Germany.*]



9.16 A combined fabric slitting and rolling device. [*Source: Vignoni, Italy.*]

compared with single jersey. Generally, the dial knits the inner face of a fabric and the cylinder the outer face.

Wool double jersey fabric is more commonly seen than single jersey. Typical examples are interlock structures for soft Merino wool underwear/base layer garments and 1 × 1 rib fabrics for leggings and outerwear products. Double jersey fabrics tend to be heavy so that fine yarn counts have to be used. A typical yarn providing a compromise between knitting efficiency and cost is Nm 48/1 spun from 21 µ or finer Merino wool. Single yarns do not give spirality problems as the double layer construction balances the yarn torque.

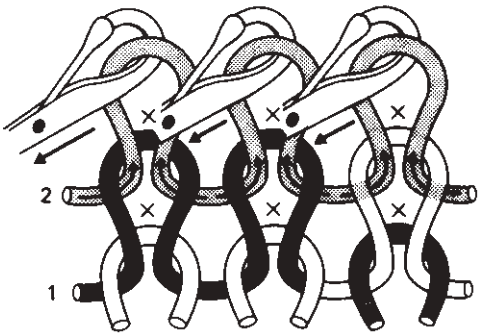
Extremely high rates of production (25–50 mm of fabric per revolution) are available from machines having 72, 96 or 108 yarn feeders. Such machines are less suitable for knitting delicate wool yarns.

A recent development is combined fabric slitting and open width roll-up (as shown in Fig. 9.16), aimed at eliminating crease marks.

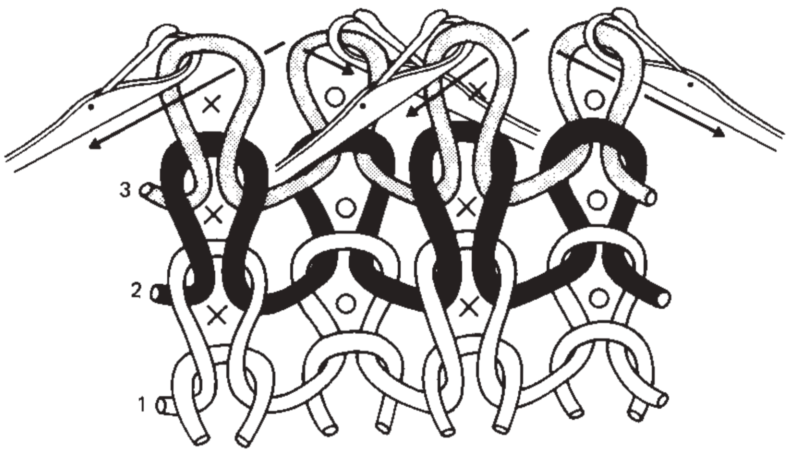
9.8.2 Common wool knitted structures

Single jersey (plain knit or stocking stitch) is formed by the inter-meshing of a number of loops from side to side and top to bottom (Fig. 9.17). The characteristics of a single jersey fabric are:

- single sided
- thin/light weight
- fast and efficient production
- edges curl, difficult to handle
- partially unstable, stitch distortion.



9.17 A single jersey structure. [*Source: Knitting Technology, D J Spencer, Woodhead Publishing.*]

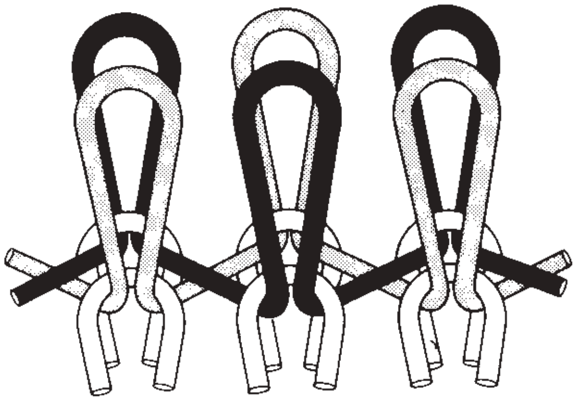


9.18 Structure of 1×1 rib fabric. [*Source: Knitting Technology, D J Spencer, Woodhead Publishing.*]

Rib fabric covers a broad range of knitted structures including 1 × 1, 2 × 1, 2 × 2, and half gauged and fancy ribs. The simplest rib fabric is 1 × 1 (Fig. 9.18) formed using two beds of needles, passing yarn from one bed to the other alternately. The characteristics of a 1 × 1 rib fabric are:

- double sided fabric
- thick/medium weight
- excellent width stretch/recovery
- balanced structure/fairly stable.

Interlock fabric is similar to 1 × 1 rib fabric in that it is knitted alternately on opposite needle beds, but on alternate needles and requires two



9.19 Structure of interlock fabric. [*Source: Knitting Technology, D J Spencer, Woodhead Publishing.*]

opposing knitted courses or traverses to complete one row (Fig. 9.19). Interlock is mostly produced on circular machines. The characteristics of interlock fabric are:

- double side fabric (same face and reverse)
- thick/heavy weight
- good width stretch/recovery
- balanced structure/very stable.

Milano fabric can come in the form of milano rib, milano jacquard, milano and full milano, but all are quite similar in construction. The milano structure combines the 1 × 1 rib with an additional single bed row to improve stability. All variations of milano are widely used, mainly from knitwear machines. The characteristics of a wool milano fabric are:

- single sided fabric
- thick/medium weight
- limited stretch recovery
- reasonably balanced structure
- fairly stable
- suitable for jacquards.

9.8.3 Fabric quality

Fabric quality in wool knitwear can refer to the fabric density or cover factor; it can sometimes apply to the incidence of faults; or to the fineness (micron) of the wool.

9.8.3.1 Fabric density

Stitch density is directly related to the length of yarn in a knitted loop. Factors affected by adjusting loop length are:

- stitch density/fabric density
- fabric weight and fabric cost
- fabric dimensions and panel size (shaped knitwear)
- dimensional stability; relaxation shrinkage
- physical performance; pilling, burst strength.

Wool yarn count and loop length of a fabric should be correlated by the cover factor, CF:

$$CF = \frac{1}{\sqrt{R} \times LL}$$

Where:

R = resultant count of yarn
LL = loop length

The cover factor is selected to achieve the best possible compromise between fabric performance and softness/drape. The yarn count must also be matched to the knitting machine type and gauge (see Table 9.1).

9.8.3.2 Fabric faults

Fabric faults associated with wool knitwear are:

- stitch distortion
- fabric spirality
- yarn irregularity (thick/thin) and neps
- barré (horizontal stripes/bands).

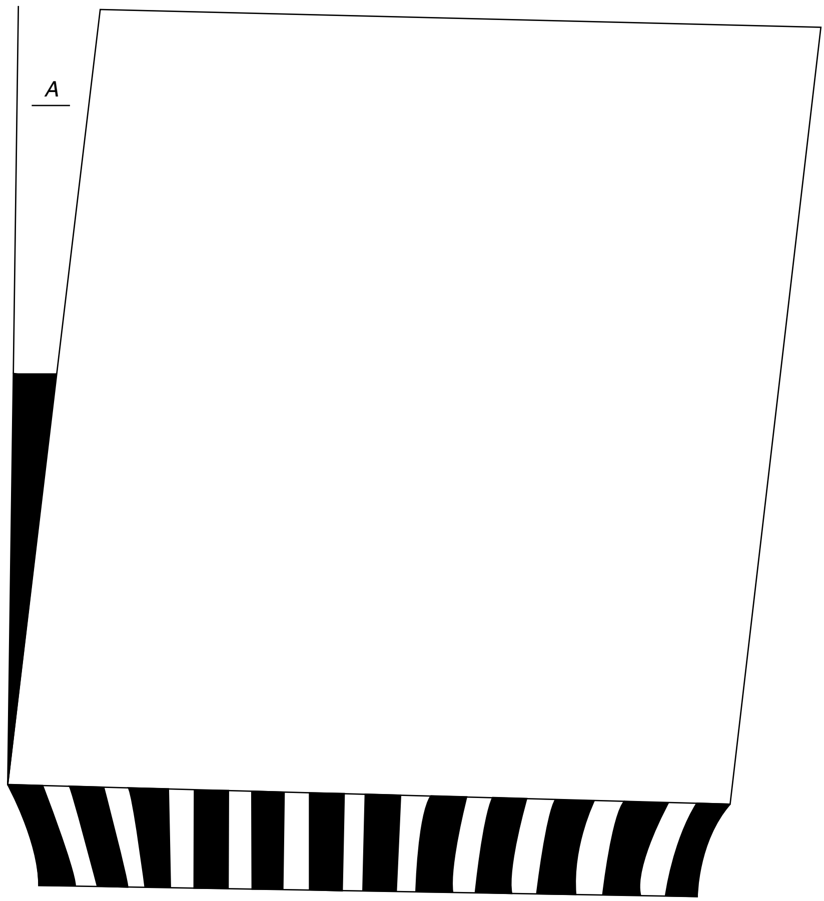
Stitch distortion and fabric cockling tends to be associated with plain knit shaped garments. Yarn properties are one possible cause. Yarn irregularities or yarn faults can give intermittent thick/thin horizontal stripes across the fabric, and neps can look rather like small lumps of fibre or knots.

Fabric spirality results when singles yarns or unbalanced 2-fold yarns are knit into single-bed structures. The fabric twists on steaming or wetting (see Fig. 9.20) leading to garment seams that are no longer vertical.

Yarn irregularity. Some poor quality yarns are uneven, having thick and thin places, resulting in irregular effects within the fabric. Visually these faults appear as a streaky effect in the fabric and can quite often contribute to stitch distortion.

Table 9.1 Examples of yarn count/machine gauge relationships

Straight Bar	Nm
9	9/2–12/2
12	12/2–17/2
15	13/2–20/2
18	20/2–28/2
21	22/2–32/2
24	28/2–26/2
27	32/2–40/2
V-Bed	Nm
3	2/2–2/4
5	2/4–2/9
7	2/10–2/14
8	2/12–2/17
10	2/20–2/24
12	2/24–2/32
Single Jersey	Nm
8	17/2–24/2
10	22/2–36/2
12	28/2–40/2
14	32/2–48/2
18	40/2–30/1
20	48/2–32/1
22	28/1–36/1
24	32/1–40/1
26	36/1–44/1
28	48/1–55/1
Double Jersey	Nm
12	18/1–26/1
14	22/1–32/1
16	28/1–36/1
18	32/1–40/1
22	36/1–48/1



9.20 Fabric spirality. [*Source: The Woolmark Co.*]

Barré can be caused by incorrectly set or badly adjusted knitting equipment. Machines with multiple feeders (both circular and flat machines), if not well controlled, can knit vastly different loop lengths from one feeder (or system) to the next. This problem is more applicable to older generations of circular machinery and hand-operated flat bed machines that have ineffective or no yarn feed control devices.

9.8.4 Garment manufacture

Three manufacturing routes are used, depending on the knitting technology:

- fully fashioned (shaped knitwear)
- cut and sew
- complete garment

Some are more suited to wool products than others.

9.8.4.1 Fully fashioned

Fully fashioned (shaped) knitwear is engineered to size and shape at the point of knitting. Some machines produce only symmetrical designs, whereas others can produce asymmetric styles, enabling shapes such as front panels for cardigans to be produced. As the welts and cuffs are incorporated at knitting, only the collars remain to be added during make-up. Usually, the garment sides, sleeves and underarms are cup seamed using a fine thread, and the shoulders and collars are linked with the same yarn used for knitting.

9.8.4.2 Cut and sew

Individual panel shapes are cut to size from panels (V-bed or flat bed) or from a length of fabric (circular knitting machines), and are sewn together with overlocking. Cutting waste may be as much as 25% of the total fabric, which makes the technique unattractive for wool. The cut and sew route is, however, used for relatively fine gauge wool circular jersey products, but the bulky seams in heavier knitwear are more appropriate to down-market qualities.

9.8.4.3 Complete garment

Products from complete garment machinery effectively require no further making-up, except for sewing into the seam of loose ends of yarn.

The adoption of complete garment technology has been focused on high quality knitwear, using wool, cashmere, silk, etc.

9.8.5 Summary

Wool knitwear of high quality has traditionally been made on fully fashioned machines (fine gauges) and flatbed machines (coarser gauges). More limited volumes of knitwear and tailored garments are made from circular-knitted fabrics. Progressive developments in patterning systems for flatbed machines have enabled designs that could once be accomplished only by hand knitting to be produced. The most recent developments in the knitting of complete garments on one machine are strongly associated with wool. For information about finishing knitwear and knitted fabrics, see Chapter 11.

Bibliography

Ormerod A and Sondhelm W S, *Weaving–Technology and Operations*, The Textile Institute, Machester, 1995.
Spencer D, *Knitting Technology*, Woodhead Publishing, Cambridge, 2001.