1

An introduction to textile technology

1.1 The evolution of textiles

Although man's first articles of clothing and furnishing were probably animal skin wraps, sometimes stitched together using bone needles and animal sinews, he soon attempted to manipulate fibrous materials into textile fabrics, encouraged by experience gained from interlacing branches, leaves and grasses in the production of primitive shelters.

The word '*textile*' originates from the Latin verb *texere* – to weave – but, as the Textile Institute's Terms and Definitions Glossary explains, it is now 'a general term applied to any manufacture from fibres, filaments or yarns characterised by flexibility, fineness and high ratio of length to thickness'.

1.2 Textile fabrics

Textile fabrics can be produced directly from webs of fibres by bonding, fusing or interlocking to make non-woven fabrics and felts, but their physical properties tend to restrict their potential end-usage. The mechanical manipulation of yarn into fabric is the most versatile method of manufacturing textile fabrics for a wide range of end-uses.

There are three principal methods of mechanically manipulating yarn into textile fabrics: interweaving, intertwining and interlooping. All three methods have evolved from hand-manipulated techniques through their application on primitive frames into sophisticated manufacturing operations on automated machinery.

1 *Interweaving* (Fig. 1.1) is the intersection of two sets of straight threads, warp and weft, which cross and interweave at right angles to each other. Weaving is by far the oldest and most common method of producing continuous lengths of straight-edged fabric.
2 *Intertwining and twisting* (Fig. 1.2) includes a number of techniques, such as braiding and knotting, where threads are caused to intertwine with each other

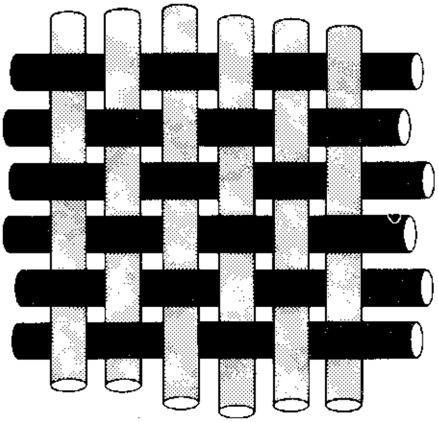

Fig. 1.1 Interweaving.

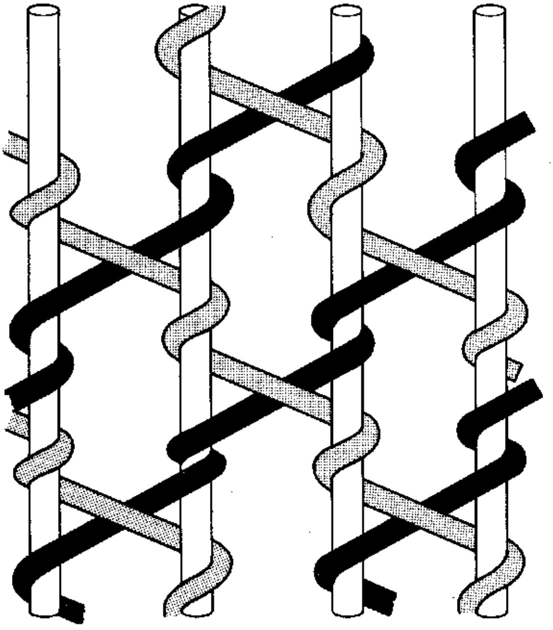

Fig. 1.2 Intertwining and twisting.

at right angles or some other angle. These techniques tend to produce special constructions whose uses are limited to very specific purposes.

3 *Interlooping* (Fig. 1.3) consists of forming yarn(s) into loops, each of which is typically only released after a succeeding loop has been formed and intermeshed with it so that a secure ground loop structure is achieved. The loops are also held together by the yarn passing from one to the next. (In the simplified illustration this effect is not illustrated.)

Knitting is the most common method of interlooping and is second only to weaving as a method of manufacturing textile products. It is estimated that over 7 million

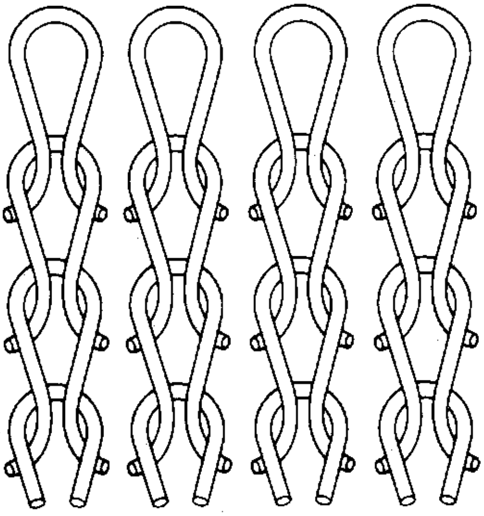

Fig. 1.3 Interlooping.

tons of knitted goods are produced annually throughout the world. Although the unique capability of knitting to manufacture shaped and form-fitting articles has been utilised for centuries, modern technology has enabled knitted constructions in shaped and unshaped fabric form to expand into a wide range of apparel, domestic and industrial end-uses.

1.3 Textile yarns and fibres

Yarns are the raw materials manipulated during knitting. A *yarn* is defined as 'an assembly, of substantial length and relatively small cross-section, of fibres or filaments, with or without twist'. The term '*thread*' is loosely used in place of yarn and does not imply that it is as smooth, highly twisted and compact as a sewing thread.

Textile fibres are the raw materials of the yarns into which they are spun. There are two configurations of fibres: staple fibres and filament fibres.

- *Staple fibres* are of comparatively short length – for example, cotton and wool fibres, which require spinning and twisting together in order to produce a satisfactory length of yarn of suitable strength.
- A *filament* is a fibre of indefinite length – for example silk, which requires combining with other filaments, usually with some twist, in order to produce a yarn of sufficient bulk.

Originally, all textile fibres occurred naturally – for example, animal fibres such as wool and silk, and vegetable fibres such as cotton and flax. The first artificially-produced fibres were the *rayons*, developed by the regeneration of long-chain cellulose polymers that occur naturally in wood pulp and cotton linters. Derivatives such as cellulose acetate and triacetate were later produced by the acetylation of cellulose polymers. *Nylon*, the first truly synthetic fibre, was invented by

Wallace H. Carothers in 1938. It is based on a synthetically-built, long-chain polyamide polymer that previously did not occur naturally. A wide range of synthetic fibre polymers, including polyesters and polyacrylics, has since been developed. Many of the synthetic polymers may be converted into yarns in continuous filament form (in which state they were extruded during manufacturing). The filaments may also be cut or broken into staple fibre form, to be later spun on systems originally developed for natural fibres such as wool or cotton.

The properties of more than one type of fibre may be incorporated into a fabric as the result of blending the fibres during spinning, or by knitting two or more types of yarn.

Knitting requires a relatively fine, smooth, strong yarn with good elastic recovery properties. The worsted system has proved particularly suitable for spinning yarns used for knitwear, outerwear and socks, and the combed cotton system for underwear, sportswear and socks.

The introduction of synthetic fibres, which can be heat set in a permanent configuration, has led to the development of *texturing processes* that directly convert these filaments into *bulked yarns*, thus bypassing the staple fibre spinning process. During texturing, the filaments are disturbed from their parallel formation and are permanently set in configurations such as crimps or coils that help to entrap pockets of air and confer properties such as bulkiness, soft handle, porosity, drape, cover, opacity and (if necessary) elasticity to the resultant yarn. Examples of yarns of this type include *false twist nylon* and *Crimplene*, the latter being a registered trade name for a technique whereby the properties of the textured polyester yarn are modified during a second heat-setting operation so that the stitch clarity, handle and stability of the fabric are improved.

The development of synthetic fibres and of their texturing processes has proved particularly beneficial to the knitting industry and has resulted in a close association between the two industries. The most recent development is the widespread use of the elastane fibre *Lycra* to support the elastic properties of knitted garments. The period from the mid-1960s to 1973 is often regarded by knitters as a ‘golden age’ because fashionable demand for textiles composed of synthetic fibres reached a peak during that period [1,2].

1.4 Yarn count numbering systems

A *yarn count* number indicates the *linear density* (yarn diameter or fineness) to which that particular yarn has been spun. An important consideration in choosing a yarn count is the *machine gauge* which defines the spacing of the needles in the needle bed (usually as *needles per inch*).

Obviously, the finer the machine gauge, the finer the required yarn count. Choice of yarn count is also restricted by the type of knitting machine employed and the knitting construction.

The count, in turn, influences the cost, weight, opacity, handle and drapability of the resultant structure. In general, staple spun yarns tend to be comparatively more expensive the finer their count because finer fibres and a more exacting spinning process are necessary in order to prevent the yarn from showing an irregular appearance.

Unfortunately, a number of differently based count numbering systems are still currently in use. Historically, most systems are associated with particular yarn-spinning systems. Thus, a yarn spun on the worsted system from acrylic fibres may be given a worsted count number.

The *worsted count system* is of the *indirect* type based on *length per fixed unit mass*, i.e. the higher the count number, the finer the yarn. The weight is fixed (1 lb) and the length unit (number of 560-yard hanks) varies. A 1/24's worsted yarn (24 × 560-yard hanks weighing 1 lb) will be twice the cross-sectional area of a 1/48's worsted yarn (48 × 560-yard hanks weighing 1 lb).

The designation 2/24's worsted indicates that the yarn contains two ends of 1/24's so that the resultant count is twice the cross-sectional area (24/2 = 12's).

The denier system is used in continuous filament silk spinning, and when the silk throwsters began to process textured synthetic continuous filament yarns, these nylon and polyester yarns were given denier count numbers.

The *denier system* is of the *direct* type based on *mass per fixed unit length*, i.e. the lower the number, the finer the yarn. The length unit is fixed (9000 metres) and the weight unit (in grams) is variable. A 70 denier yarn (9000 metres weigh 70 g) will be twice as fine as a 140 denier yarn (9000 metres weigh 140 g). A 2/70 denier yarn will give a resultant count of 140 denier.

The *tex system* was introduced as a universal system to replace all the existing systems. As tex sometimes produces a count number having a decimal point, it has been found more satisfactory to multiply the count number by 10 to give a *deci-tex* number. The tex system has not been universally accepted, particularly for spun yarns, and on the continent of Europe the metric system is used for these yarns.

In this book, common commercial practice has been followed, with decitex being used for filament yarn counts and the metric system for spun staple yarn counts.

The main count systems, with their continental abbreviations, are as follows:

Indirect Systems
Bradford Worsted System (NeK) – the number of 560-yard hanks that weigh 1 lb (453.6 g).
English Woollen System (NeW) (Yorkshire Skeins) – the number of 256-yard hanks that weigh 1 lb.
English Cotton System (NeB) – the number of 840-yard hanks that weigh 1 lb.
Continental Metric System (Nm) (Cotton System) – the number of 1000-metre hanks that weigh 1000 g (1 kg).

Direct Systems
Denier System (Td) – the weight in grams of 9000 metres.
Tex System (Tt) – the weight in grams of a 1000 metres.
Decitex System (dtex) – the weight in grams of 10 000 metres.

1.5 Conversion formulae

Tex counts may be obtained from count numbers in other systems by using one of the following formulae:

$$\frac{886}{\text{NeK}} \quad \frac{1938}{\text{NeW}} \quad \frac{591}{\text{NeB}} \quad \frac{1000}{\text{Nm}} \quad \frac{\text{Td}}{9}$$

(To obtain the decitex count, multiply the tex result by ten.)

Example: An interlock underwear fabric is weft knitted from 1/40's NeB at a weight of 5 ounces per square yard. Convert the yarn count to decitex and the fabric weight to grams per square metre.

(a) The conversion for Tex is 591/NeB so it is necessary to also multiply by 10 to obtain decitex.

$$\text{The } \textit{decitex} \text{ count therefore} = (591/40) \times 10 = 148 \text{ dtex}$$

(b) $1\,\text{oz} = 28.35\,\text{g}$ and $1\,\text{yd}^2 = 0.836\,\text{m}^2$.

Therefore $5\,\text{oz/yd}^2 = (5 \times 28.35) = 142\,\text{g} \times 1/0.836 = 170\,\text{g/m}^2$.

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2

From hand knitting to hand frame knitting

2.1 The evolution of hand knitting

The term *knitting* describes the technique of constructing textile structures by forming a continuous length of yarn into columns of vertically intermeshed loops.

It relies heavily on the availability of fine, strong, uniformly spun yarn. The term 'knitting' dates from the mid-sixteenth century, earlier words such as the Saxon 'cnyttan' and the Sanskrit 'nahyat' being less precise, indicating that knitting probably evolved from sources such as the experience gained by knotting and Coptic knitting.

In *Coptic knitting* or *Nalbinding*, an upside-down looped structure is produced using a single-eyed needle (like a sewing needle) containing a short length of yarn. Normally, crossed loops are formed. The technique can achieve fashioning, closing, circular knitting and stitch patterning. Leicester's Jewry Wall Museum possesses a sock of cross stitch construction from the Antinoe site in Roman Egypt dating from the fifth century AD [1].

2.2 The spread of knowledge of hand pin knitting

Weft knitting, using the fingers to produce open loop structures, may well have been practised long before the use of hand-held pins. Hand pin knitting was first recorded in religious paintings in 1350 in Northern Italy. It then spread through the rest of Europe [2]. Maitre Bertram's painting of Mary knitting Christ's seamless garment (Fig. 2.1) is dated to just before 1400. Unfortunately, Christ's garment is more likely to have been made by the 'sprang' or braiding technique, in a similar manner to the vestments of Saint Cuthbert [3].

Cap knitting was established as a technique in Britain by 1424, and by 1488 Parliament controlled the price of knitted caps. Coarse woollen stockings may have been worn prior to 1600 but they were not as fine as woven cloth stockings cut on the bias to give greater extensibility. Henry VIII (1509–1547) was the first British

Fig. 2.1 The Madonna knitting Christ's seamless garment. The earliest recorded illustration of a knitted garment. Part of a church architectural painting by Maitre Bertram (1345–1415) [Hamburg Kunsthalle Museum].

monarch to wear fine expensive knitted silk stockings. Queen Elizabeth I wore them in about 1561 and was so impressed by their elasticity and fineness that she never again wore cut and sewn woven hose [4]. In 1564 William Rider knitted a pair of worsted stockings by copying a pair knitted in Italy.

2.3 The principles of hand knitting using two pins

In Fig. 2.2a, the left-hand pin A is retaining the previously formed row of loops (course). The right-hand pin B is being used to draw through and retain the next course of loops, one at a time.

In Fig. 2.2b, pin B has drawn the newly formed loop 2 through loop 1 of the previous course. Pin A then releases loop 1, which hangs from loop 2, which itself is hanging from pin B. (Note that loop 1 has been drawn under the head of the lower loop and that loop 2 has been drawn over the head of loop 1.)

At the start of the next row (course), the pins may be changed hands and the action continued. If this happens, the fabric will be turned around and the next course of loops will mesh through from the opposite side of the fabric. Each course

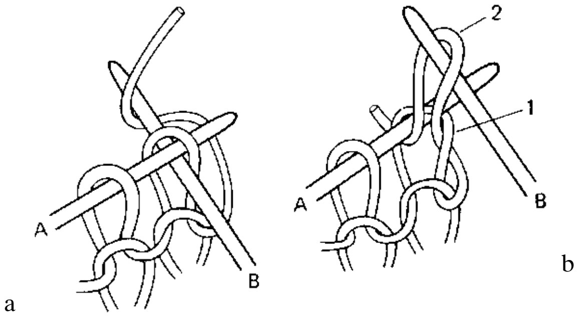

Fig. 2.2 Hand pin knitting.

of loops will be drawn through the heads of the previous course of loops, in the *same direction* in the fabric. As the pins are straight and pointed, skill is required to ensure that the loops do not slip off the end and cause *drop stitches*.

2.4 The invention of the stocking hand frame

'The Reverend' William Lee 'of Calverton in Nottinghamshire' is generally credited with inventing the stocking hand frame in 1589. 'The advance it represented, by mechanising complex hand movements at a single stroke, was 150–200 years in advance of its time.' [5]

The concept of its operation was so brilliant that, through an evolutionary process of technical refinement, modification and innovation by many inventors throughout the world over the succeeding centuries, it laid the foundations for today's weft and warp knitting and machine lace industries.

Unfortunately there is no dated documentary evidence concerning Lee's life, efforts and achievements prior to 1589 [6]. Imaginative descriptions and paintings from a much later period provide a mythical and confusing back-cloth to the event. The first extant illustrations of a frame were drawn for *Colbert* by the French spy *Hindret* in 1656, and the earliest existing stocking frames appear to date from about 1750.

Lee's original frame was undoubtedly crude, and knitted poor quality woollen stockings with a gauge of only 8 needles per inch (25 mm). It required two men to operate it. Not until 1750 were frame knitted stockings accepted as comparable in quality to those knitted with pins. Lee is believed to have knitted a pair of silk stockings in 1596/7 [7], although a reported gauge of 20 needles per inch seems to be too fine for that period. A gauge of 16 needles per inch was only commercially attained after 1620, when *Aston* applied lead *sinkers* (dividers) in the hand-frame.

Frustrated in his attempts to obtain a patent from either Elizabeth I or James I by the fear of unemployment amongst hand pin knitters, William Lee and his brother James took their nine machines and knitters to France at the invitation of Henry IV in 1609. Lee set up a workshop in Rouen and signed a partnership agreement with Pierre de Caux in 1611, with a further agreement in 1614.

The protection of Protestant workers in France ended when Henry IV was assassinated in 1610 and it is believed that (at an unspecified date) James brought most of the machines and knitters back to London and that William died in poverty in Paris whilst hiding from persecution. England then prohibited the export of stocking frames, but Hindret's accurate drawings and knowledge enabled frames to be built in Paris from 1656 onwards and thus the knowledge of their operation spread across Europe.

Gradually London declined as the centre of frame-work knitting and, by 1750, the major areas could be broadly classified as Derby for silk, Nottingham for cotton and Leicester for wool knitting.

Improvements in the spinning of cotton yarns led particularly to an increase in knitted underwear and open-work point lace fabrics, in addition to cotton hose. The knitting industry then expanded rapidly until 1810 when over-production resulted in stagnation, unemployment and the Luddite riots. It was not until conditions improved in the second half of the century that new innovations and inventions in knitting technology received encouragement and practical application.

2.5 The bearded needle

From a logical viewpoint, Lee's hand frame has more in common with a knitting *peg frame* (Stuhl) than with a pair of hand-held pins. There is evidence of a prior art of peg frame knitting dating back at least to 1535 in Strasbourg [8].

Lee quickly discarded the idea of trying to imitate hand-held circular knitting. His brilliance lay in his adaptation and integration of the straight peg frame with the foot- and hand-controls of the hand-operated weaving loom, and with the employment of a hooked loop holder (*the bearded needle*) for loop intermeshing.

The bearded needle has an extended hook or beard that is pressed to enclose the newly-formed loop so that this loop can be drawn through the previously-formed loop as the latter is being released.

Lee set the needles in a row across the width of the frame, whose working parts were more intricate than that of the existing hand-weaving loom. Skilled hand knitters could only form up to 100 loops per minute whereas Lee's first frame could achieve 500 to 600 loops per minute, and the later silk hose frame could produce 1000 to 1500 loops per minute.

2.6 The principles of frame knitting

Figure 2.3 shows a side view of the knitting elements. After the weft yarn has been laid by hand across the horizontally-mounted needle bed, thin metal sinkers descend

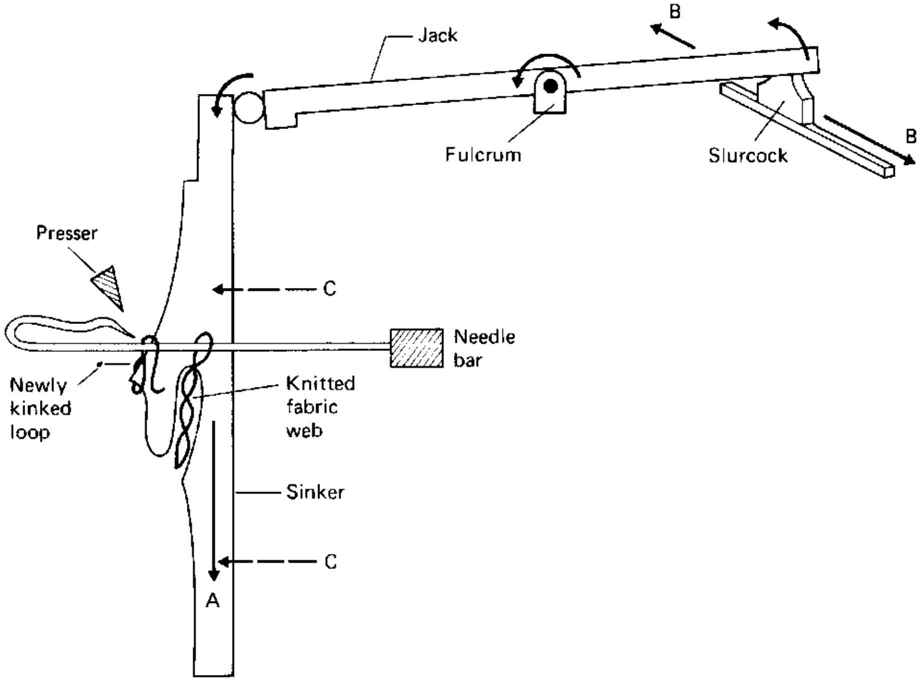

Fig. 2.3 The action of frame knitting.

(in direction A) individually between each pair of adjacent needles to kink or sink it into a loop shape around each needle stem. Each sinker is caused to descend because it is hinged at its upper end to a pivoted jack that is lifted at its outer end by a wedge-shaped piece of iron termed a *slurcock*.

The slurcock is traversed backwards and forwards (direction B) across the needle bed width by a rope. A forward motion of the sinkers (in direction C) takes the new loops under the beards. The beard is then closed by the presser bar.

Figure 2.4 shows a general view of the hand frame. There are three foot-pedals. After the weft yarn has been laid across, the right pedal is pressed down causing the rope attached to it to turn the wheel clockwise and draw the slurcock from left to

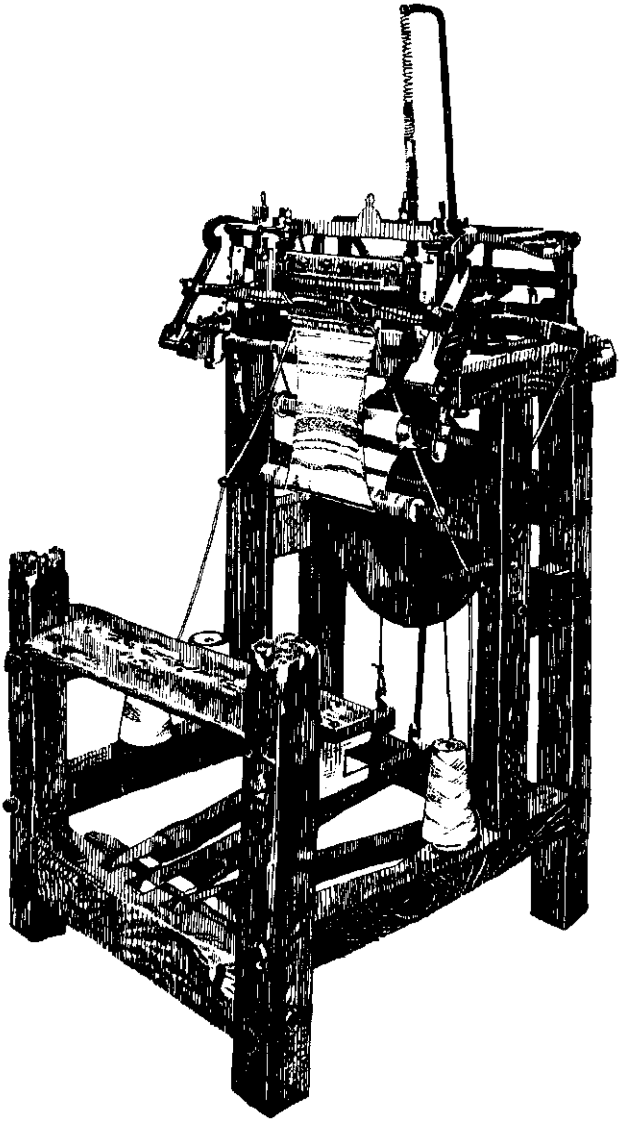

Fig. 2.4 Hand frame (c. 1820) [Copyright: Leicestershire Museums, Art Galleries and Record Service].

right. For the next row of loops, the slurcock is traversed across from right to left by pressing down the left foot-pedal after the yarn has been laid across. This turns the wheel in the opposite direction. The middle pedal causes the presser bar to be lowered to press and close the needle beards.

2.7 The evolution of other weft knitting machines

The fineness of the needles and sinkers relied heavily on the developing skills of English mechanics, a skill which was lacking on the continent of Europe at that time. Lee's original invention, although workable, was not economically viable as it required two men to operate it. Improvements were carried out and by 1620, *Aston*, a former apprentice of Lee's, had arranged the sinkers into alternating sets and thus, with skill and precision, had obtained better uniformity of loop length, much finer machine gauges (24 gauge) and easier operation of a frame consisting of 2000 parts.

The jack sinkers continued to be individually raised and lowered but the lead or dividing sinkers were afterwards moved down *en bloc* to equalise the loop lengths. The principle of sinkers and dividers is still employed on fine gauge Cotton's patent straight bar frames. Other improvements were trucks (wheels bearing the weight of the mechanism), sley castor backs and front stops.

These developments led to attempts to prevent the export of the improved British frames and to the growth of framework knitting in the second half of the seventeenth century, but a hundred years passed before further significant developments occurred. Strutt's *Derby Rib* attachment dates from 1759 (see Section 7.3). In 1769 the frame was successfully adapted to rotary drive (Section 17.1). It was not until the second half of the nineteenth century that vertical needle bars began to be employed or circular frames became viable (Section 8.4.3), despite earlier circular-machine patents ranging from Decroix's in 1798 to Brunel's in 1816.

It was the invention of Cotton's straight bar frame that automated the production of fashion shaped articles and developed the full potential of loop transfer shaping (Section 17.1).

Matthew Townsend's versatile latch needle (Section 3.14), however, mounted a challenge to the monopoly of the bearded needle frame and, with the later support of precision engineering techniques, it paved the way for electronically-controlled individual needle selection (Sections 11.13 and 12.6) on V-bed and circular machines.

2.8 The development of warp knitting

Warp knitting, the second and smaller section of machine knitting, was never a hand-manipulated craft. It was first developed by Crane and Porter in 1769 as a method of embroidery plating, by means of multiple warp thread guides, onto stocking fabric as it was being knitted on the hand frame.

As the technique improved, purely warp intermeshed loop structures without the weft knitted ground began to be knitted and *Crane* patented his warp loom in 1775. Tarrat is credited with developing the first efficient treadle-operated warp knitting frame in 1785. Two important later developments were *Dawson*'s wheels for shogging the guide bars, and *Brown*'s use of two separately-controlled, warp-supplied guide bars. In 1807, another Nottingham frame-smith, *S. Orgill*, introduced the

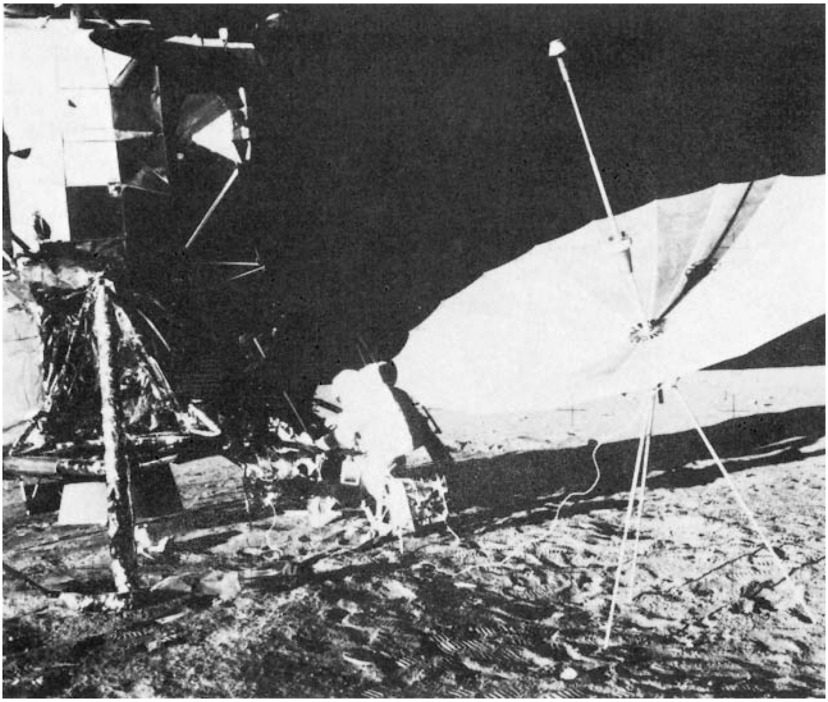

Fig. 2.5 Warp knitted fabric on the moon [Photo credit NASA]. The photograph, taken during the Apollo 12 mission, shows the warp knitted antenna which transmitted the television pictures of the lunar landing back to Earth. The two-bar mesh fabric, weighing less than one ounce per square yard, was warp knitted from gold plated metallic yarn. [*Knit O'wr Times*, July 7, 1969, 34–7].

rotary shaft driven knitting frame, having a width up to 72 inches (1.8 m) and cam-controlled knitting motions capable of knitting up to 30 rows (courses) of loops per minute.

The German warp knitting industry developed in Chemnitz and Apolda, after *Reichel* brought a British hand warp loom to Berlin in 1795.

During the Napoleonic wars, 500 hand warp looms were producing woollen uniform fabric for the British forces. However, the power-driven weaving loom was soon to out-produce the warp loom in plain fabric and, by the 1840s, the fancy lace market was lost to the patterning capabilities of the Leaver's lace machine.

The ingenuity of machine builders and warp knitters, and a combination of modern engineering technology and the advent of new yarns and finishing processes, have at last enabled warp knitting to realise the potential it first demonstrated in its early years of development (Fig. 2.5).

2.9 The potential of knitting technology

The unique loop structure of knitting provides opportunities for

- using a minimum number of yarns.
- easy flow of yarn from one loop to another under tension.
- varying the size of loops.

- loop distortion when under tension.
- loop transfer.
- knitting single face, double face, open-work and surface interest structures.
- increasing or decreasing the number of loops in width or depth.
- knitting to shape either fabric pieces or separate articles.
- knitting from a selection of yarns.
- engineering extensibility or stability.
- introducing (by inlay) yarns unsuitable for knitting.

2.10 Meeting the challenge of new markets

Today, knitting machines can manufacture most previously hand-knitted designs and structures in a fraction of the time as well as knitting structures that are too fine, intricate or complex to be attempted with hand-held pins. The manufacture of textiles is a highly competitive industry requiring the harnessing of the very latest technology to meet the instant demands of fashion and changing end-use requirements.

Fortunately the unique properties of knitted constructions, their ability to be engineered to exacting requirements and their potential for producing shaped articles as well as fabrics, enables knitting technology to rapidly respond to requirements in non-apparel areas whilst retaining its traditional markets in sweaters, hosiery, jersey and tricot fabrics, and raschel lace [9].

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3

General terms and principles of knitting technology

3.1 Machine knitting

Knitted structures are progressively built-up from row after row of intermeshed loops. The newly-fed yarn is converted into a new loop in each needle hook. The needle then draws the new loop head first through the old (fabric) loop, which it has retained from the previous knitting cycle. The needles, at the same time, release, (*cast-off* or *knock-over*) the old loops so that they hang suspended by their heads from the feet of the new loops whose heads are still held in the hooks of the needles.

A cohesive knitted loop structure is thus produced by a combination of the intermeshed needle loops and yarn that passes from needle loop to needle loop.

3.2 The knitted loop structure

The knitted loop structure may not always be noticeable because of the effect of structural fineness, fabric distortion, additional pattern threads or the masking effect of finishing processes. However, unless the intermeshing of the loops is securely achieved by the needles receiving new loops of yarn into their hooks before the old loops are ‘cast-off’, and the ground structure is not fractured during finishing or wear, a breakdown or separation of the structure will result.

The properties of a knitted structure are largely determined by the interdependence of each stitch to its neighbours on either side and above and below it.

Knitted loops are arranged in rows, roughly equivalent to the weft and warp of woven structures. These are termed ‘*courses*’ and ‘*wales*’ respectively.

3.3 A course

A *course* is a predominantly horizontal row of needle loops (in an upright fabric as knitted) produced by adjacent needles during the same knitting cycle. (The last five words help to prevent confusion when describing complex weft knitted fabrics).

3.3.1 A course length

In weft knitted fabrics (with the exception of structures such as jacquard, intarsia and warp insertion), a course of loops is composed of a single length of yarn termed *a course length*. Weft knitted structures will *unrove* from the course knitted last unless it is secured, for example, by binding-off.

3.3.2 A pattern row

A *pattern row* is a horizontal row of needle loops produced by adjacent needles in one needle bed. In plain weft knitted fabric this is identical to a course but in more complex fabrics a pattern row may be composed of two or more course lengths. In warp knitting, every loop in a course is usually composed of a separate yarn.

3.4 A wale

A *wale* is a predominantly vertical column of intermeshed needle loops generally produced by the same needle knitting at successive (not necessarily all) knitting cycles. A wale commences as soon as an empty needle starts to knit.

- When loop transfer occurs it is possible to transfer a wale of loops from one needle A to another B and to recommence knitting with the second needle, in which case more than one needle will have produced intermeshed loops in the same wale. (If needle B knits continuously, the wale knitted by needle A will merge into it).
- In warp knitting a wale can be produced from the same yarn if the same warp guide laps the same needle at successive knitting cycles.
- Wales are connected together across the width of the fabric by sinker loops (weft knitting) or underlaps (warp knitting).
- Wales show most clearly on the technical face and courses on the technical back of single needle bed fabric.

3.5 Stitch density

Stitch density refers to the total number of loops in a measured area of fabric and not to the length of yarn in a loop (*stitch length*). It is the total number of needle loops in a given area (such as a square inch, or three square centimetres). The figure is obtained by counting the number of courses or pattern rows in one inch (or three centimetres) and the number of wales in one inch (or three centimetres), then multiplying the number of courses by the number of wales. (Using a measurement of three centimetres rather than one, is preferable for accuracy in counting).

Stitch density gives a more accurate measurement than does a linear measurement of only courses or only wales. Tension acting in one direction might produce a low reading for the courses and a high reading for the wales; when they are multiplied together this effect is cancelled out. Pattern rows rather than courses may be counted when they are composed of a constant number of courses.

3.6 Technically upright

A knitted fabric is *technically upright* when its courses run horizontally and its wales run vertically, with the heads of the needle loops facing towards the top of the fabric and the course knitted first situated at the bottom of the fabric.

3.7 Design appearance requirements

The terms *technical face*, *technical back*, and *upright* are purely technically descriptive terms. They do not necessarily indicate the orientation of the fabric from the designer's viewpoint.

For example:

- Socks and ladies hosiery are usually worn upside-down compared to their sequence of production.
- The technical back of structures is often used for *plush* and *pile* effects.
- Curtains may be hung sideways compared to the wales.
- Diagonal stripes may be achieved for dress-wear by cutting the fabric at an angle.

3.8 The main features of the knitting machine

Originally, the term '*machine*' used to refer to a mechanism on a bearded needle frame such as the fashioning mechanism on the straight bar frame. Today, it refers to the complete assembly.

A *knitting machine* is thus an apparatus for applying mechanical movement, either hand or power derived, to primary knitting elements, in order to convert yarn into knitted loop structures.

The machine incorporates and co-ordinates the action of a number of mechanisms and devices, each performing specific functions that contribute towards the efficiency of the knitting action.

The main features of a knitting machine (see Fig. 13.12) are as follows:

1 *The frame* or *carcass*, normally free standing and either circular or rectilinear according to needle bed shape, provides the support for the majority of the machine's mechanisms.
2 *The machine control* and *drive system* co-ordinates the power for the drive of the devices and mechanisms.
3 *The yarn supply* consists of the yarn package or beam accommodation, tensioning devices, yarn feed control and yarn feed carriers or guides.
4 *The knitting system* includes the knitting elements, their housing, drive and control, as well as associated pattern selection and garment-length control device (if equipped).

5 *The fabric take-away mechanism* includes fabric tensioning, wind-up and accommodation devices.
6 *The quality control system* includes stop motions, fault detectors, automatic oilers and lint removal systems.

Machines may range from high-production, limited-capability models to versatile, multi-purpose models having extensive patterning capabilities. The more complex the structure being knitted, the lower the knitting speed and efficiency. The simplest of the knitting machines would be hand-powered and manipulated whereas power-driven machines may be fully automatically-programmed and controlled from a computer system.

3.9 The needle

The hooked metal needle is the principal knitting element of the knitting machine.

Prior to yarn feeding, the needle is raised to clear the old loop from the hook and to receive the new loop above it on the needle stem. The new loop is then enclosed in the needle hook as the needle starts to descend. The hook then draws the new loop down through the old loop as the latter slides over the outside of the descending bridge of the closed hook. All needles must therefore have some method of closing the needle hook to retain the new loop and exclude the old loop.

3.10 Fabric draw-off

The fabric loops are always drawn from the needles on the side remote from their hooks. When two sets of needles are employed, either arranged vertically back-to-back or at some other angle to each other, each set of hooks will face away from the other set and the fabric will be produced and drawn away in the gap between the two sets.

3.11 The front of rectilinear needle bar machines

All rectilinear needle bar machines have a front and a back. The front of the machine is the side to which the fabric is drawn away, removed and inspected during knitting.

If the machine has a single vertical needle bar, its hooks will face towards the back. If the machine has two vertical needle bars, the fabric will be drawn down between them and will then pass underneath one needle bar (the front bar) and will be removed from that side of the machine.

On warp knitting machines, the guide bars and their corresponding warp beams are numbered and described according to their position in relation to the front and back of the machine.

On circular machines, there is no front or back as the fabric is drawn towards the centre, usually below the needle circle. The cylinder face loops show on the outside of the fabric tube as it is drawn downwards during knitting.

3.12 The basic knitting action of a needle

Figure 3.1 (1–7) illustrates the basic action of a needle. Except for the manner in which the hook is closed (in this case by pressing the beard), the knitting action is similar for all needles. The arrows indicate the relative movement of the loops along the needles. (Whether the needle moves through the loops or the loops are moved over the needle by some other elements depends upon the machine design.)

1 The needle is in the (so-called) *rest position*, with the previously formed loop (a) held on its stem and covered by the hook.
2 The loop is *cleared* from the needle hook to a lower position on the needle stem.
3 The new yarn (b) is *fed* to the needle hook at a higher position on the needle stem than the position of the previous ('old') loop.
4 The yarn is *formed* into a 'new' loop.
5 The hook is *closed*, enclosing the new loop and excluding and *landing* the old loop onto the outside of the closed hook.
6 The new loop (b) is *drawn through* the head of the old loop (a). Simultaneously the old loop slides off the closed hook of the needle and is *cast-off* or *knocked-over*.
7 The old loop now hangs from the feet of the fully formed new loop and the knitting cycle starts again.

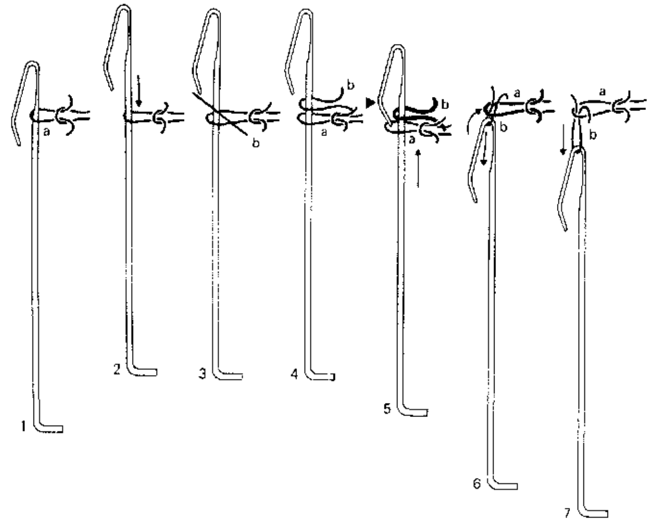

Fig. 3.1 Basic knitting action of a needle.

3.13 The bearded needle

As mentioned previously (Section 2.5), the *bearded* or *spring needle* was the first type of needle to be produced. It is the cheapest and simplest type to manufacture as it is made from a single piece of metal, in machine gauges as fine as 60 needles per inch, with the needles being pliered to ensure accurate needle spacing.

The bearded needle is essentially a *frame needle*, the needles being fixed to move collectively with the straight needle bar or being attached to a circular frame and revolving with it.

When bearded needles are reciprocated in their bed, the action is a collective one because of the problems of individual pressing and needle movement. The serial action of weft knitting is thus achieved by other loop-forming and controlling knitting elements that form the yarn into new loops and may (on sinker wheel and loop wheel frames) move the loops along the needle stems. A knitting section occupies a considerable amount of space on bearded needle circular machines, thus limiting productivity. Selective beard pressing facilities used to be provided on some weft and warp knitting machines.

In weft knitting, accurate control of the loops throughout the knitting sequence made the bearded needle *sinker wheel* and *loop wheel* frames particularly suitable for the production of plush and inlay, whilst the ease of flexing and deflection of the bearded needle made the sinker wheel and straight bar frames useful for loop transfer effects. However, bearded needle technology was unable to meet the challenging requirements of modern knitting machinery, such as individual needle selection of stitches, use of two needle beds and high productivity. Once fine-gauge latch needle machines could knit, to a consistently high quality, structures that were previously only knitted on bearded needle machines, the latter were no longer competitive.

3.13.1 The main parts of the bearded needle

There are five main parts of the bearded needle (Fig. 3.2):

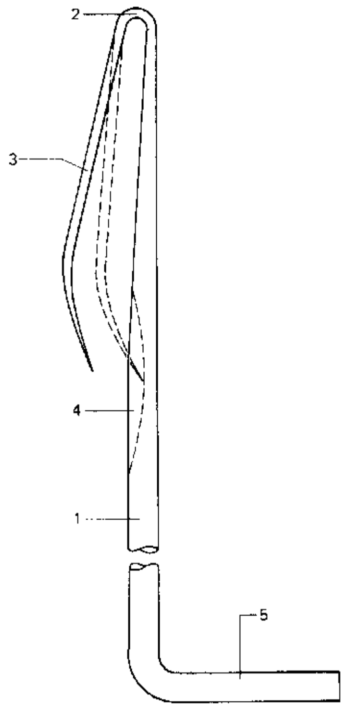

Fig. 3.2 Main parts of the bearded needle.

1 The *stem*, around which the needle loop is formed.
2 The *head*, where the stem is turned into a hook to draw the new loop through the old loop.
3 The *beard*, which is the curved downwards continuation of the hook that is used to separate the trapped new loop inside from the old loop as it slides off the needle beard.
4 The *eye*, or groove, cut in the stem to receive the pointed tip of the beard when it is pressed, thus enclosing the new loop.
5 The *shank*, which may be bent for individual location in the machine or cast with others in a metal 'lead'.

3.13.2 The knitting action of the bearded needle

The knitting action of the bearded needle has been illustrated in Fig. 3.1. Depending upon the machine, the needles are set vertically or horizontally. The needle has the disadvantage of requiring a pressing edge to close the bearded hook and enclose the new loop. The presser may be in the form of a bar, blade, verge or wheel, with either the presser or the needle remaining stationary whilst the other element moves towards it.

Another feature of bearded needle knitting is that individual loop formation has to be achieved by a *loop forming element*. This leads to a more complicated knitting action but also provides for a more gentle and careful loop formation.

3.14 The latch needle

3.14.1 The history and development of the latch needle

Fact and fiction envelopes the invention of the *latch needle* in a similar manner to that of the bearded needle. *Pierre Jeandeau* patented the first latch needle (also known as the *tumbler needle*) in 1806 but there is no evidence of its practical use [1,2]. There is also no evidence that the pivoting of a broken pocket knife blade led to the development of the latch spoon.

However, it was *Townsend* and *Moulden's* practical patents applying the use of this *self-acting* needle that, in 1849, began the challenge to the 260-year reign of the bearded needle.

Matthew Townsend was a Leicester fancy hosier who was searching for a simpler method of knitting purl fabrics than using a frame with two sets of bearded needles and pressers. Townsend not only realised that a latch needle, which dispensed with the need for a presser, could be employed in a double-headed form to knit purl, he also foresaw the use of single-headed latch needles in plain and rib circular machines, flat machines and single and double needle bar warp knitting machines, as well as the use of holding-down sinkers for single needle bed knitting.

Although the first needles were crude, a *Mr. D. Fitchett* used them to knit borders for cravats which he exhibited at the Great Exhibition of 1851. Townsend, who lacked engineering skill and financial backing, sold the rights of his latch needle to *Joseph Pool* of Leicester and *Hine Mundella* of Nottingham, and emigrated to Canton, Massachusetts in 1858. In 1865 he was successfully sued for infringing the American latch needle patent of *James Hibbert*, which pre-dated his own by a mere month and four days. In his defence, Townsend stated that latch needles had been in use in France for many years, but he was unable to provide evidence. He died in 1879.

The latch needle was a more expensive and intricate needle to manufacture than the bearded needle. It was more prone to making needle lines as it slides in its trick, particularly if the latch was damaged or there was dirt in the trick. However, the latch needle was quickly employed by the newly emerging American knitting machine industry, whilst British companies preferred the bearded needle. The latter believed the bearded needle, which could be more precisely manufactured, had a knitting action which produced a better quality knitted structure.

It is now accepted that precision-manufactured latch needles can knit structures of the highest quality.

3.14.2 The features of the latch needle

The latch needle has nine main features (Fig. 3.3):

1 The *hook*, which draws and retains the new loop.
2 The *slot* or *saw cut*, which receives the latch-blade (not illustrated).
3 The *cheeks* or *slot walls*, which are either punched or riveted to fulcrum the latch-blade (not illustrated).
4 The *rivet*, which may be plain or threaded. This has been dispensed with on most plate metal needles, by pinching in the slot walls to retain the latch blade.
5 The *latch-blade*, which locates the latch in the needle.

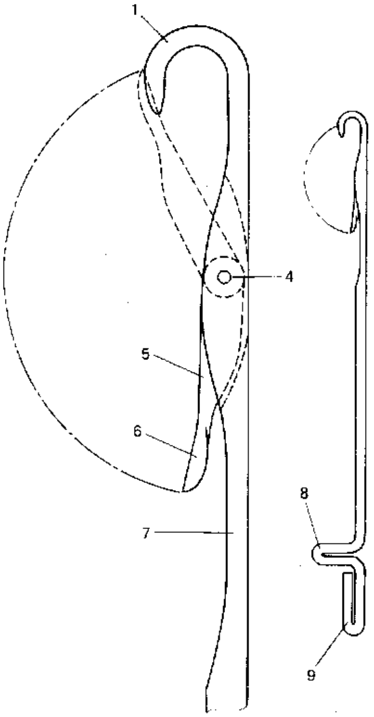

Fig. 3.3 Main features of the latch needle.

6 The *latch spoon*, which is an extension of the blade, and bridges the gap between the hook and the stem covering the hook when closed, as shown in broken lines.
7 The *stem*, which carries the loop in the clearing or rest position.
8 The *butt*, which enables the needle to be reciprocated when contacted by cam profiles on either side of it, forming a track. Double-ended purl type needles have a hook at each end; whilst one hook knits, the inactive hook is controlled as a butt by a cam-reciprocated element called a *slider*.
9 The *tail*, which is an extension below the butt, giving additional support to the needle and keeping the needle in its trick.

3.14.3 The knitting action of the latch needle

Figure 3.4 shows the position of a latch needle as it passes through the cam system, completing one knitting cycle or course as it moves up and in its trick or slot.

1 *The rest position*. The head of the needle hook is level with the top of the verge of the trick. The loop formed at the previous feeder is in the closed hook. It is prevented from rising as the needle rises, by *holding-down sinkers* or web holders that move forward between the needles to hold down the sinker loops.
2 *Latch opening.* As the needle butt passes up the incline of the clearing cam, the old loop, which is held down by the sinker, slides inside the hook and contacts the latch, turning and opening it.
3 *Clearing height*. When the needle reaches the top of the cam, the old loop is cleared from the hook and latch spoon on to the stem. At this point the feeder guide plate acts as a guard to prevent the latch from closing the empty hook.
4 *Yarn feeding and latch closing*. The needle starts to descend the stitch cam so that its latch is below the verge, with the old loop moving under it. At this point the new yarn is fed through a hole in the feeder guide to the descending needle hook, as there is no danger of the yarn being fed below the latch. The old loop contacts the underside of the latch, causing it to close on to the hook.
5 *Knocking-over and loop length formation.* As the head of the needle descends below the top of the trick, the old loop slides off the needle and the new loop is drawn through it. The continued descent of the needle draws the loop length, which is approximately twice the distance the head of the needle descends, below the surface of the sinker or trick-plate supporting the sinker loop. The distance is determined by the depth setting of the stitch cam, which can be adjusted.

The *rest position* actually occurs between positions 1 and 2, when the open needle hook just protrudes above the needle trick verge. In this position, a feeder would be passed without the needle receiving a new loop and the old loop would not be cast off, so that a float stitch would be produced. The *tucking in the hook position* occurs between positions 2 and 3, when the needle can receive the new yarn but the old loop has not been cleared from the open latch.

The latch needle used on the *Stoll* CMS V-bed flat machine has a spring-loaded latch so that it fully opens and fully closes. Also, the latch spoon does not project beyond the needle head. Loops thus slide easily over the hook and latch, the yarn is less likely to be split, and there is greater security for the knitted loops.

NB: Although the above knitting action is described assuming the needle to be moving through the knitted loops, the movement is relative and the same effect can be achieved by moving the loops over a stationary needle. Similarly, the knock-over

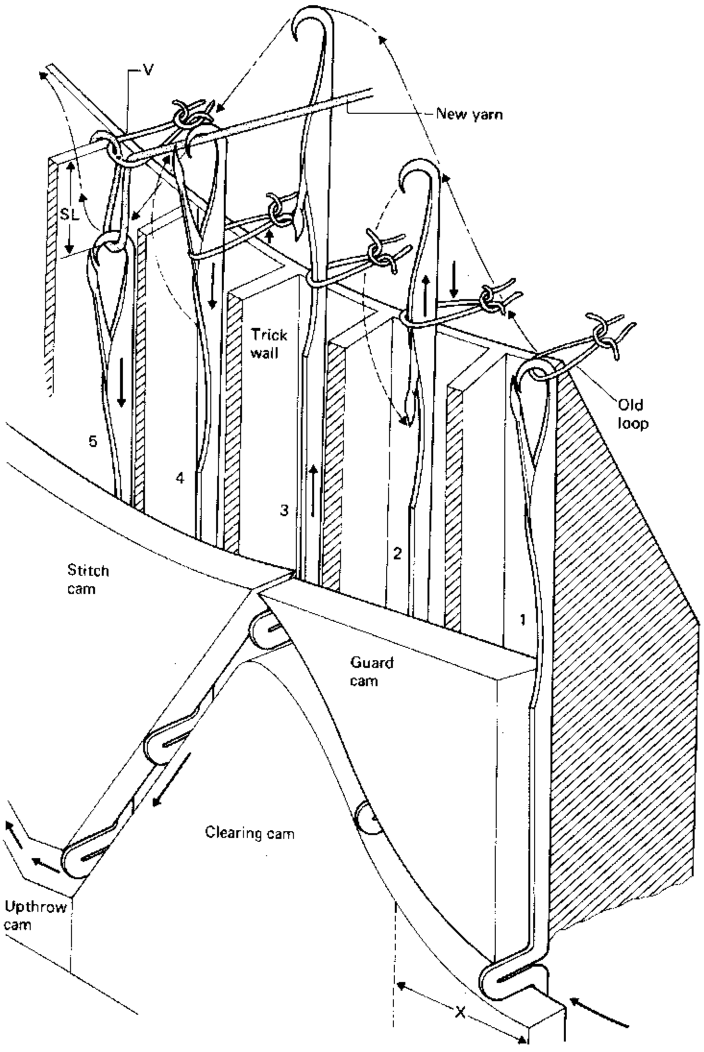

Fig. 3.4 Knitting action of the latch needle.

surface can be moved in opposition to the needle movement. (see *Relanit*, Chapter 13; and *Shima* contra sinkers, Chapter 19).

3.14.4 The advantages of the latch needle

The latch needle has the major advantage of being self-acting or loop-controlled, so that individual movement and control of the needle enables stitch selection to be achieved. It is ideally suited for use with computer-controlled electronic selection devices. For that reason, it is the most widely used needle in weft knitting and is sometimes termed the *'automatic' needle* (provided there are loops on the needle).

The old loop is cleared from the hook automatically when the needle is lifted because the loop slides down inside the hook and contacts the latch or tumbler, causing it to pivot open allowing the loop to slide off the latch down onto the stem. The hook is closed automatically after yarn feeding by lowering the needle because the old loop, which was on the stem, slides upwards contacting and pivoting the latch tightly closed and drawing and enclosing the newly fed loop inside the hook.

Latch needles thus knit automatically as they are reciprocated and draw the length of the new loop as they descend to knock-over. Except in raschel warp knitting machines, they are arranged to move independently in their tricks or grooves. They can operate at any angle but often require a latch-guard or latch-opening facilities as there is a tendency for latches to spring closed as tightly-knitted loops are cleared from the open latches.

Individually moving latch needles can draw and form their own needle loops in succession across the needle bed, unlike bearded needles and needles in warp knitting machines which move as a unit and thus require sinkers or guides to form the loops around their stems. The Germans classify the first method as '*Strickerei*' or *loop drawing* and the second method as '*Wirkerei*' or *loop forming*.

Variation of the height of vertical reciprocation of a latch needle at a feeder can produce either missing, tucking or knitting, and depth of descent normally determines loop length. Specially designed latch needles are capable of facilitating rib loop transference by selective lifting to a height above clearing height. Double-ended purl needles can slide through the old loops in order to knit from an opposing bed and thus draw a loop from the opposite direction to the previously knitted loop.

3.15 Friction and frictionless needles

There are two types of latch needle – friction and frictionless. *Friction needles* have a slight flex, crimp or bend in the tails so that they contact the side-walls of the tricks in which they are housed. They are used in open-cam systems, where cams may be introduced or taken out of action to divert the needle path. *Frictionless needles* are employed in closed cam-tracks that have guard or safety cams on the opposite side to the knitting cams to produce a completely enclosed track, through which the needles run (otherwise the freely-moving needles would be thrown out of their tricks at high knitting speeds).

3.16 The bi-partite compound needle

Compound needles (Fig. 3.5) consist of two separately-controlled parts – the *open hook* and the *sliding closing element* (tongue, latch, piston, plunger). The two parts rise and fall as a single unit but, at the top of the rise, the hook moves faster to open the hook and at the start of the fall the hook descends faster to close the hook. It is easier to drive the hooks and tongues collectively from two separate bars in warp knitting than to move each hook and tongue individually, as in weft knitting.

A compound needle with a sliding latch was first patented by *Jeacock* of Leicester in 1856. It now dominates the warp knitting industry after suffering a set-back against high-speed bearded needle machines in the 1960s. However, in weft knitting, where versatility and needle selection are as important as knitting speed, it has only made limited inroads in certain specialist or prototype areas.

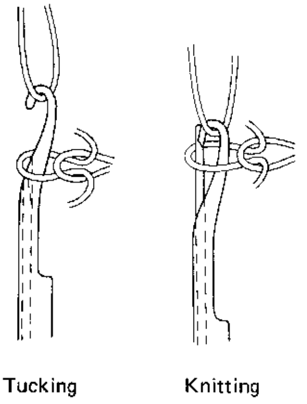

Fig. 3.5 Compound needle.

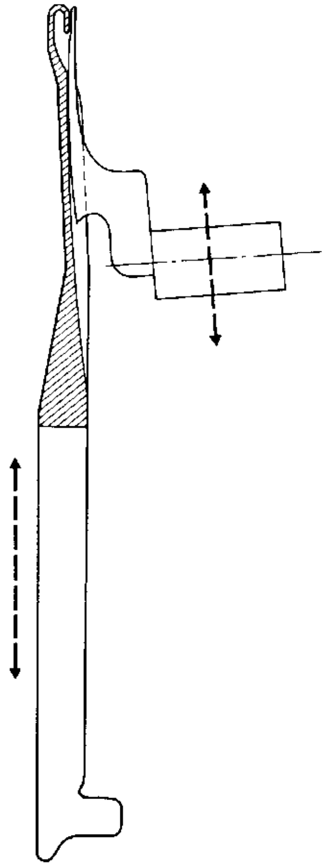

Fig. 3.6 Open-stem slide needle.

Two types of compound needle have been employed in warp knitting machines. *The tubular pipe needle* has its tongue sliding inside the tube of the open hook. It was successfully employed in *Sir James Morton's* high-speed *FNF tricot warp knitting machine* during the late 1940s and 50s. Development then ceased and bearded needle tricot machines recaptured their market with higher speeds, only to be later outpaced by a more efficient type of compound needle, *the slide compound needle*.

The *open-stem 'pusher type'* or *slide needle* (Fig. 3.6) has a closing wire or tongue that slides externally along a groove on the edge of the flat hook member. This needle is now preferred because it is simpler, cheaper, more compact and each of the two parts can be separately replaced.

3.17 A comparison of latch and compound needles

Compared with the latch needle, the compound needle is more intricate and expensive to manufacture. Each of its two parts must be separately and precisely controlled during knitting. In circular knitting, yarn feeding is very critical because, if the yarn lands on the tongue, it will not enter the open hook, whereas in latch needle knitting the closing latch will flick the yarn into the hook. It is particularly a problem when knitting multiple tucks. Adjustment of a machine setting is therefore a very skilled operation. Lifting of the tongue out of its guide groove at high speeds or as the result of dirt or fly can also be a problem, particularly if it splits filament yarns. In addition, differential heat expansion between the hook and its closer can cause problems.

On the other hand, the vertical clearing height for the compound needle is not so high because only the open hook and not an open latch spoon has to be cleared. The shorter vertical stroke can be achieved with a smaller cam system in V-bed flat knitting.

Also, when clearing, the compact head of the compound needle does not cause stretching of needle loops and robbing of yarn from adjacent sinker loops as the needle rises to clear or descends to knock-over, as is the case with the latch needle. The needle can knit tight, uniform stitches that tend to be rounder than the long, narrow loops produced by latch needles.

The compound needle has a short, smooth, simple harmonic movement without latch and beard inertia problems, so there is less vibration. Also, there is no stress on needle loops to open and close latches. The hook of the compound needle does not have to withstand the shock of a latch spoon hitting it. It can therefore be tapered to a slimmer diameter, producing a larger area inside the hook that can accommodate thicker yarns. This is particularly useful in the case of fine gauge, V-bed flat machinery.

Its slim construction and short hook make it particularly suitable for knitting fine warp knitted structures at high speed. It can knit chain stitches without the loops rising up the needles, and its sturdy construction resists the deflection generated by elastic yarns or thick places in yarns. Accumulations of lint are pushed out of the hook by the action of the closing element.

It is now employed in all types of warp knitting machines apart from double needle bar raschels and raschel simplex machines. Horizontal yarn tension between front and back needle bars can cause the two sets of needle hooks to be drawn towards each other and away from contact with their hook-closing sliders.

The compound needle has not lived up to its earlier promise in circular weft knitting. It has failed to gain a foothold in hosiery and even in simple plain knit single jersey. *Vignoni* are now the only circular machine builder to continue to include it as an option.

In V-bed flat knitting, *Shima Seiki* are successfully employing an open-slot compound needle in their coarse gauge (3 to 5 gauge) V-bed flat machines, resulting in a more compact cam box and reduced width of machine. The needle has conventional knit, tuck, miss and rib loop transfer facilities. The closing element passes through a slot in the hook element to the back, so that the two elements are held in contact with each other. Stop ledges on the two elements engage so that, after a certain distance, the individual movement of the element is converted into a collective movement of the two elements together.

Shima Seiki also used compound needles in their prototype four needle bed model SWG-X *WholeGarment* machine because the four needle beds are so close to each other that there is no space for latches to turn-over. Shima, again employ compound needles in their *model FIRST* machine. These ascend during knitting to only half the height of latch needles. They have a uniquely designed hook closer whose leading-end shoulder can project across to receive or transfer a loop from a needle in the opposite bed. This closing element also has a small cut-away section on its outward surface that can be used for retaining loops separately from those inside the hook. On the Shima machine, the slide needles are centre-mounted, minimising yarn stress and damage.

3.18 Machine gauge

Normally, all primary elements (those directly involved in the knitting action) in the same machine are set to the same gauge. It should be noted that the gauge is measured on one needle bed, so a machine of the same gauge but with two needle beds will have a total of twice as many needles as a machine with one bed. The gauge measured at the point of needle location is the same as that at the point of loop formation.

The *pitch*, or distance between one needle and another, is proportional to the needle gauge or thickness. The space available, which determines the maximum thickness of the yarn (i.e. the yarn count) that may be knitted, is the gap between the side of the needle and the trick wall as the needle descends to draw a new loop.

Machine gauge can be calculated by dividing the total number of needles into the length of the needle bed. The figure is rounded to the nearest whole number. For example, a 4-inch diameter sock machine has 168 needles. The circumference of a circle is πd where $\pi = 22/7$ and d = the diameter. The circumference is therefore $4 \times 22/7 = 12.57$ inches. The gauge is $168/12.57$ = approximately 14 needles per inch. This may be expressed as 'E 14', E being the number of needles per inch.

The diameter of a yarn is proportional to its count, so a relationship exists between the range of optimum counts of yarn that may be knitted on a particular machine and its gauge. Machine gauge thus influences choice of yarn count and affects fabric properties such as appearance and weight.

For a given machine diameter or width, finer gauge machines tend to knit a wider fabric because more wales are involved. Loop sizes will naturally be smaller so more courses of loops will be required per centimetre of fabric knitted and production rates in linear metres of fabric will be less than for a coarser gauge machine.

Also, with more and finer needles there is a higher machine cost and a greater potential for needle damage to occur. A 30-inch diameter single jersey circular machine might have 1716 needles in E 18 and 1872 in E 20.

Coarse gauge machines have needles with larger dimensions and larger needle movements. The knitting cam systems are correspondingly larger, so coarse gauge machines tend to have larger cam boxes and less feed systems around their cylinder than finer gauge machines. It can thus be assumed that machines at the coarse and fine ends of gauge ranges are more expensive to build and operate than machines in the middle of the gauge range.

Originally, needles were cast in small metal blocks termed *leads*, which were then fitted into a needle bar. In the bearded needle straight bar frame, needles were cast two to a lead and gauged in the number of leads per 3 inches of the needle bar, which is equivalent to a gauge of the number of needles in $1\frac{1}{2}$ inches. In bearded needle warp knitting machines, needles were cast three to a lead, giving a gauge directly in needles per inch. In the raschel warp knitting machine, the needles were cast in 2-inch leads giving a raschel gauge of needles per 2 inches. Latch needle weft knitting machines normally have a gauge expressed in needles per inch, which in the USA is referred to as 'cut', being short for the phrase 'tricks cut per inch'. As mentioned previously, there is an increasing universal use of the symbol 'E' in warp and weft knitting – for example, raschel E 28 which is 28 needles per inch (25.4 mm). If two needle beds are employed (e.g. V-bed or double-jersey circular machines), the gauge is measured on one bed since the needles in the other bed are to the same gauge unless stated. Also, small diameter single- and double-cylinder hosiery machines have a gauge expressed in the form diameter multiplied by total number of needles, because the number of double-headed needles in a particular cylinder of the double-cylinder machine varies according to the rib set-out.

On some machines it is possible to change the needle beds and camming, and therefore the gauge. The extra spare parts can, however, cost about one third of the cost of a machine. It is also sometimes possible to employ finer or coarser needles than the machine gauge, thus producing finer or coarser knitted stitches. One well-known technique used on the V-bed flat machine is to *half-gauge* the needle bed by taking every other needle out of action. Thus a machine with 10 needles per inch would become twice as coarse, with only 5 needles per inch. Increasing or decreasing the number of ends of a particular count of yarn will also produce the appearance of a heavier or finer gauge.

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