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

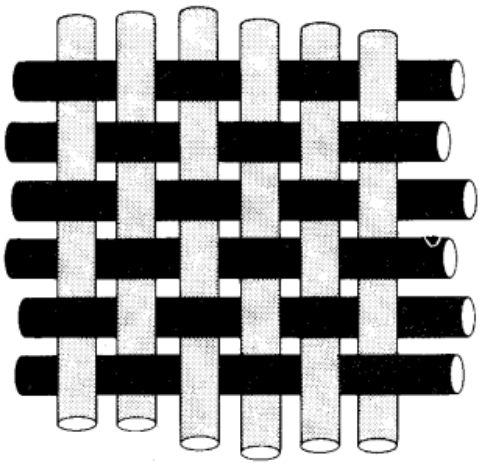

Fig. 1.1 Interweaving.

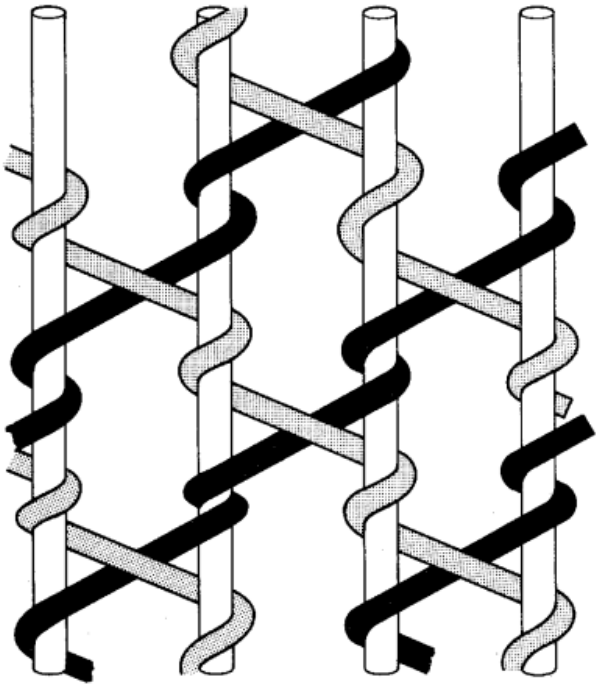

Fig. 1.2 Intertwining and twisting.

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

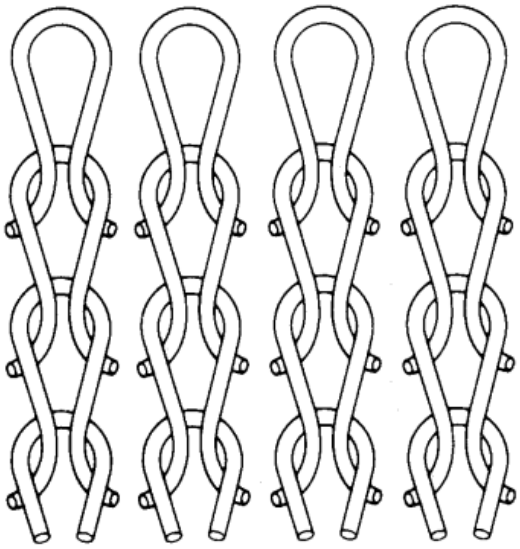

Fig. 1.3 Interlooping.

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.

The *decitex* count therefore = $(591/40) \times 10 = 148$ dtex

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

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

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

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

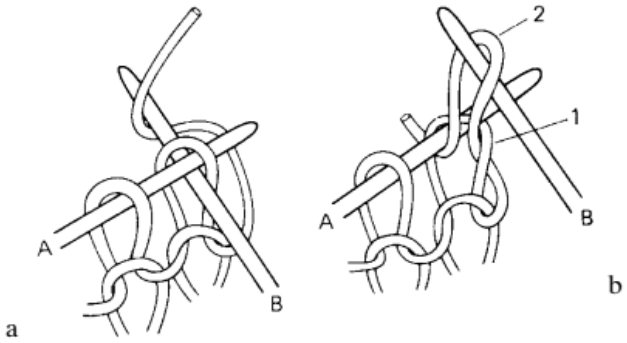

Fig. 2.2 Hand pin knitting.

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

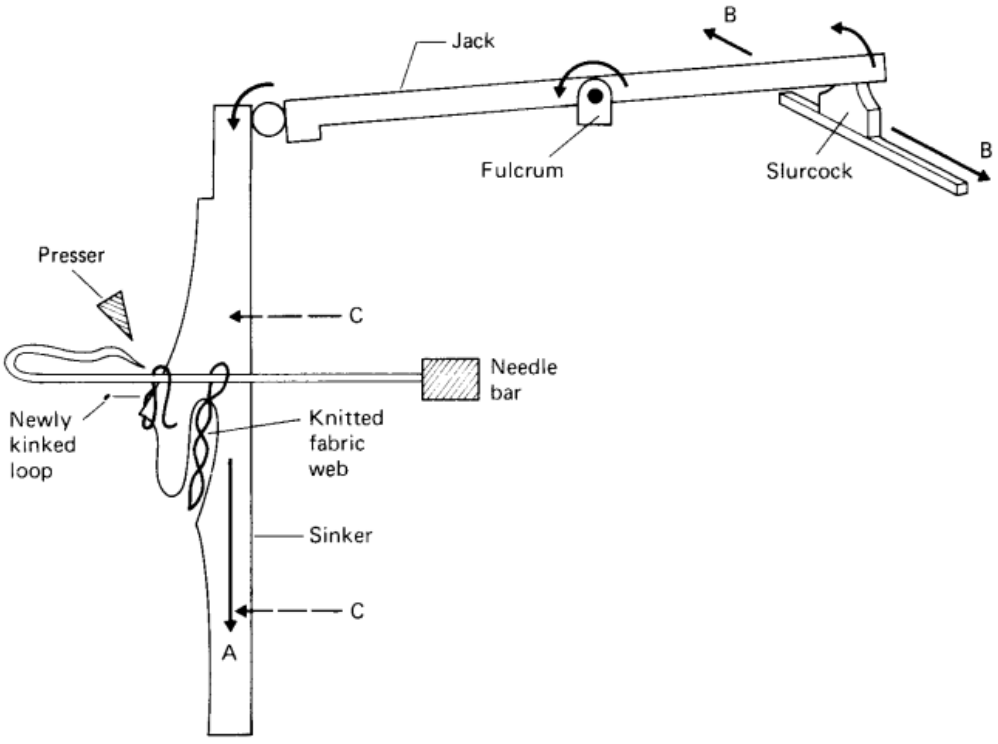

Fig. 2.3 The action of frame knitting.

(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

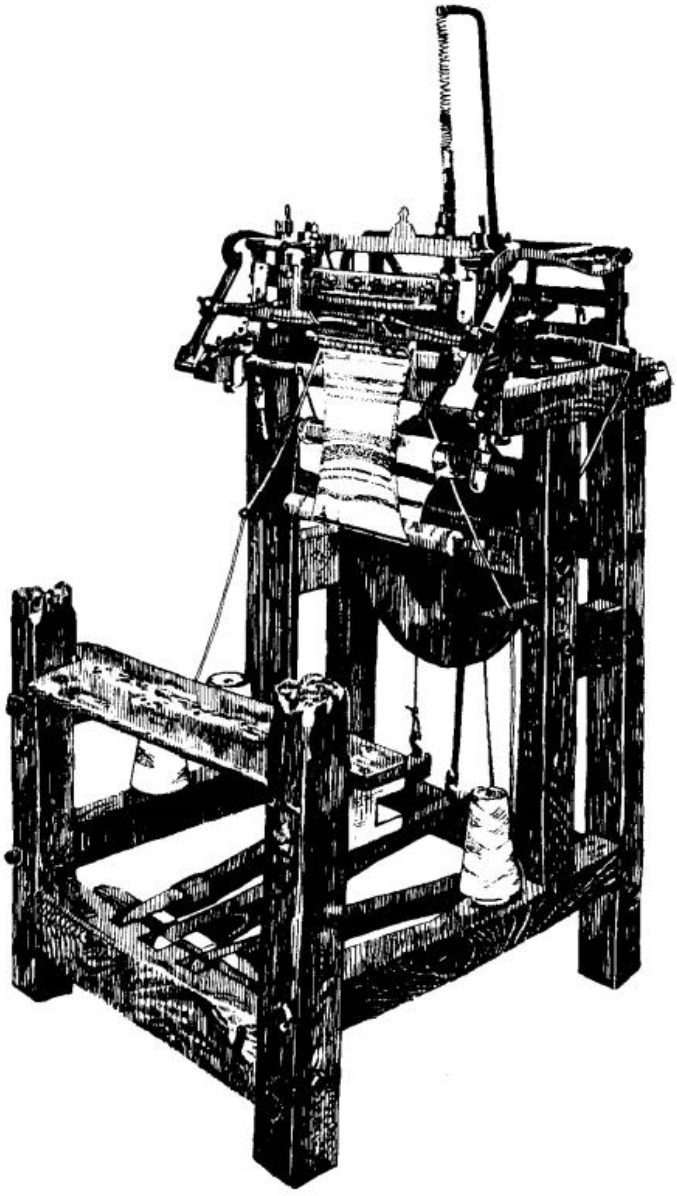

Fig. 2.4 Hand frame (c. 1820) [Copyright: Leicestershire Museums, Art Galleries and Record Service].

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 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

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

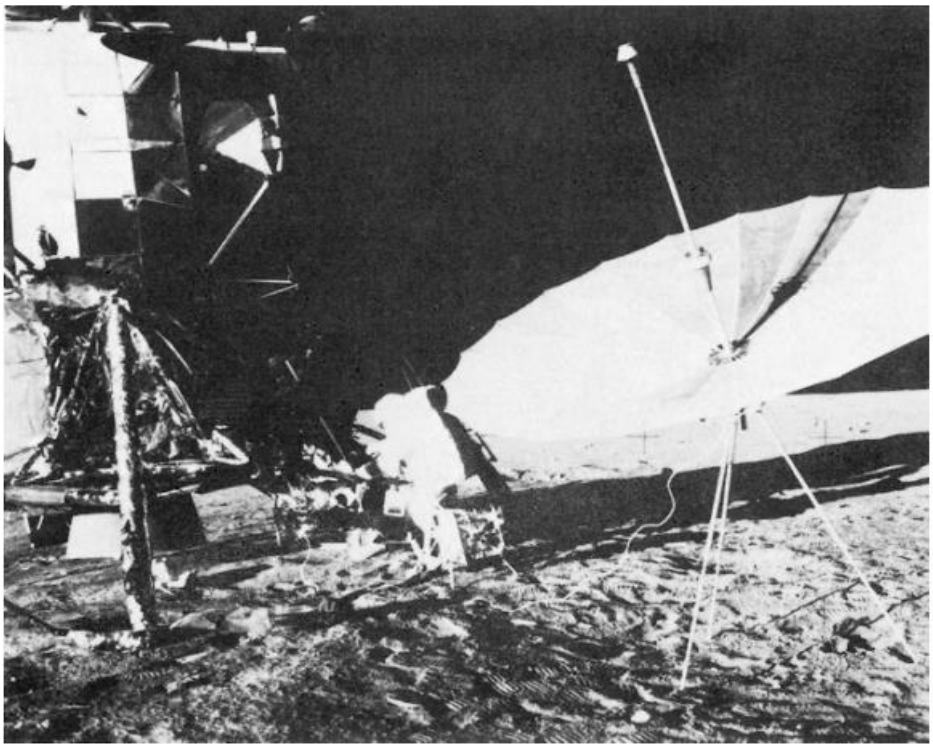

Fig. 2.5 Warp knitted fabric on the moon [Photo credit NASA]. The photograph, taken during the Apollo 12 mission, shows the warp knitted antenna which transmitted the television pictures of the lunar landing back to Earth. The two-bar mesh fabric, weighing less than one ounce per square yard, was warp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

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].