4

Basic mechanical principles of knitting technology

4.1 The sinker

The sinker is the second primary knitting element (the needle being the first). It is a thin metal plate with an individual or a collective action operating approximately at right angles from the hook side of the needle bed, between adjacent needles. It may perform one or more of the following functions, dependent upon the machine's knitting action and consequent sinker shape and movement:

Loop formation
Holding-down
Knocking-over

(It is always advisable to use one or more of the above terms as adjectives when referring to a sinker, in order to avoid confusion.)

On bearded needle weft knitting machines of the straight bar frame and sinker-wheel type (as on Lee's hand frame), the main purpose of a sinker is to *sink* or kink the newly laid yarn into a *loop* (Fig. 4.1) as its forward edge or catch (C) advances between the two adjacent needles. On the bearded needle loopwheel frame, the blades of burr wheels perform this function, whereas on latch needle weft knitting machines (Fig. 4.2) and warp knitting machines (Fig. 4.3), loop formation is not a function of the sinkers.

(NB: On the European mainland, particularly in Germany, the term *couliering* is used to describe the presentation of a yarn, the kinking of it into a needle loop and the knock-over of the old loop. Also the term 'sinker' often refers confusingly to a jack or other element (that can be sunk into a trick so that its butt is no longer in action.)

The *second* and more common function of sinkers on modern machines is *to hold down the old loops* at a lower level on the needle stems than the new loops that are being formed, and to prevent the old loops from being lifted as the needles rise to clear them from their hooks.

In Fig. 4.1, the protruding *nib* or *nose* of' sinker (N) is positioned over the sinker

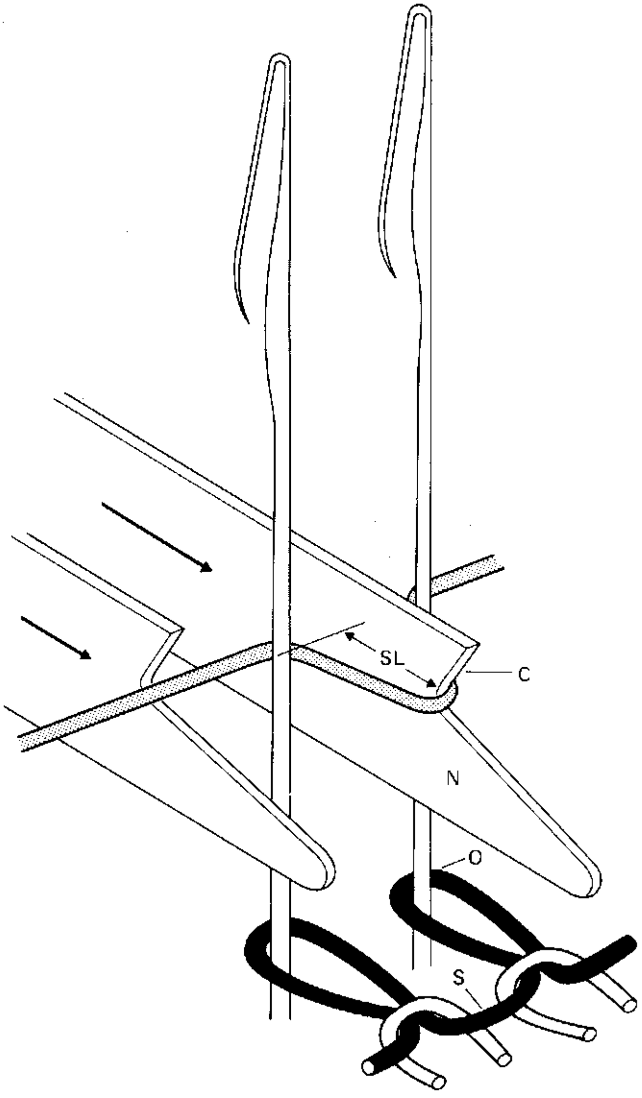

Fig. 4.1 Action of the loop-forming sinker.

loop of the old loop (O), preventing it from rising with the needle. On tricot warp knitting machines and single bed weft knitting machines, a *slot* or *throat* (T in Fig. 4.2) is cut to hold and control the old loop.

The sole function of' the sinker may be to act as a *web holder* or *stitch comb* as on the raschel warp knitting machine, in which case only the underside of the nose performs this function. On single cylinder latch needle weft knitting machines the holding-down sinkers have a rectangular gap cut into their upper surface, remote from the nose, into which the *sinker cam race* fits, to positively control the sinker's movement.

Holding-down sinkers enable tighter structures with improved appearance to be obtained, the minimum draw-off tension is reduced, higher knitting speeds are

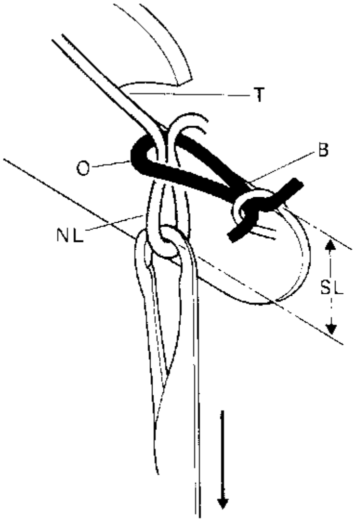

Fig. 4.2 Action of the knock-over sinker.

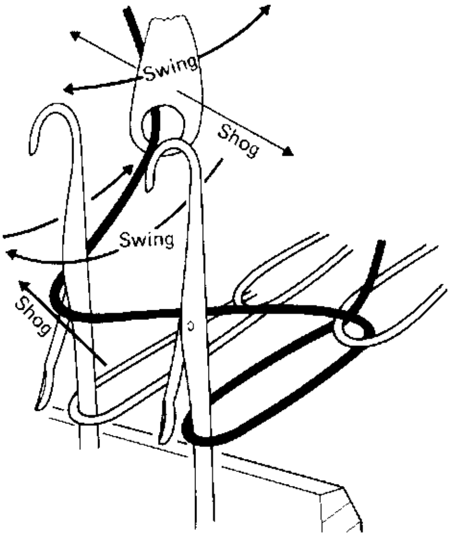

Fig. 4.3 Loop forming by warp guides.

possible and knitting can be commenced on empty needles. Holding-down sinkers are often unnecessary when knitting with two needle bed machines as the second bed restrains the fabric loops whilst the other set of needles moves. However, if single bed knitting or held loop structure is knitted, a form of holding-down element may still be required (as is the case with some V-bed flat knitting machines).

The *third function* of the sinker – as a *knock-over surface* – is illustrated in Fig. 4.2 where its upper surface or *belly* (B) supports the old loop (O) as the new loop (NL) is drawn through it. On tricot warp knitting machines the sinker belly is specially shaped to assist with *landing* as well as knock-over. On raschel warp knitting machines, many V-bed flats, and cylinder and dial circular machines, the verge or upper surface of the trick-plate (V in Fig. 3.4) serves as the knock-over surface.

On some machines, the knock-over surface moves in opposition to the descent of the needle (see *Relanit*, Chapter 13; and *Shima* contra sinkers, Chapter 19).

4.2 The jack

The jack is a secondary weft knitting element which may be used to provide versatility of latch needle selection and movement. It is placed below and in the same trick as the needle and has its own operating butt and cam system.

4.3 Cams

All needles have a reciprocating action either *en masse* or serially (except on now obsolete bearded needle sinkerwheel and loopwheel frames, where the circle of fixed bearded needles merely revolves). Cams are the devices which convert the rotary machine drive into a suitable reciprocating action for the needles and other elements. The cams are carefully profiled to produce precisely-timed movement and dwell periods and are of two types, *engineering cams* and *knitting cams*. The movements may be represented in the form of a time-displacement graph.

4.3.1 Engineering cams

Circular engineering cams or high speed eccentrics control the motion of bars of elements which move *en masse* as single units in Cottons Patent and warp knitting machines. They are attached to a rotary drive shaft situated parallel to, and below, the needle bar. A number of identical cams are positioned along the shaft to ensure correctly aligned movement. The drive is transmitted and adapted via cam-followers, levers, pivots and rocker shafts. One complete 360-degree revolution of the drive shaft is equivalent to one knitting cycle, and it produces all the required movements of the elements in their correctly-timed relationship.

In warp knitting machines, four types of cam drive have been employed: single acting cams, cam and counter cam, box cams and contour cams. The first type requires a powerful spring to negatively retain the cam truck or follower in contact with the cam surface, where bounce and excessive wear occur at speed. The cam and counter cam arrangement provides a cam and its follower in each direction of movement, but is obviously more expensive to manufacture. The box or enclosed cam employs a single cam follower, which is guided by the two cam races of a groove on the face of the cam. However, change of contact from one face to the other causes the follower to turn in the opposite direction, producing wear which cannot be compensated. The contour, ring or pot cam is the reverse of the box cam as the cam profile projects out from one face of the cam in the form of a lip with a cam-follower placed on either side of it. This is a popular and easily adaptable arrangement. Although cams are comparatively cheap, simple and accurate, at speeds above 800 courses per minute they are subject to excessive vibration. For this reason, at speeds in excess of that, eccentric drive is now employed.

The *eccentric* is a form of crank which provides a simple harmonic movement with smooth acceleration and deceleration. Its widespread use is the result of adapting this simple motion and modifying it to the requirements of the warp knitting machine, so that even dwell (stationary periods) in the element cycle can be achieved. On the *FNF compound needle machine*, the movements of two eccentric drive shafts, one turning twice as fast as the other, were superimposed on each other. Now, however, the simpler, single eccentric drive is successfully driving element bars at speeds in excess of 3000 courses per minute.

4.3.2 Knitting cams

The other type of cam, the angular *knitting cam* (see Fig. 3.4), acts directly onto *the butts* of needles or other elements to produce individual or serial movement in the tricks of a latch needle weft knitting machine.

Two arrangements exist:

(a) Revolving cylinder machines – the needle butts pass through the stationary cam system and the fabric hanging from the needles revolves with them.

(b) Reciprocating cam-carriage flat machines or rotating cam-box circular machines – the cams with the yarn feeds pass across the stationary needle beds.

In weft knitting, the yarn feed position is fixed in relation to the cam system (Fig. 3.4). The yarn feed moves with or remains stationary with the cam system, as do the yarn packages and tackle (except in the case of flat machines where the cam-carriage only reciprocates away from and towards the stationary yarn packages and does not revolve).

In the past, most *garment-length* knitwear and underwear machines have had revolving cam boxes because changes to the cam settings during the garment sequence can be initiated from a single control position as the cam-boxes pass by; also the garment lengths are stationary and may be inspected or removed whilst the machine is knitting. Now, most new electronically-controlled garment-length machines are of the revolving cylinder type as electronics have removed the need for the complex arrangement of rods and levers found, for example, on mechanically-controlled half-hose machines (Fig. 21.3.)

All hosiery machines and all fabric-producing machines are revolving cylinder machines because the weight of revolving multi-feeder yarn packages and tackle creates inertia problems that reduce efficiency and knitting speeds.

Knitting cams are attached, either individually or in unit form, to a cam-plate and, depending upon machine design, are fixed, exchangeable or adjustable. In the last case, on garment-length machines this might occur whilst the machine is in operation. Elements such as holding-down sinkers and pelerine (loop-transfer) points are controlled by their own arrangement of cams attached to a separate cam-plate.

At each yarn feed position there is a set of cams consisting of at least a raising cam, a stitch cam and an upthrow cam (Fig. 3.4.), whose combined effect is to cause a needle to carry out a knitting cycle if required. On circular machines there is a removable cam section or door so that knitting elements can be replaced.

The *raising cam* causes the needles to be lifted to either tuck, clearing, loop transfer or needle transfer height, depending upon machine design.

The *swing cam* is fulcrummed so that the butts will be unaffected when it is out of the track and it may also be swung into the track to raise the butts.

The *bolt cam* can be caused to descend into the cam track to control the element butts or be withdrawn out of action so that the butts pass undisturbed across its face; it is mostly used on garment-length machines to produce changes of rib set-outs.

The *stitch cam* controls the depth to which the needle descends, thus controlling the amount of yarn drawn into the needle loop; it also functions simultaneously as a *knock-over cam*.

The *upthrow* or counter cam takes the needles back to the rest position and allows the newly-formed loops to relax. The stitch cam is normally adjustable for different loop lengths and it may be attached to a slide together with the upthrow cam, so that the two are adjusted in unison. In Fig. 3.4 there is no separate upthrow cam; section X of the raising cam is acting as the upthrow cam.

The *guard cams* are often placed on the opposite side of the cam-race to limit the movement of the butts and to prevent needles from falling out of track.

Separate cam-boxes are required for each needle bed or associated element bed and they must be linked together or co-ordinated. If the cam-box itself is moving from right-to-left, the needle butts will pass through in a left-to-right direction.

On circular fabric machines, the cams are designed to act in only one direction, but on flat and circular leg-wear machines, the cams are symmetrically arranged to act in both directions of cam-box traverse, with only the leading edges of certain cams in action. All cam systems are a compromise between speed, variety, needle control and selection systems [1].

4.4 The two methods of yarn feeding

As mentioned in Section 4.3.2, yarn feeding involves either (a) moving the needles past the stationary yarn feed or (b) moving the yarn past the stationary needle bed.

When the yarn moves past the needles, the fabric will be stationary because the loops hang from the needles. This arrangement exists on all warp knitting machines, and on weft knitting machines with straight beds and circular machines with stationary cylinders and dials.

On straight machines of both weft and warp type, the yarn-carrier or guide has a reciprocating traversing movement that takes it towards and away from a suitably-placed yarn supply. On stationary cylinder and dial machines, however, the yarn supply packages must rotate in order to keep with the continuously revolving yarn feeds.

Because the latch needle beds of these flat and circular weft knitting machines are thus stationary, it is necessary to reciprocate the cam-carriage and revolve the cam-boxes so that the needle butts of the stationary tricks pass through. The needles are thus reciprocated to rise and receive the yarn at the exact moment when the traversing yarn feed is passing by (Fig. 4.4).

Most circular weft knitting machines have revolving needle cylinders and stationary cams, feeders and yarn packages. In this case, the fabric tube must revolve with the needles, as must the fabric rollers and take-up mechanism.

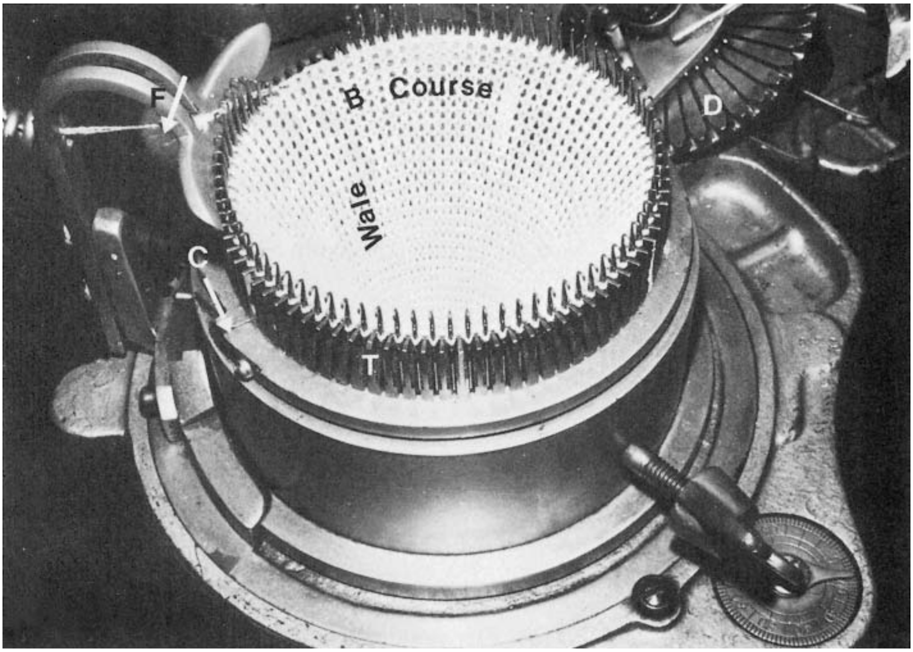

Fig. 4.4 Simple hand-turned Griswold type machine [Walter Bulwer, Leicestershire Polytechnic]. T = stationary needle tricks; C = revolving cam-box; F = revolving feeder; D = replaceable dial and needles; B = technical back of plain fabric.

4.5 The three methods of forming yarn into needle loops

There are three methods of forming the newly-fed yarn into the shape of a needle loop:

1 (Fig. 4.1) – by sinking the yarn into the space between adjacent needles using loop forming sinkers or other elements which approach from the beard side. The action of a straight bar frame is illustrated. (Other obsolete circular bearded needle machines such as the sinkerwheel and loopwheel frame employ the same technique.) The distance SL, which the catch of the sinker moves past the beard side of the needle, is approximately half the stitch length,
2 (Fig. 4.2) – by causing latch needles to draw their own needle loops down through the old loops as they descend, one at a time, down the stitch cam. This method is employed on all latch needle weft knitting machines. The distance SL that the head of the latch needle descends below the knock-over surface (in this case, the belly of the knock-over sinker) is approximately half the stitch length, and
3 (Fig. 4.3) – by causing a warp yarn guide to wrap the yarn loop around the needle.

The lapping movement of the guide is produced from the combination of two separate guide bar motions:

- A swinging motion which occurs between the needles from the front of the machine to the hook side and return.
- A lateral shogging (or racking) motion parallel to the needle bar on the hook side and also on the front of the machine.

The swinging motion is fixed, but the direction and extent of the shogging motion may or may not be varied from a pattern mechanism. This method is employed on all warp knitting machines and for wrap patterning on weft knitting machines (when a fixed wrapping movement is used). The length of yarn per stitch unit is generally determined by the rate of warp yarn feed.

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5

Elements of knitted loop structure

5.1 The needle loop

The needle loop (H + L in Fig. 5.1) is the basic unit of knitted structure. When tension in the fabric is balanced and there is sufficient take-away tension during knitting, it is an upright noose formed in the needle hook. It consists of a *head* (H) *and two side limbs* or *legs* (L). At the base of each leg is a foot (F), which meshes through the head of the loop formed at the previous knitting cycle, usually by that needle. The yarn passes from the foot of one loop into the foot and leg of the next loop formed by it.

(NB: If the loop is the first loop knitted on that needle, its feet and legs will not be restricted and it will open out to give the appearance of a tuck loop. If the loops are knitted on a flat machine with a pressing down device and no take-down tension, the loops will be more rounded and will tend to incline due to the traversing movement of the presser.)

In warp knitting the feet may be *open* or *closed* at the base of the loop. In the latter case, the yarn guide has passed across the back of the needle across whose hook it has previously formed a loop.

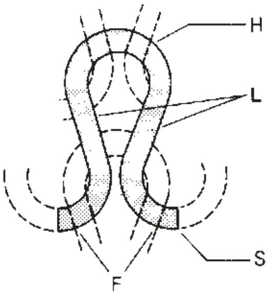

Fig. 5.1 Intermeshing points of a needle loop.

In weft knitting, the feet are normally open because the yarn continues to be supplied in one direction (except at the selvedges of straight knitting machines). Exceptionally, closed loops have occasionally been produced in the past on the bearded needle sinkerwheel machine, by twisting a loop over as it is transferred to another needle, or by using a twizzle beard which closes onto the back of the needle so that, as the loop is cast-off, it twists over itself.

5.2 The sinker loop

The sinker loop (S in Fig. 5.1) is the piece of yarn that joins one weft knitted needle loop to the next. On bearded needle weft knitting machines, *loop-forming sinkers* form the sinker loops in succession between the needles – hence the origin of the term sinker loop. On latch needle weft knitting machines, however, the sinker loops are automatically formed as the needles, in succession, draw their new loops.

Sinker loops show on the opposite side of the fabric to the needle loops because the needle loop is drawn onto the opposite side from which the yarn was originally fed. The terms 'sinker loop' and 'needle loop' are convenient descriptive terms but their precise limits within the same loop length are impossible to exactly define.

5.3 Warp knitted laps

Loops are termed '*laps*' in warp knitting because the warp guides lap their yarn around the needles in order to form the loop structure. The loops (overlaps) may be open or closed.

On the original warp frame (as on many present-day crochet machines), the needle bar was in a horizontal and not a vertical position, with its beards facing upwards (Fig. 5.2). To produce a needle loop it was thus necessary to swing the guide upwards and shog it over the needle hook; hence the term '*overlap*' which refers both to the movement and the loop which it forms. Similarly, the guide was shogged under the needles to a new starting position for the next overlap. This movement and the lapped thread it produces is still termed an '*underlap*'. In the warp knitting cycle, it is always understood that the overlap precedes the underlap.

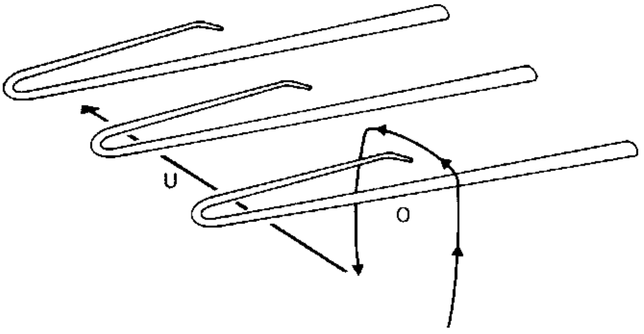

Fig. 5.2 Overlapping and underlapping (warp knitting).

5.4 The overlap

The *overlap* (Fig. 4.3) is a shog, usually across one needle hook, by a warp guide (at the back of a single needle bar machine) which forms the warp yarn into the head of a needle loop. Every needle on a conventional warp knitting machine must receive an overlapped loop from at least one guide at every knitting cycle, otherwise it will press-off the fabric.

The swinging movement of the guide to the hook side and the return swing after the overlap, produce the two side limbs of the loop which give a similar appearance on the face side of warp knitted fabric to a weft knitted needle loop.

Very rarely are overlap shogs across two needle hooks, as this produces severe tension on the warp yarn and knitting elements because the needles knock-over in unison and the needles are sharing yarns (unlike in single needle overlap warp knitted structures). Two needle overlaps also generally have a poor appearance and physical characteristics because the first overlap of the two will have a different configuration of underlap to that of the second. In the former, the underlap will be passing along the course to the second overlap in a similar manner to a sinker loop. However, the underlap from the second overlap will lap upwards to the next course in the manner of a normal underlap.

5.5 The underlap

The *underlap* shog occurs across the side of the needles remote from the hooks on the front of single-needle bar, and in the centre of double-needle bar, warp knitting machines. It supplies the warp yarn between one overlap and the next (Fig. 5.3). The underlap shog generally ranges from 0 to 3 needle spaces, but it might be 14 needle spaces or more depending upon the design of the machine and the fabric structure

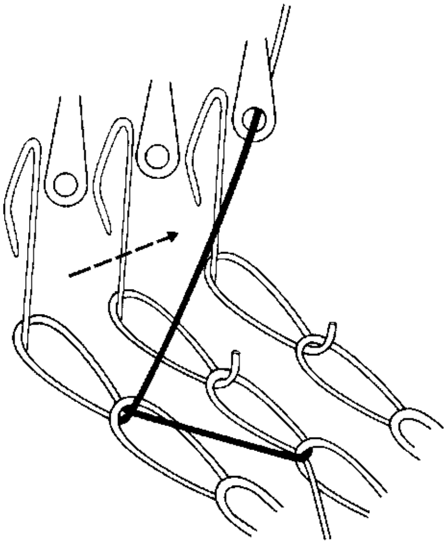

Fig. 5.3 The underlap shog.

(although efficiency and production speed will be correspondingly reduced with long underlaps).

Underlaps as well as overlaps are essential in warp knitted structures in order to join the wales of loops together but they may be contributed by different guide bars.

5.6 The closed lap

A *closed lap* is produced when a subsequent underlap shogs in the opposite direction to the preceding overlap, thus lapping the same yarn around the back as well as around the front of the needle (Fig. 5.4).

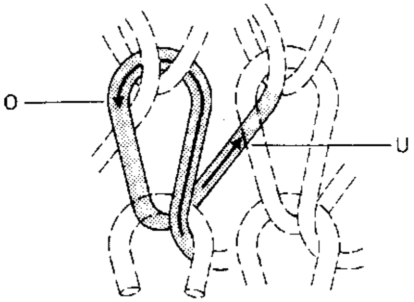

Fig. 5.4 The closed lap.

5.7 The open lap

An *open lap* is produced either when a subsequent underlap is in the same direction as the preceding overlap (Fig. 5.5) or an underlap is omitted so that the overlap of the next knitting cycle commences in the needle space where the previous overlap finished. Closed laps are heavier, more compact, more opaque, and less extensible than open laps produced from the same yarn at a comparable knitting quality.

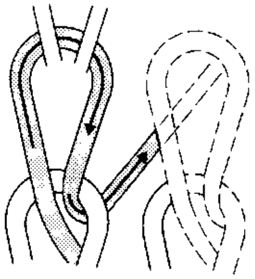

Fig. 5.5 The open lap.

5.8 Wrapping

Wrapping is a method of producing vertically-orientated patterning with warp threads on a single jersey weft knitted base structure. Specially controlled warp thread guides are used which make unidirectional warp knitted overlaps into selected needle hooks. If selected empty needle hooks rise to receive the warp yarn (as is the case on a few single jersey machines), *pure wrapping* or *warp insertion* is produced. If, however, wrapping takes place on needles, all of which already hold a ground yarn at that knitting cycle, *embroidery plating* or *wrap striping* is produced; this is a technique occasionally used on some half-hose machines.

5.9 The knitted stitch

The *knitted stitch* is the basic unit of intermeshing. It usually consists of three or more intermeshed needle loops (Fig. 5.6). The centre loop has been drawn through the head of the lower previously-formed loop and is, in turn, intermeshed through its head by the loop above it.

The *repeat unit* of a stitch is the minimum repeat of intermeshed loops that can be placed adjoining other repeat units in order to build up an unbroken sequence in width and depth.

A needle loop only has its characteristic appearance because its legs are prevented from spreading outwards by being intermeshed through the head of the loop below it. If there is no previous loop to mesh through, the legs of the new loop will spread outwards.

The term stitch is unfortunately sometimes used to refer to a single needle loop.

Stitch length is a length of yarn which includes the needle loop and half the sinker loop on either side of it. Generally, the larger the stitch length, the more extensible and lighter the fabric and the poorer the cover, opacity and bursting strength.

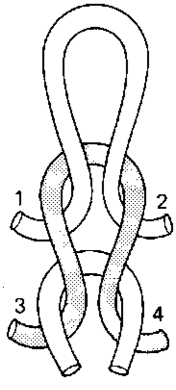

Fig. 5.6 The knitted stitch.

5.10 The intermeshing points of a needle loop

All needle loops or overlaps have four possible intermeshing points (Fig. 5.6) – 1 and 2 at the head, where the next new loop will be drawn through by the needle, and 3 and 4 at the base, where the loop has intermeshed with the head of the previously formed loop. The intermeshings at 1 and 2 are always identical with each other as are intermeshings 3 and 4 with each other. It is impossible to draw a new loop through the old loop so that its two feet are alternately intermeshed (Fig. 5.7). This could only be achieved by taking the yarn package through the old loop. Although this would produce a locked loop, the package used would not be large enough to provide a continuous supply.

A *new loop* can thus only be intermeshed through the head of the old loop in a manner that will show a face loop stitch on one side and a reverse loop stitch on the other side. This is because the needle hook is uni-directional and can only draw a new loop down through an old loop.

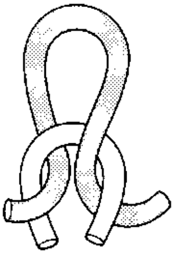

Fig. 5.7 An impossible intermeshing.

5.11 The face loop stitch

The *face side* of the stitch (Fig. 5.8) shows the new loop coming towards the viewer as it passes over and covers the head of the old loop. It is referred to as the *right side* in mainland Europe.

Face loop stitches tend to show the side limbs of the needle loops or overlaps as a series of interfitting ‘V’s. The face loop-side is the underside of the stitch on the needle.

5.12 The reverse loop stitch

This is the opposite side of the stitch to the face loop-side and shows the new loop meshing away from the viewer as it passes under the head of the old loop. It is referred to as the *left side* on the mainland of Europe. Reverse stitches show the sinker loops in weft knitting and the underlaps in warp knitting most prominently on the surface. The reverse loop side is the nearest to the head of the needle because the needle draws the new loop downwards through the old loop (Figures 4.4 and 5.8).

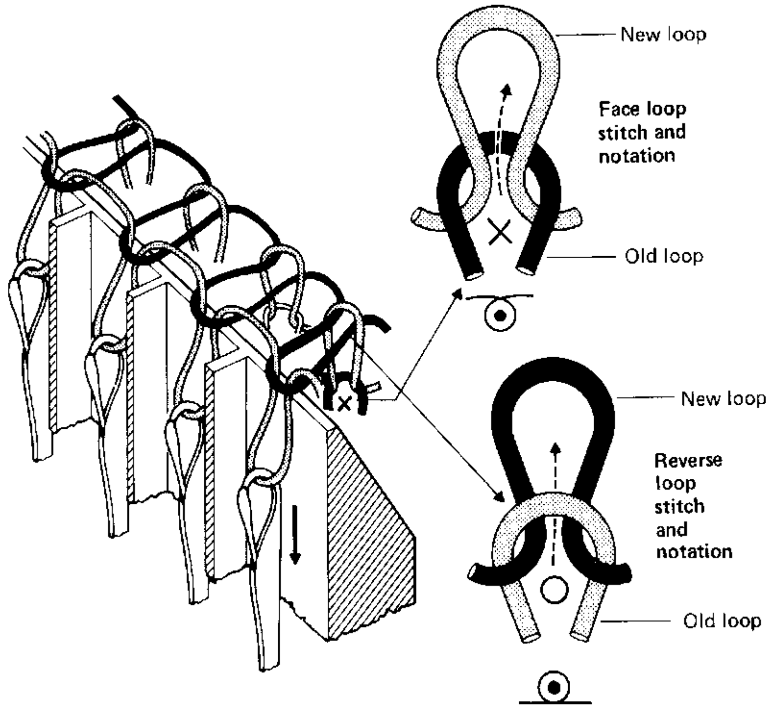

Fig. 5.8 Face- and reverse-meshed loops.

5.13 Single-faced structures

Single-faced structures are produced in warp and weft knitting by the needles (arranged in either a straight line or a circle, with their hooks facing outwards) operating as a single set. Adjacent needles will thus have their hooks facing towards the same direction and the heads of the needles will always draw the new loops downwards through the old loops in the same direction so that intermeshing points 1 and 2 will be identical with intermeshing points 3 and 4.

The under-surface of the fabric on the needles (termed the *technical face* or *right side*) will thus only show the face stitches in the form of the side limbs of the loops or overlaps as a series of interfitting 'V's. The upper surface of the fabric on the needles (termed the *technical back* or *left side*) will show reverse stitches in the form of sinker loops or underlaps as well as the heads of the loops.

5.14 Double-faced structures

Double-faced structures are produced in weft and warp knitting when two sets of independently-controlled needles are employed with the hooks of one set knitting or facing in the opposite direction to the other set. The two sets of needles thus draw their loops from the same yarn in opposite directions, so that the fabric, formed in the gap between the two sets, shows the face loops of one set on one side and the face loops of the other set on the opposite side.

The two faces of the fabric are held together by the sinker loops or underlaps, which are inside the fabric so that the reverse stitches tend to be hidden. The two faces may be knitted from different yarns and the two fabrics thus formed may only occasionally be joined together. Sometimes the two faces are cohesively produced and are far enough apart for the connecting sinker loops or underlaps to be severed in order to produce two single-faced fabrics.

5.15 A balanced structure

A *balanced structure* is a double-faced structure that has an identical number of each type of stitch produced on each needle bed which therefore show on each fabric surface, usually in the same sequence. Balanced structures need not, however, have the same design in coloured yarn on either surface. Such structures do not normally show curling at their edges.

5.16 Face and reverse stitches in the same wale

Face and reverse stitches in the same wale are normally produced on purl weft knitting machines that have double-headed needles capable of drawing a face stitch with one hook and a reverse stitch with the other, so that intermeshing points 1 and 2 will not always be identical with intermeshing points 3 and 4. Transfer of a wale of loops from a needle knitting face loops to one knitting reverse loops (or vice-versa) will produce the same result.

5.17 Selvedged fabric

A *selvedged fabric* is one having a '*self-edge*' to it and can only be produced on a straight machine whose yarn carrier reciprocates backwards and forwards across the needle bed so that a selvedged edge is formed as the yarn rises up to the next course at either edge of the fabric.

5.18 Cut edge fabric

A *cut edge fabric* is usually produced by slitting open a tube of fabric knitted on a circular machine. A slit tube of fabric from a 30-inch (76 cm) diameter machine will have an open width of 94 inches (2.38 m) (πd) at knitting and before relaxation.

5.19 Tubular fabric

Tubular fabric may be produced in double-faced or single-faced structures on circular machines; or in a single-faced form on straight machines with two sets of needles, provided each needle set only knits at alternate cycles and the yarn only passes across from one needle bed to the other at the two selvedge needles at each end, thus closing the edges of the tube by joining together the two single-faced fabrics produced on each needle set.

Tubular double faced fabrics can be produced on straight machines with two sets of needles, needle bed racking and transfer facilities, provided empty complimentary needles are always available to receive and transfer loops.

5.20 Upright loop structures

Structures with upright loops in straight wales are produced only if the tension on the yarn on either side of the needle loop head is balanced. This condition often exists in weft knitted structures because balanced sinker loops enter from either side of the needle head, but it may be disturbed by racking, by knitting twist lively yarn or by traversing pressing-down elements.

Warp knitted structures, however, seldom have perfectly upright overlaps because the underlaps, even if they enter from either side of the overlap head, rarely balance each other. When closed laps are produced, both underlaps will be on one side of the previous overlap head, causing it to incline towards that direction. Even a progressive open lap will not produce a balanced loop structure, because the underlap entering the overlap head from below will not balance the effect of the underlap on the opposite side as it leaves for the course above.

Single guide bar fabrics are thus very unstable structures. This is one of the reasons why most warp knitted structures are produced from two or more sets of warp threads. Often the guide bars supply yarn to each needle but lap in opposite directions, so that the tensions of their underlaps tend to balance each other.

5.21 Knitting notations

A *knitting notation* is a simple, easily-understood, symbolic representation of a knitting repeat sequence and its resultant fabric structure that eliminates the need for time-consuming and possibly confusing sketches and written descriptions. Figure 5.8 gives the symbols used in the two types of notation system. A method universally recognised for warp knitting lapping diagrams and which is also popular for weft knitting running thread path notations requires the use of point paper.

Each point represents a needle in plan view from above and, after the thread path has been drawn, it also represents its stitch.

Each horizontal row of points thus represents adjacent needles during the same knitting cycle and the course produced by them.

The lowest row of points represents the starting course in knitting but it must be understood that, when analysing structures, the courses are normally unroved in a reverse order to the knitting sequence.

When knitting with a single set of needles, each vertical column of points represents the same needle at successive knitting cycles or a wale in the resultant structure. For double needle bar knitting, every second row represents the back needle bar and its wales with all needle hooks facing towards the top of the paper to facilitate the drawing of a continuous lapping movement. For weft knitting with two sets of needles, it is assumed that the lower row of points represent needles whose hooks face towards the bottom of the paper and the upper row, needles whose hooks face towards the top of the paper.

A second notation method is that developed by the Leicester School of Textiles for weft knitting only. In this method squared paper instead of point paper is employed, with each square representing a needle or stitch. An 'X' symbol is placed in a square where a face stitch occurs and an 'O' where there is a reverse stitch.

When notating each stitch, it is necessary to examine the intermeshing direction *at the base of the loop* because the intermeshing at its head determines the direction of the intermeshing of the new loop formed above it.

Computer-aided design systems have their own methods of notation which may involve realistic appearance and the use of colour.

6

Comparison of weft and warp knitting

6.1 Yarn feeding and loop formation

In a *weft knitting* machine, even when the needles are fixed or are caused to act collectively, yarn feeding and loop formation will occur at each needle in succession across the needle bed during the same knitting cycle (Fig. 6.1). All, or a number of, the needles (A, B, C, D) are supplied in turn with the same weft yarn during the same knitting cycle so that the yarn path (in the form of a course length) will follow a course of the fabric passing through each needle loop knitted from it (E, F, G, H).

In a *warp knitting* machine there will be a simultaneous yarn-feeding and loop-forming action occurring at every needle in the needle bar during the same knitting cycle (Fig. 6.2). All needles (A, B, C, D) in the needle bar are simultaneously lapped

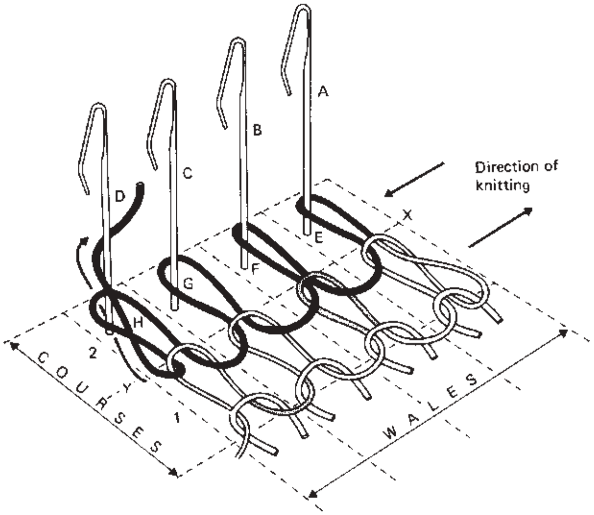

Fig. 6.1 Weft knitting.

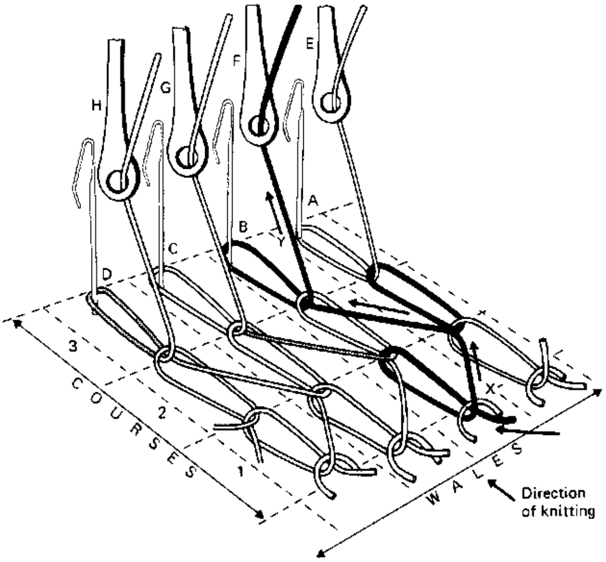

Fig. 6.2 Warp knitting.

by separate warp guides (E, F, G, H). As all needles receive their overlaps simultaneously, a guide underlapping from one needle to another will be passing from one knitting cycle or course to the next. Thus, the warp yarn passes from an overlap produced in one course to an overlap produced in the succeeding course (for example, guide F underlapping from needle B to needle A).

6.2 The two industries

Occasionally parts of both knitting techniques are combined in a single machine; generally, however, the techniques have tended to diverge to produce entirely separate industries each having its own specialist technology, machine builders, fabric characteristics and end-uses.

6.2.1 Weft knitting

Weft knitting is the more diverse, widely spread and larger of the two sectors, and accounts for approximately one quarter of the total yardage of apparel fabric compared with about one sixth for warp knitting. Weft knitting machines, particularly of the garment-length type, are attractive to small manufacturers because of their versatility, relatively low total capital costs, small floor space requirements, quick pattern and machine changing facilities, and the potential for short production runs and low stock-holding requirements of yarn and fabric.

A major part of the weft knitting industry is directly involved in the assembly of garments using operations, such as overlocking (Fig. 6.3), cup seaming (Fig. 6.4), and linking, that have been specifically developed to produce seams with compatible properties to those of weft knitted structures. There are, however, production units

Fig. 6.3 Overlock seaming [Corah].

Fig. 6.4 Cup-seaming.

that concentrate on the knitting of continuous lengths of weft knitted fabric for apparel, upholstery and furnishings, and certain industrial end-uses.

6.2.2 Warp knitting

Warp knitted fabric is knitted at a constant continuous width, although it is possible to knit a large number of narrow width fabrics within a needle bed width, usually separating them after finishing. There is considerable potential for changing fabric properties during the finishing process, as well as during knitting.

It is also possible to produce length sequences such as scarves with fringed ends, articles produced on double needle bar raschels based on the tubular knitting principle, and scalloped shaping of net designs by cutting around the outline after finishing.

British Celanese set the trend for the establishment of large, vertically-organized warp knitting plants self-sufficient in beaming, and in dyeing and finishing operations. During the 1930s they installed large plants with a total of 600 two-guide bar locknit machines, in order to convert their acetate and viscose rayon yarn into lingerie, shirting, blouse and dress fabrics. The much later introduction of continuous filament nylon and polyester yarn provided ideal raw materials for high-speed conversion into fine-gauge warp knitted fabrics.

From the mid 1950s, the patterning potential of multi-guide bar raschels has been progressively improved, based particularly on the conversion of nylon and polyester filament yarns. Thus, the lace and curtain net trade taken from warp knitting during the 1820s by twist, bobbinet and Leaver's lace machines has been extensively regained [1]. Warp knitting suffered in the swing of fashion away from continuous filament synthetic yarns towards blended spun yarns in solid fabrics, so there has been a tendency for the industry to seek new markets in household furnishings, car upholstery (Fig. 6.5) and industrial cloths.

Staple fibre spun yarns and textured continuous filament yarns create major difficulties for warp knitters. The precise setting of the elements, their fine gauge, the plating of two yarns in a needle hook, and the supply of parallel ends of yarn necessitate the use of fine and therefore expensive yarns. Problems can be caused by lint accumulation or filamentation, and the increased cross-sectional area caused by these seriously reduces the total length of warp yarn that can be accommodated on a specific warp beam flange diameter, thus increasing handling costs and machine down-time. For example, increasing the warp beam diameter from 21 to 40 inches (53 to 100 cm) enables the total length of accommodated warp to be quadrupled, but changing the yarn from 30 denier nylon to 150 denier textured polyester decreases the total length of accommodated warp ten-fold.

Fig. 6.5 Warp-knitted car upholstery [Karl Mayer].

6.3 Productivity

Productivity (P) is expressed in pattern rows per minute. In warp knitting this is the same as courses, but in weft knitting a pattern row may be composed of more than one course (feed).

In warp knitting, $P = R \times E$, where R is the number of camshaft revolutions per minute and E is the machine efficiency.

In weft knitting, $P = F \times R$ or $T \times (E/C)$, where F is the number of active yarn feeds, R or T the number of machine revolutions or cam-carriage traverses per minute, and C the number of courses or colours which comprise one pattern row.

6.4 Machine design

In warp knitting machines, all elements of the same type (needles or sinkers or guides of one guide bar) act as a single unit and are therefore fitted into, and controlled from, an element bar. Each guide in the same (conventional) guide bar requires the same warp-yarn feed rate and tension. This is most conveniently achieved by supplying a large number of parallel ends of warp yarn to the guide bar from a *warp beam*.

The shogging movement of the guide bars is controlled from one end of the machine. All these factors tend to restrict warp knitting machines to *rectilinear frames* and s*traight needle bars*.

In weft knitting machines there are only a limited number of yarn feed positions, often requiring different rates of yarn feed, so these are supplied from yarn packages such as cones. Since the needles knit in serial formation, the weft knitting machine frame may be arranged with either a circular or a straight needle bed, depending upon end-use requirements.

6.5 Comparison of patterning and fabric structures

Individual element movement (particularly of latch needles) enables weft knitting machines to produce designs and structures based upon needle selection for loop intermeshing and transfer. This also facilitates the production of garment parts shaped on the knitting machine. Weft knitted loops tend to distort easily under tension and yarn can freely flow from one loop to another that is under greater tension, a characteristic which aids form-fitting and elastic recovery properties (Figures 6.6, 6.7 and 6.8). Change of yarn by horizontal striping is another major weft knitting patterning technique.

Weft knitted structures can generally be unroved, a course at a time, from the end of the fabric knitted last and this, together with a tendency for loop breakdown to cause laddering, can create problems.

Most patterning on warp knitting machines is based on selective control over guide bar lapping movements (i.e. the direction and extent of the overlap and underlap movements) and on the threading of the individual guides of each guide bar (i.e. with or without warp threads or with different types or colours of yarn). Yarn change by striping is not available on warp threads.

Warp knitted threads tend to have an approximately vertical path through the

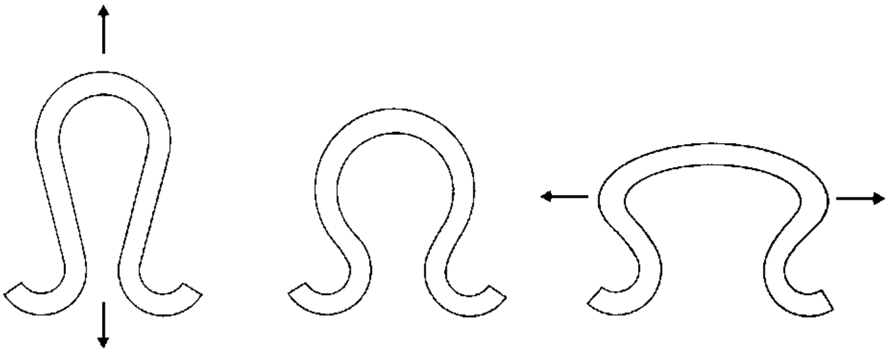

Fig. 6.6 Loop extension and recovery.

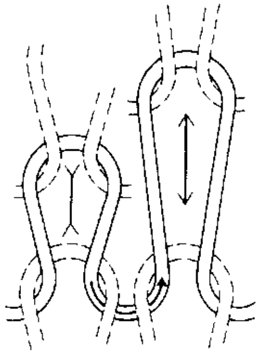

Fig. 6.7 Yarn flow in knitted structure.

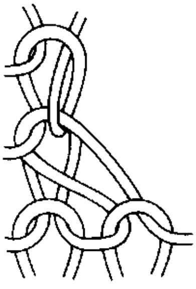

Fig. 6.8 Weft knitted loop transfer.

structure, which makes the warp threads less likely to fray or unrove and, in the absence of weft threads allows almost any width up to the full knitting width to be achieved. Effects in open work and colour can be obtained without the use of special mechanisms, and lapping movements can be arranged to produce fabrics ranging from dimensionally stable to highly elastic without necessarily changing the type of yarn.

6.6 Course length and run-in per rack

In weft knitting, the term '*course length*' refers to the measurement of a straight length of yarn knitted by all or a fraction of the needles in the production of a particular course. It consists of the stitch length multiplied by the number of needles knitting that stitch length. It may be measured at a yarn feed during knitting or after unroving the yarn from a knitted fabric, either as a complete course length or from the counted wales between two vertical cuts in the fabric. In Fig. 6.1, the length of black yarn between X and Y would be the course length.

In warp knitting, *run-in per rack* is equivalent to course length in weft knitting and is measured in inches or millimetres. All threads from the same warp are supplied from the same beam-shaft under identical conditions of yarn feed and tension, so it is only necessary to measure the length of one representative runner from each warp. The *rack* is an internationally recognized unit of 480 courses or knitting cycles. For fabric weight calculations, the threading arrangement of each bar must also be taken into consideration.

The simplest method of measuring run-in is to divert one thread through two guide eyes so that it runs at right-angles to the rest of the warp sheet at that point. It is then marked and, after the machine has been run for 480 cam-shaft revolutions, the distance the mark has moved towards the needles is measured. The length of yarn in an average stitch unit can be calculated by dividing the run-in by 480.

In Fig. 6.2, the length of black warp thread between X and Y would be the run-in if the measurement was multiplied by 160, giving a total of 480 courses.

6.7 Fabric quality

The term fabric '*quality*' is sometimes used when referring to wales and courses per inch or centimetre, either in a knitted or a finished relaxed state. As knitted loops tend to assume a recognizable configuration, the results can give an indication of the approximate stitch length and possible machine gauge used in knitting the structure, provided the state of relaxation and type of structure is taken into consideration. Generally, the higher the figure for a given linear measurement of wales, the finer the machine gauge and the smaller the stitch length.

6.8 Structural modifications commonly used in weft and warp knitting

Certain techniques are possible during the knitting action that can radically change the physical appearance and properties of a knitted construction without seriously affecting the cohesive nature of the loop structure. These techniques may be broadly divided into four groups – laying-in, plating, open-work and plush/pile. Although these techniques can be achieved on most knitting machines, slight modifications are often necessary and the more sophisticated versions of these techniques may require specially-designed knitting machines.

6.8.1 Laying-in

Inlaid (or laid-in) *fabric* consists of a ground structure of knitted or overlapped (warp knitted) threads that hold in position other non-knitted threads which were incorporated (laid-in) into the structure during the same knitting cycle.

An inlaid yarn is never formed into a knitted loop, although in weft knitting, when using only one bed of needles, it is necessary to form the inlay yarn into occasional tuck stitches in order to hold it in the technical back of the structure.

When weft knitting with two sets of needles, or when overlapping on the front guide bar of a warp knitting machine, it is possible to introduce the inlaid yarn into the structure merely by supplying the yarn across the backs of the needles (the front of the machine) in order to trap the yarn in the fabric.

Inlaid yarns are trapped inside double needle bed fabrics by the loops or overlaps; and towards the back of single needle bed fabrics by the sinker loops or underlaps.

Dependent upon the fabric construction and the types of yarns employed, laying-in may be used to modify one or more of the following properties of a knitted structure: stability, elastic stretch and recovery, handle, weight, surface 'interest', and visual appearance.

Laying-in offers the possibility of introducing fancy, unusual, and/or inferior or superior yarns whose physical properties such as thickness (linear density, count), low strength, irregular surface or cross-sectional area, elasticity or lack of elasticity render them difficult to knit into intermeshed loops. An inlay yarn may have a yarn count that is 6–8 times heavier than the optimum count for that machine type and gauge when operating under normal knitting conditions.

Laying-in yarn carriers or feeder guides may be of the conventional type or they may be specially designed for their function and the type of yarn; the ground yarn is knitted normally as for any structure. An inlay yarn normally assumes a relatively straight configuration, with hardly any reserve of yarn to distort or flow towards an area of the fabric under tension. It therefore requires less yarn than for knitted loops and tends to confer stability unless an elastomeric yarn is used, in which case the elastic stretch and recovery properties of the fabric will be improved.

6.8.2 Weft insertion

Weft insertion is a special type of laying-in where the yarn is laid onto special elements that, in turn, introduce it to the needles at the correct moment during the knitting cycle, instead of the yarn guide laying the yarn directly into the needles.

Although the possibility exists for introducing both weft and warp threads into either weft knitted or warp knitted fabrics during knitting, many attempts at this technique have failed to produce viable alternative structures as regards cost, design or end-use properties to effectively compete against woven structures [2–5].

In warp knitting, laying-in is achieved even on single needle bar machines by omitting the overlap movement and merely underlapping on the inlay guide bar. Provided the inlay guide bar is always behind a guide bar that is overlapping the front guide bar, overlaps and underlaps will trap the inlay underlaps into the technical back of the structure (Fig. 27.1).

When weft knitting with one set of needles, it is not possible to lay-in a yarn by merely traversing a yarn carrier across the backs of the needles because the yarn will not be trapped by the sinker loops of the knitted loops. The inlaid yarn must occasionally pass across the hooks of a needle to form a tuck stitch and thus hold itself into the structure.

6.8.3 Plating

A *plated structure* contains loops composed of two (or more) yarns, usually with differing physical properties. Each has been separately supplied through its own guide or guide hole to the needle hook, in order to influence its respective position relative to the surface (technical face and technical back of the fabric).

Plating (as an all-over effect or on selected stitches) may be used to produce surface interest, coloured patterns, open-work lace or to modify the wearing properties of the structure.

Perfect plating, so that the underneath yarn does not show or 'flash' onto the surface, is difficult to achieve with yarns that have a circular cross-section and variable physical properties. It is essential to control yarn tension, angle of feed and the already-formed loops throughout the whole knitting cycle. If the two yarns are of similar count, they should be approximately half the normal yarn count for that gauge of machine.

As the yarns slide along the underside of a normally-curved needle hook, they may roll over each other and thus destroy their plating relationship; for this reason, needles with specially shaped hooks for plating are often employed.

The basic rule of plating is that the yarn positioned nearest to the needle head shows on the reverse side of the needle loop and therefore shows on the surface of the technical back (Fig. 6.9). The second yarn is in a lower position and tends to show on the face stitches of weft- and warp-knitted structures (Figures 6.10 and 6.11). The second yarn will be prominent on the surface of face loops on both sides of rib fabrics unless it is tucked ('tuck plated') by the second set of needles. In purl fabrics, face stitches will show the second yarn and reverse stitches the first yarn.

In single jersey plating, the yarn for the technical back is fed at a low angle across the open latches from a hole drilled vertically in the feeder guide. The face yarn is fed at a sharp angle above it into the open hooks from a hole drilled horizontally into the side of the guide. As the latches close, the back yarn is lifted into the hook above the face yarn, thus ensuring the correct plating relationship in the fabric.

In tricot warp knitting, many fabrics are knitted where two guide bars simultaneously overlap the same needle in opposite directions and thus produce a plated structure. The front guide bar threads strike the needle stems first and at a lower

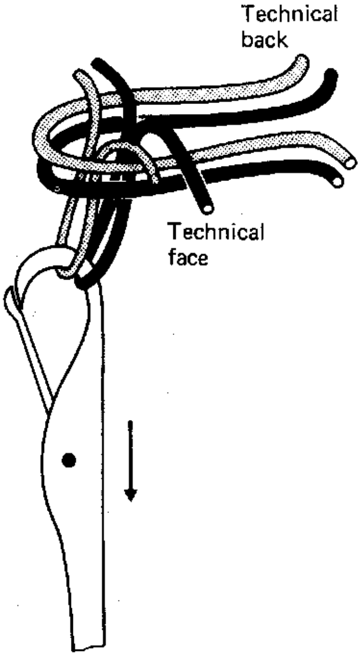

Fig. 6.9 The plating relationship of two yarns.

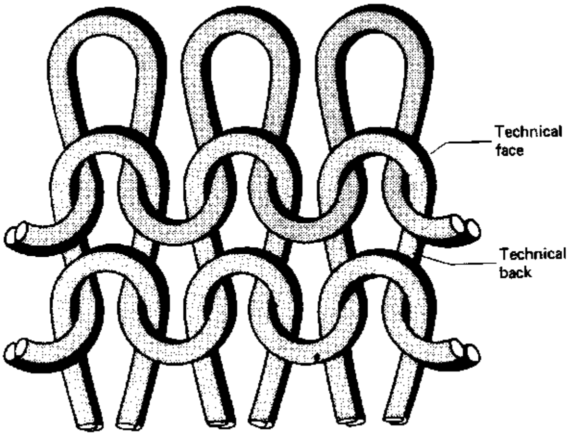

Fig. 6.10 Plating in weft knitting.

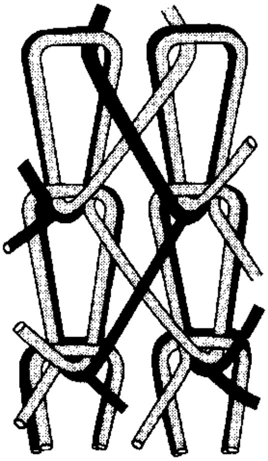

Fig. 6.11 Plating in warp knitting.

level during the return swing after the overlap, so they tend to plate on top on the technical face.

This relationship may, however, be upset if the two guide bars overlap in the same direction, because the back guide bar threads then tend to slide over the front bar threads and thus assume a lower position on the needle.

Normally the front guide threads also show on the technical back, as well as the front, because, as the underlaps emerge from out of the head of the previous loop, they are laid on top of the new overlaps in turn and the front bar underlap (black) is laid down last (Fig. 6.11).

6.8.4 Open-work structures

Knitting is noted for its production of open-work as well as close structures.

A close structure is one where the stitches provide a uniform cover across the fabric and hold the wales securely together. An *open-work structure* has normal securely-intermeshed loops but it contains areas where certain adjacent wales are not as directly joined to each other by underlaps or sinker loops as they are to the wales on their other side. The unbalanced tension causes them to move apart, producing apertures at these points. The arrows in Fig. 6.12 indicate the movement of adjacent wales towards each other at points where they are most securely joined together, thus producing an aperture on the other side of the wale.

Semi-transparent structures are produced in a similar manner but, instead of having apertures, there is less yarn crossing between the wales than elsewhere and this provides less cover at these points ('float plating', Section 9.5).

Semi-breakthrough or honeycomb structures have certain yarns that produce an open-work effect whilst others produce an all-over close structure, so that the aperture is closed on one side of the fabric.

Open-work apertures may be a number of courses in depth and, as a result of tension distortion within the structure, they may cause adjacent wales to be considerably further apart than the actual distance between two adjacent needles during knitting.

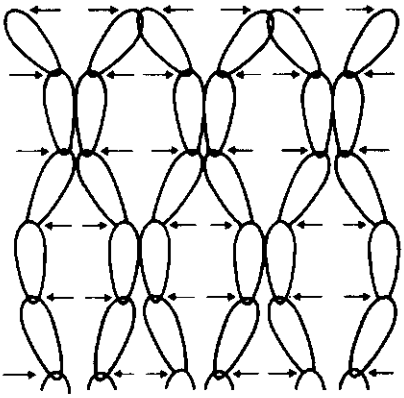

Fig. 6.12 The movement of loops to form open work.

In weft knitting only, open-work structures may be produced by the introduction of empty needles and/or by using special elements to produce loop displacement. An alternative technique is by selective press-off of fabric loops.

Open-work structures are used for fancy laces and nets for dresswear, underwear (Fig. 6.13), nightwear, lingerie, sportswear, linings, blouses and shirts, drapes and curtains, and industrial fabrics.

6.8.5 Plush and pile constructions

Although the terms 'plush' and 'pile' originally referred to specific woven structures, they are often used synonymously today in referring to a very wide range of weft and warp knitted constructions.

The essential difference between a plush and pile structure is that the *pile* is normally composed of a different type of yarn and should stand out almost at right angles from the knitted ground surface whereas the *plush* has neither of these characteristics. Both plush and pile surfaces may consist of either cut or uncut loops of yarn and, in the case of *high pile*, slivers of fibres instead of yarns are used. Generally, the production of pile fabrics tends to be a very specialized technique for both knitting and finishing. One or more of the following techniques is normally involved in the production of the two types of fabric – special points or other elements in the knitting machine, excess feeding of the pile yarn, and raising or brushing of the pile surface during finishing.

Although a certain amount of double-faced pile fabric is produced, the majority of plush and pile fabric has its surface effect on the technical back of single-faced constructions, with the sinker loops or underlaps being used to produce the effect. A variation of this technique is to use a double needle bar machine, pressing off on the second set of needles to produce the pile surface. Yet another method is to employ a double needle bar raschel to knit two separate ground constructions, one on each needle bar, each with its own yarns, and to supply a pile yarn across between the needle bars. The pile is later cut to separate the two ground fabrics and thus produce two single-sided cut pile fabrics.

Fig. 6.13 Bra and briefs made from elastic raschel lace fabric. Note also the scalloped, elasticated edge trimmings [Dupont 'Lycra'].

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