# 28

# Multi guide bar machines and fabrics

## 28.1 The development of raschel lace

*Karl Mayer* introduced the first raschel lace machine in 1956, using 12 guide bars. By 1964, 36 guide bars were achieved, followed by 42 in 1968. Electronics began to replace mechanical guide bar control and, in 1981, 42- and 56-guide bar raschels without conventional chains were introduced.

In 1985, the first '*Jacquardtronic*' lace raschel with 78 guide bars, electronic pattern guide bar control, and electronic jacquard selection was unveiled. In 1990, the '*Textronic*' lace raschel with a fall-plate and particular configuration of 53 guide bars was introduced, to knit surface-interest patterns resembling embroidery with different lace ground variations.

## 28.2 The success of raschel lace

Many factors (outlined in the following list) have contributed to the success of warp knitting in the production of lace, curtain-net and elastic fabrics:

- The inability of the slow, traditional lace and net machines to meet rapidly expanding demands for these types of fabrics.
- An availability of fine, strong, uniformly regular, continuous filament yarns ideally suitable for high-speed warp knitting, such as nylon for lace, polyester for curtaining, and elastomeric yarns for elastic laces.
- The greater suitability of the raschel machine for utilising synthetic filament yarn than traditional lace machinery, with higher productivity. It offers the benefits of low capital costs, reduced requirements for ancillary equipment, less operative supervision, and simpler pattern-changing facilities.
- Ability to achieve satisfactory imitations of mesh constructions such as tulle and marquisette by pillar inlay lapping movements.
- Development of specific purpose machines with higher speeds and greater patterning capabilities (Fig. 28.1) encouraged by the introduction of the multi-guide

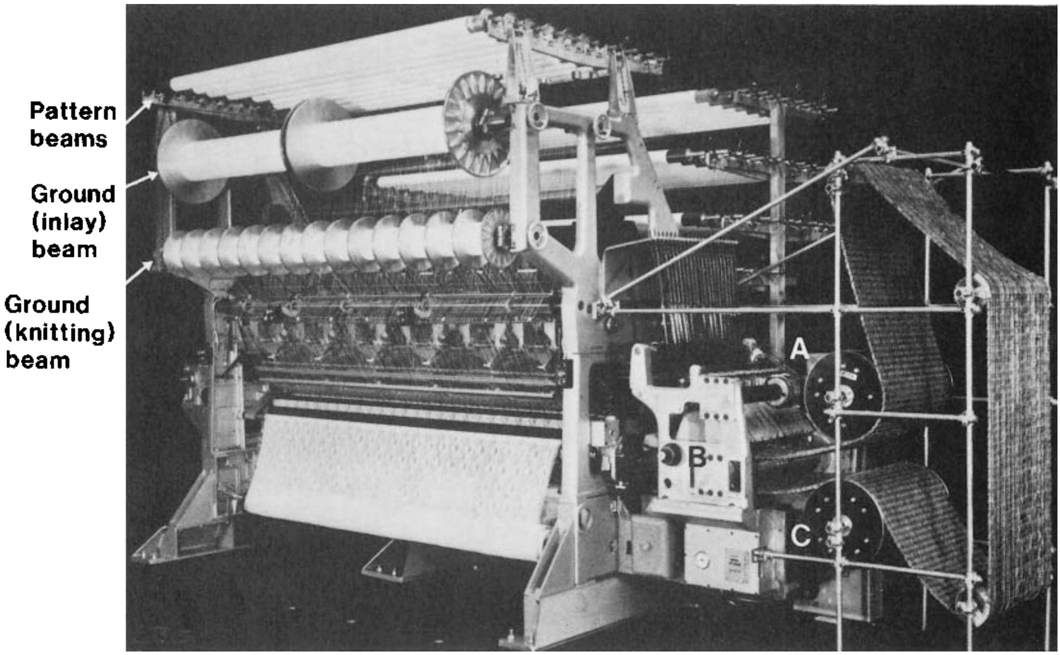



**Fig. 28.1** 42-bar raschel lace machine [Karl Mayer].

bar lace raschel in 1956 (with its separation of full-sett ground bars from the simple light-weight patterning bars together with the elimination of unnecessary movement and weight).

- Improvements in patterning techniques such as jacquard. These have provided sophisticated design potential for a widening range of end-uses beyond the confines of conventional guide bar lapping facilities.

## 28.3 Pattern guide bars

On conventional multi guide bar machines, pattern guide bars are only required to supply one thread each for a pattern repeat width. Different yarn counts or types are used to achieve greater effect. To use ordinary guide bars for this purpose would be uneconomical as their weight would lower the machine speed. Also, only about eight to thirteen shogging or displacement positions are available so the patterning capabilities would be severely restricted.

Instead, light-weight pattern guide bars are used that have drilled holes to which *finger guides* are screw-attached, only at the required spacing for the pattern. These bars are indirectly shogged by a lever arrangement (B) at a rate of one link per course (C), both for inlay and for fall-plate or embroidery patterning [1] (Fig. 28.2). In the last 2 cases, an automatic overlap mechanism is used.

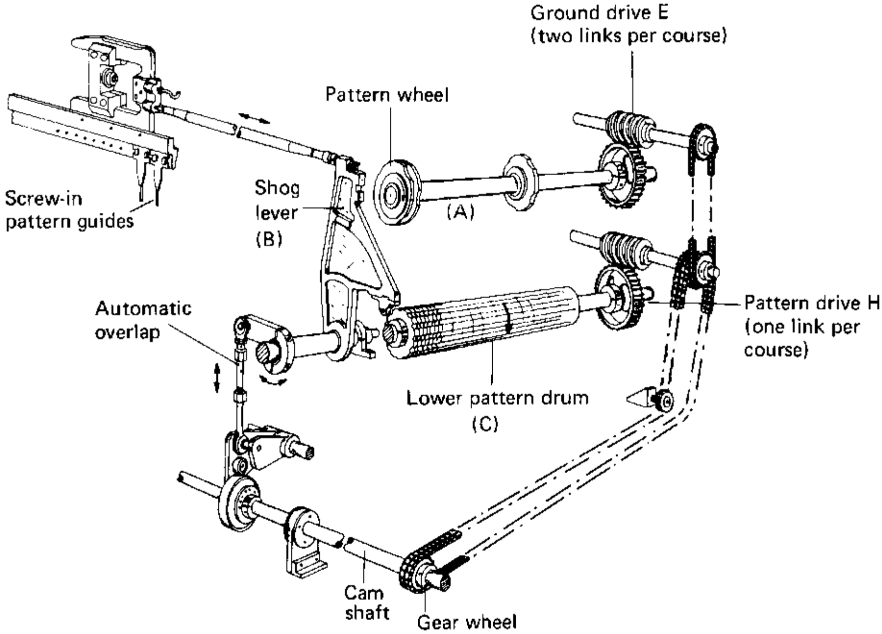



**Fig. 28.2** Automatic overlap guide bar drive.

## 28.4 Guide bar nesting

Up to four pattern bars can be '*nested*' together so that their guides converge into the same displacement line. They swing as a single guide bar but they are shogged independently, although guides of bars in the same nest cannot cross or approach within two needle spaces of each other (Fig. 28.3).

On the 42-bar lace raschel, thirteen displacement lines are available. The front two are conventional guide bars for knitting the ground, the next may be a conventional bar for draw-threads when knitting trimmings, or it can be one of two nests of two pattern bars, and there are another nine nests each of four bars.

## 28.5 Multi-bar tricot lace machines

Multi guide bar tricot machines with between eight and eighteen guide bars have been built in gauges of E 24–28 for the production of fine gauge lace [2]. Two fully-threaded bars are used to knit the ground, such as reverse locknit or queenscord, with fine yarn such as 44 dtex nylon. Pattern bars behind the ground bars are used for inlay effects. Those in front are employed for embroidery designs in the form of overlaps and underlaps, in a textured yarn so that they stand out in relief on the technical back. The knitted overlaps show through from the face and the underlaps float across the back (Fig. 28.4).

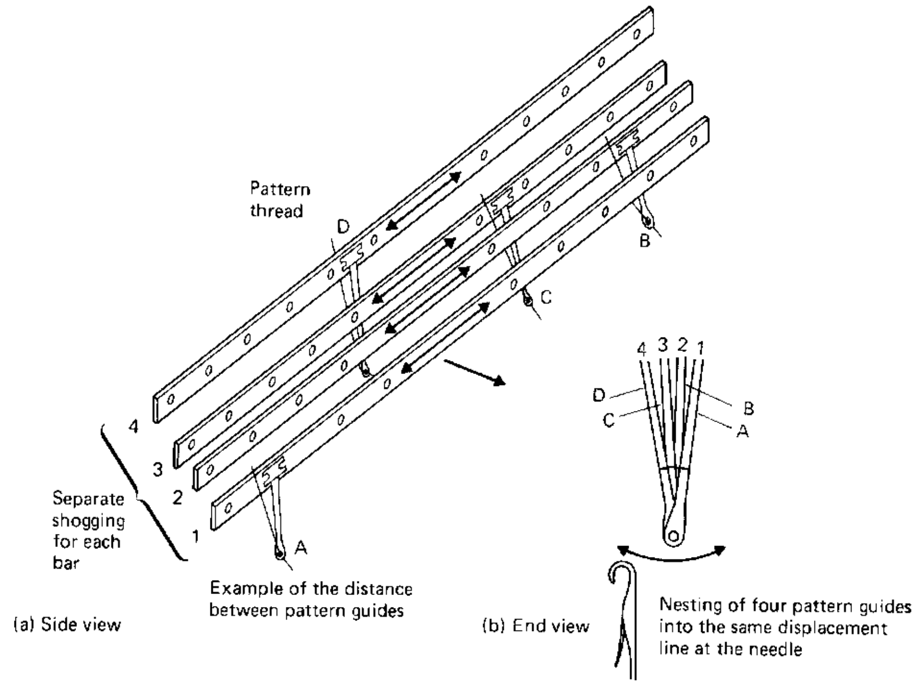



**Fig. 28.3** Raschel lace guide bar nesting.

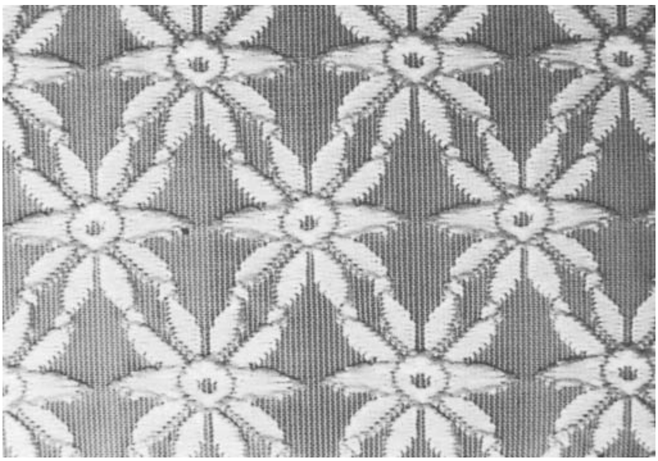


**Fig. 28.4** Embroidery patterning.

## 28.6 Chain links and electronic control of shogging

The cost of chain links and the labour involved in chain assembly are major problems with multi guide bar machines.

Ground guide bars are generally controlled directly from links or pattern wheels moving at two links per course (A). The pattern guide bars are controlled indirectly through shogging levers (B) (Fig. 28.2), using only one link per course (either they only inlay or they are caused to automatically overlap in the same direction after the underlap is completed by an eccentric working onto the shogging levers).

Leverage in the shogging arrangement can reduce the height and weight of the links. Split-chain drums that can be stopped during miss-lapping in between motif patterns can further reduce the link requirements. However, lace designs can still involve as many as 15 000 links, which can weigh over a tonne (1000 kg).

## 28.7 The summary drive

The *Karl Mayer* electronically-controlled SU guide bar shogging arrangement [3] now employed on multi-bar lace machines is typical of the efforts being made to replace chain links with a simpler and cheaper method for changing patterns more rapidly. It also eliminates the time and cost of assembling, dismantling, and storing the chain links.

The shogging data is supplied to the memory of a microprocessor by means of disc or other data carrier (Fig. 28.5). Each pattern bar has its own unit consisting of six eccentric cams that, although mounted on six separate continuously rotating shafts, are not fixed to rotate with them. On either side of each cam is an electro-magnet that, when it receives a signal from the microprocessor, locks the cam onto its shaft causing the cam to rotate, moving its push rod forward like a piston so that the roller in front causes the vertical segmented bar to move upwards. At the top of the bar, the vertical movement is transformed into a horizontal shogging motion.

When the microprocessor sends a signal to the other electro-magnet, the magnet locks onto the rotating shaft and rotates with it, pulling the roller out of vertical, causing it to be lowered and shogging the guide bar horizontally in the opposite direction.

Each of the six eccentric cams produces a different extent of shogging movement when activated. The bottom cam shogs the guide bar by 1 needle space, the second shogs the guide bar by 2 needle spaces, the third by 4, the fourth by 8, and the fifth and sixth each shog 16 needle spaces. If the first and second cams are in action, a shog of 3 needle spaces will be achieved and so on. Any number of needle space shogs from 1 up to a total of 47 can be obtained. On some machines there is another eccentric that, when in action, produces an automatic overlap; for example, for fall-plate pattern guide bars.

## 28.8 Raschel mesh structures

Mesh structures may be used alone or as the ground for designs produced by pattern bars (Chapter 27). The three main raschel lace gauges are: 28-gauge (E 14), which is coarse gauge (Fig. 28.6) and is mainly used for dress-wear with the designs being emphasised by heavy outline threads; 36-gauge (E 18) which is the standard gauge (Fig. 28.7); and 48 gauge (E 24) which is fine gauge, provides better definition in designs, and is also used for lace edgings, etc. (Fig. 28.8).

*Three-course tulle* is the standard mesh for raschel lace, producing three courses on each wale with the inlay reinforcement lapping in unison. When the pillar and inlay lap in opposition, a square mesh known as *cross tulle* or *bridal veil net* is produced. *3/2 tulle* produces alternate rows of smaller mesh and its lapping covers three

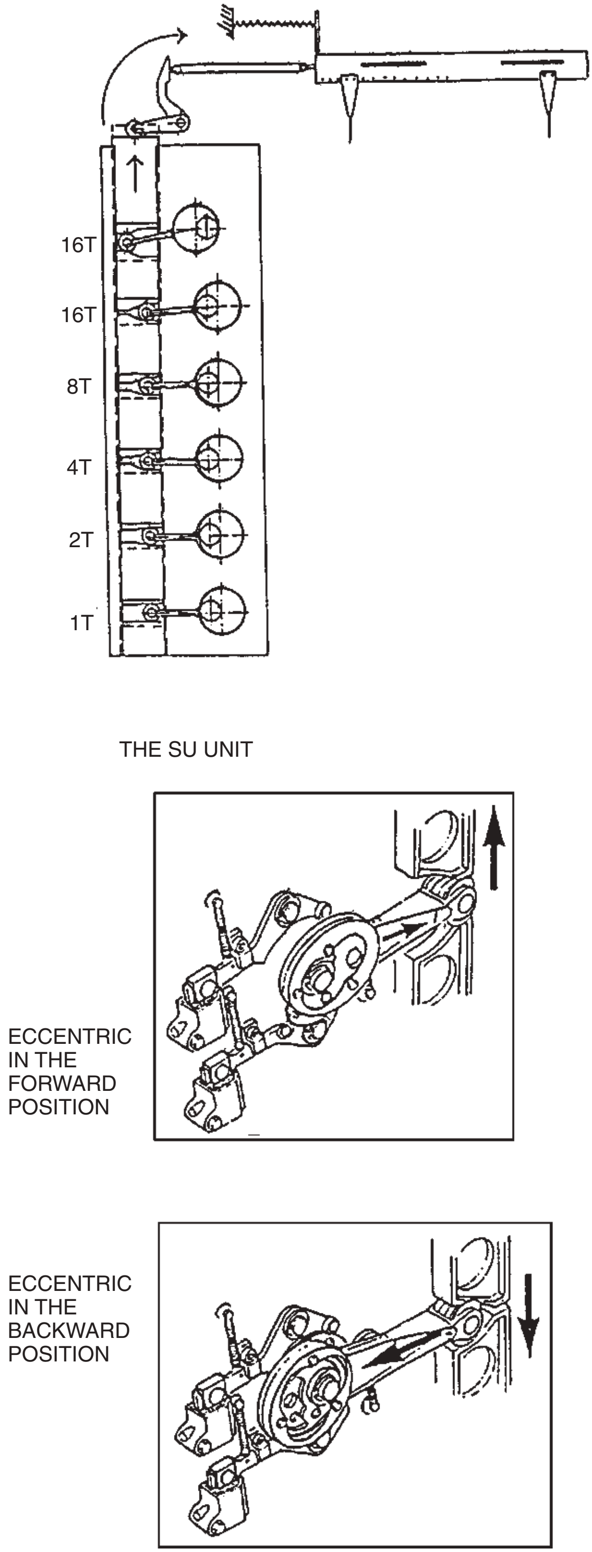



**Fig. 28.5** The summary drive (SU) electronic patterning mechanism [Karl Mayer].

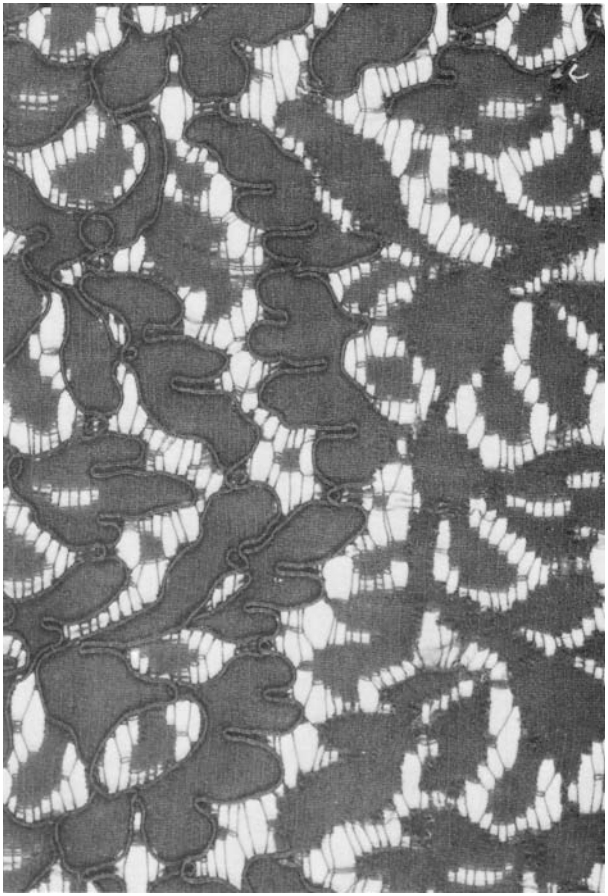


**Fig. 28.6** 28 gauge (E 14) pillar inlay using outline threads [Karl Mayer].

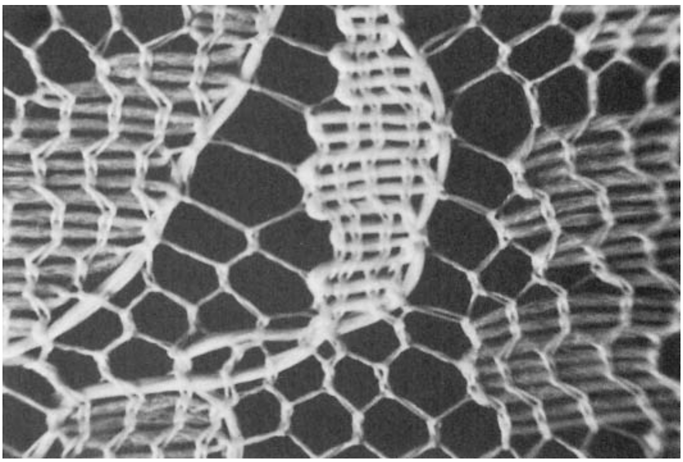


**Fig. 28.7** 36-gauge (E 18) raschel tulle lace (technical face).

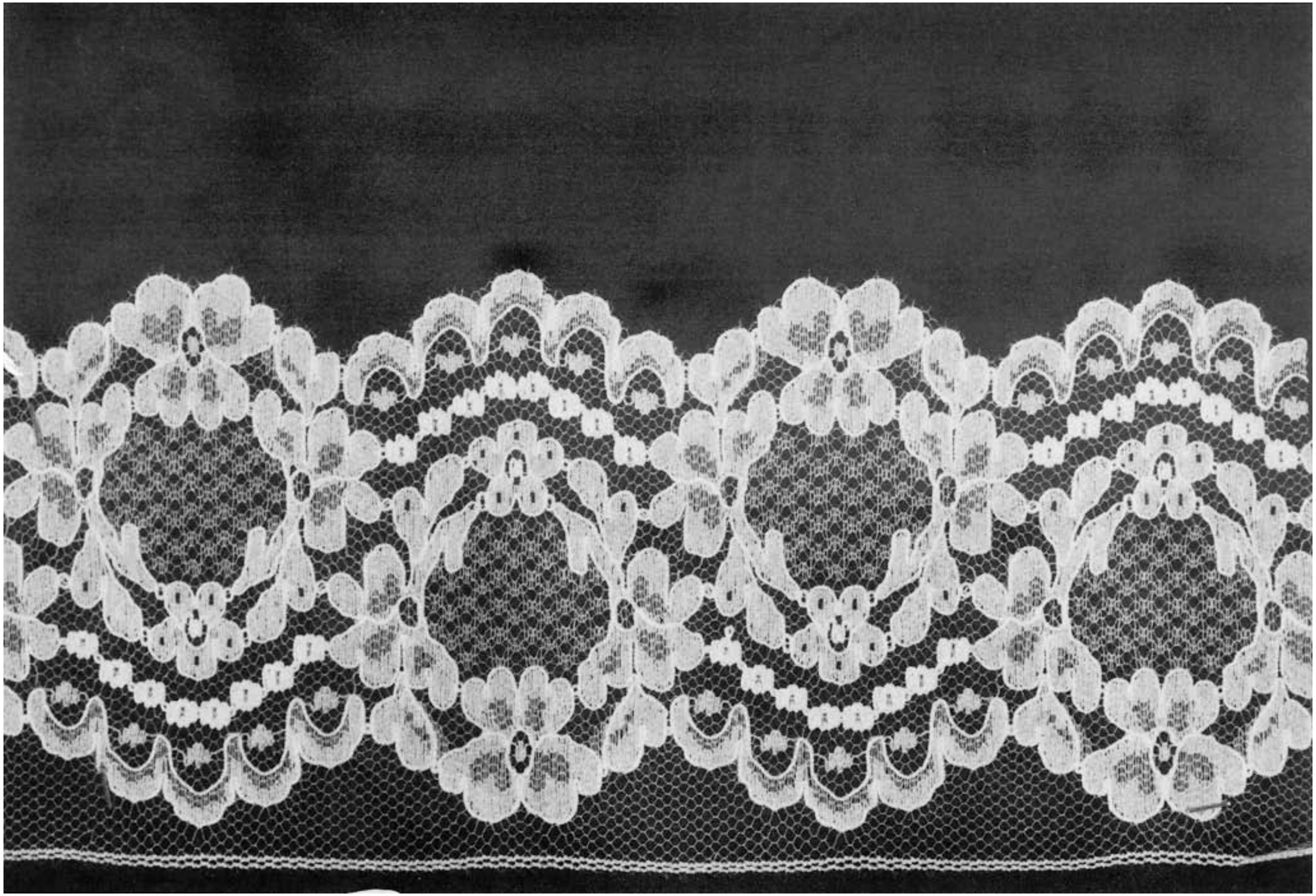


**Fig. 28.8** 48-gauge (E 24) fine gauge raschel lace; the edge has been scalloped by cutting [Karl Mayer].

(a)

(b)

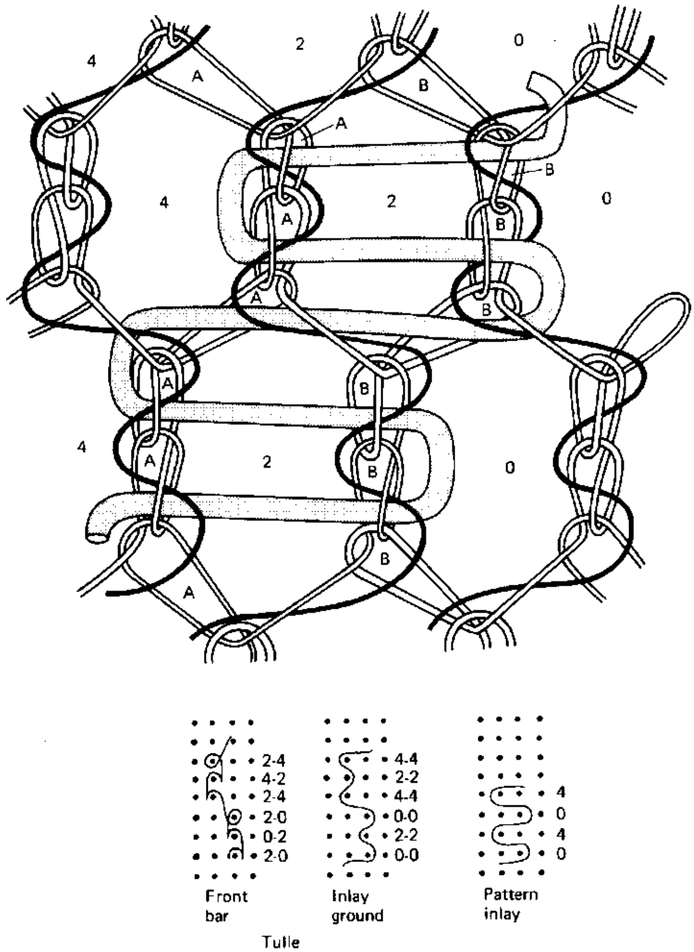



**Fig. 28.9** Raschel lace five course tulle with inlay; (a) structure; (b) notation.

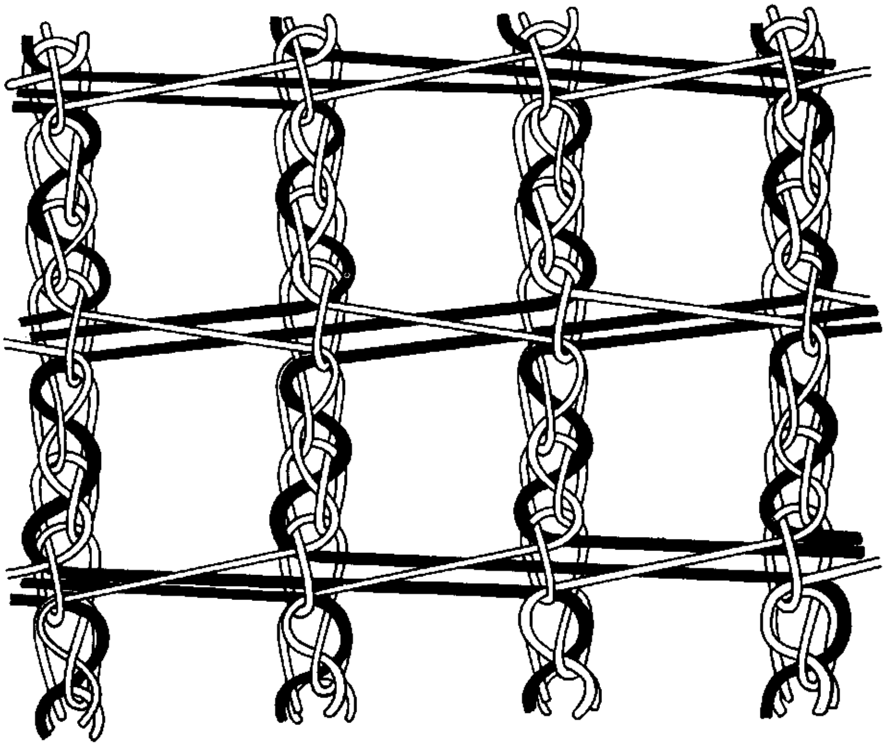
wales. *Five-course tulle* produces larger mesh and is more suitable for 28-gauge fabrics.

Hexagonal pattern paper is more useful than point paper when plotting inlay designs for lace. The staggered vertical column of hexagonals that represent the 0 height link position is then established. Each hexagonal in a horizontal row moving away from the 0 link position will represent an increase of chain link height (in even numbers) (Fig. 28.9, A).

Sometimes, more elaborate grounds are produced by varying the inlay movements of partly-threaded bars or a jacquard-controlled guide bar whilst employing a fully-threaded guide bar to make a ground pillar stitch.

## 28.9 Marquisette and voile

*Marquisette* and *voile* curtain nets, which are both named after woven constructions, are produced with fully-threaded guide bars the front of which makes a pillar stitch



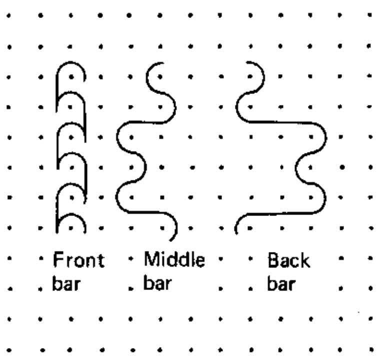



Fig. 28.10 Three bar marquisette.

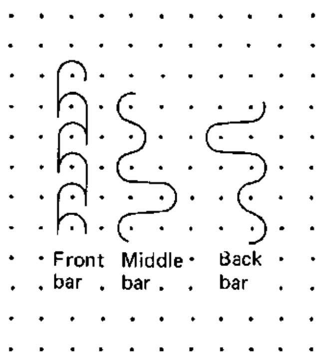



Fig. 28.11 Three bar voile.

(Figures 28.10 and 28.11). Heavier, stronger, but more expensive meshes are made when two inlay bars lap to different extents in opposition to each other (Fig. 28.10). Marquisette has a square mesh (Fig. 28.10) whereas voile (Fig. 28.11) tends to show diagonal inlays.

## 28.10 Elasticised fabrics

Elasticised fabrics have long been used for corsetry, foundation garments, and swimwear, but the introduction of fine-diameter elastane yarns whose elastic exten-

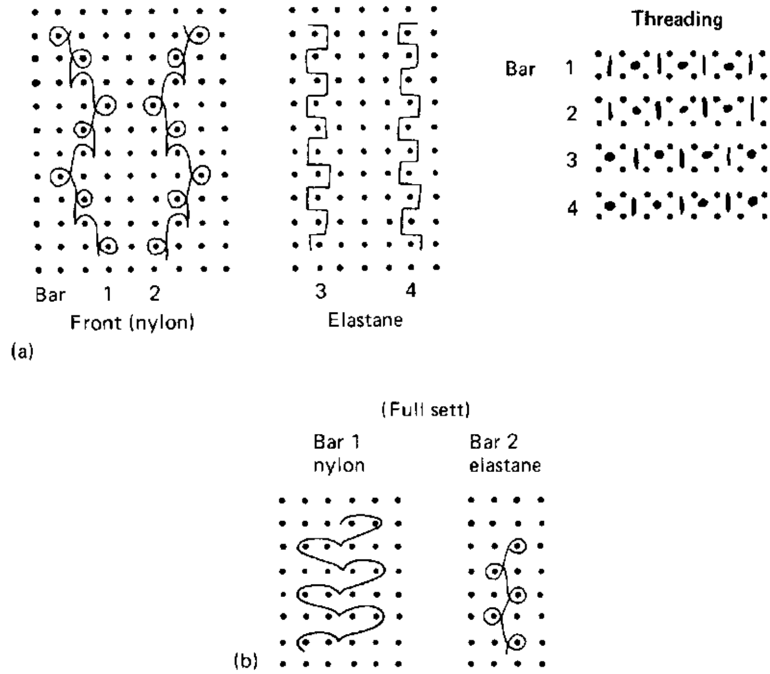



**Fig. 28.12** Elastane fabrics.

sibility and recovery can be 'engineered' to particular requirements has extended the use of these structures into lingerie and active sports and leisure wear. Elasticised fabrics are knitted on high-speed raschel and tricot machines as well as in patterned form on multi guide bar lace machines.

The main prerequisites of these machines is delivery of the elastane yarn under conditions of controlled tension, robust knitting elements that will not deflect under the tension of the elastic yarn, and controlled tension for the fabric take-up.

*Power net* (Fig. 28.12a) is the most widely-known structure for foundation wear. Four half-sett threaded guide bars are used. The two front bars knit the nylon ground and the two back bars inlay the elastane yarn. Only two fully-sett beams, one of nylon and the other of elastic yarn may be needed to supply the requirements of the guide bars. This structure can provide a length-wise extension of 75–85 per cent and a width-wise extension of 65–75 per cent.

For fine-gauge fabrics, elastane yarns with counts from 22 to 78 dtex may be knitted into '*stretch tricot*' using a locknit construction or special lapping movement (Fig. 28.12b). Compound-needle high-speed raschels are favoured for this type of work.

In patterned multi guide bar elastic lace fabrics, the pattern threads are sandwiched in the centre of the structure with the fully-threaded knitting guide bar placed at the front and the elastane yarn being inlaid by the back bar(s).

## 28.11 Jacquard raschels

Although first patented by *Samuel Draper* of Nottingham in 1837, the selective control of individual guide lapping in a guide bar by means of an overhead jacquard only developed into a sophisticated technique during the late 1960s.

On *Karl Mayer* machines using mechanical jacquard control, the principle employed was to deflect selected guides in a fully-threaded jacquard bar guide bar by means of selectively lowered dropper pins carried in a separately-shogged displacement pin bar.

Those guides have a greater or lesser extent of lap than the undeflected guides of the same guide bar which lap the distance controlled by the guide bar shogging at that course. The pins are kept in the displacement position or raised out of action by means of a *verdol* jacquard apparatus and harness arranged above the machine.

By this means, the underlaps of individual guides in knitting, inlay or fall-plate jacquard guide bars can be varied in extent. Also, on some machines, an inlay movement may be converted into a selected overlap, thus producing a plated overlap design in colour on the technical face of the fabric.

The type of deflection is dependent upon the relative lapping movements of both bars and the exact moment when the pin contacts the guide, so that the guide is either deflected towards or away from its direction of lapping. Figure 28.13 illustrates how a semi-transparent two-needle inlay (a) can be deflected to the left at odd courses to produce open-work areas of one-needle inlays (b), or at even courses to produce solid areas of three-needle inlays (c).

Usually it is necessary to supply the warp for the jacquard bar from individual packages mounted on a creel. There is normally only one, or occasionally two, jacquard guide bars and the remainder are conventionally controlled guide bars.

The guides of the jacquard bar may have a gauge twice as fine as the needles so that there are two guides between adjacent needles, arranged in two staggered rows (A, Fig. 28.14), each capable of having a different yarn type or count if necessary.

The jacquard bars are arranged not to swing, otherwise the harness strings could become entangled.

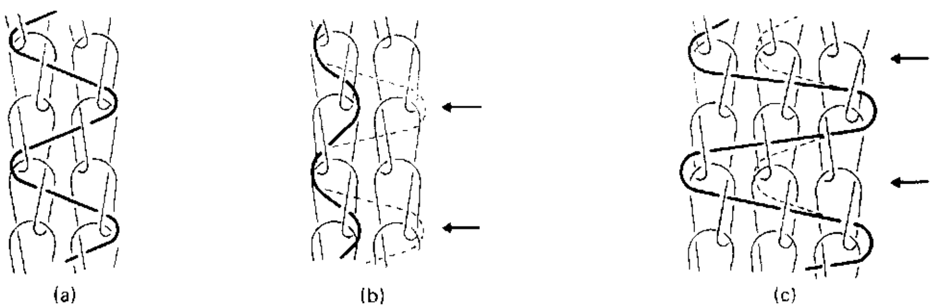



**Fig. 28.13** Jacquard inlay deflection units.

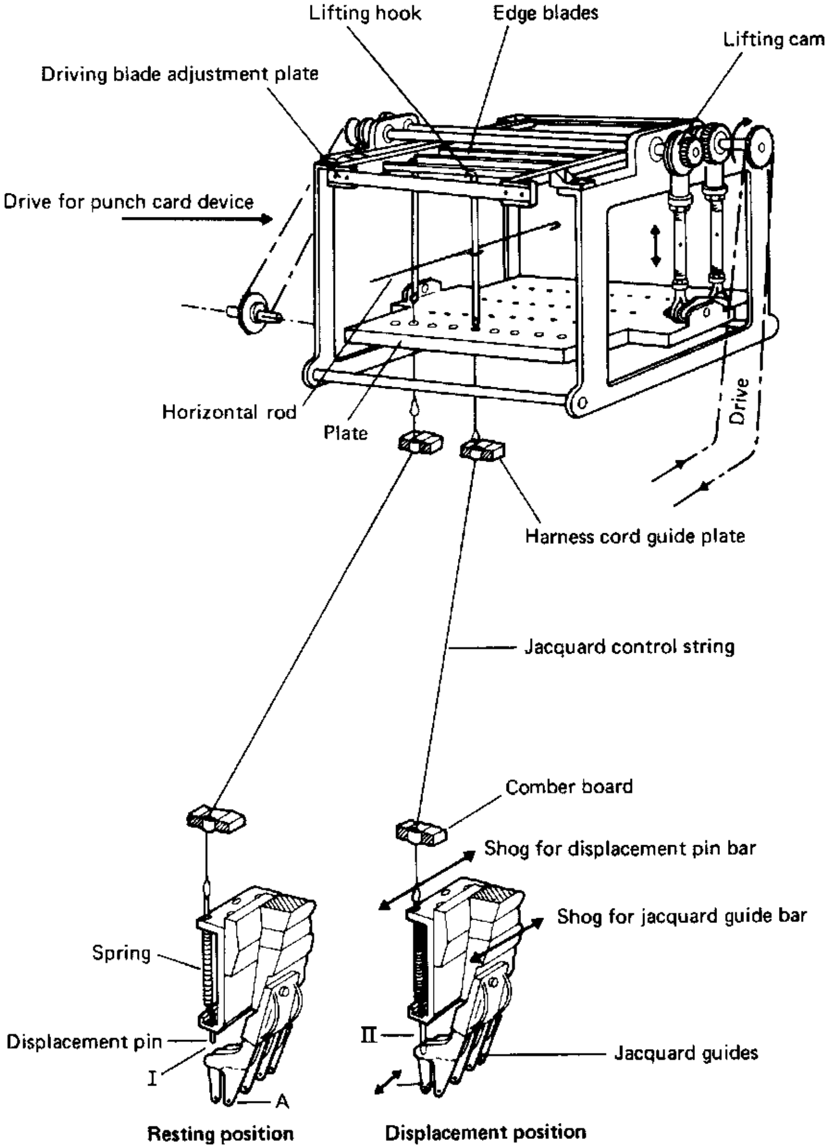



**Fig. 28.14** Mechanical jacquard apparatus.

## 28.12 The Mayer Jacquardtronic multi-bar lace raschels

The traditional mechanical *verdol* jacquard control, previously described, is slow, cumbersome and time-consuming when changing designs. On the latest electronic machines, the jacquard head has been replaced by a computer control that is simply linked by a cable to the combined selection element and jacquard guide, which are one unit. There are no jacquard harness cords for lifting and guide displacement which would restrict the use of the conventional guide bar swinging movement.

At first, *Karl Mayer* used electro-magnets to obtain the jacquard deflection movement; this has now been replaced by piezo technology (Fig. 28.15a and b) [4]. When

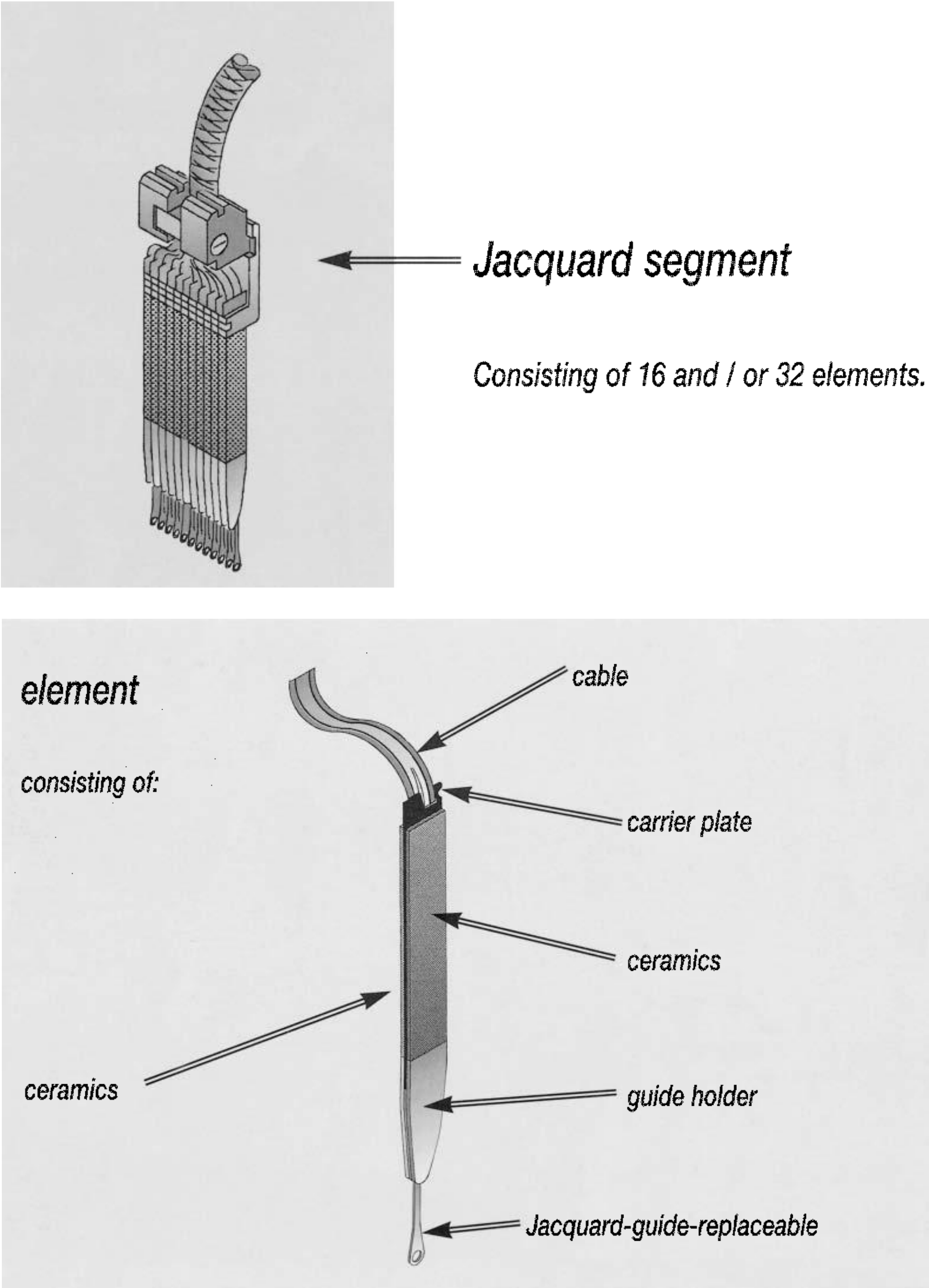



**Fig. 28.15** a. jacquard segment of 16 or 32 segments [Karl Mayer].
b. Jacquard element [Karl Mayer].

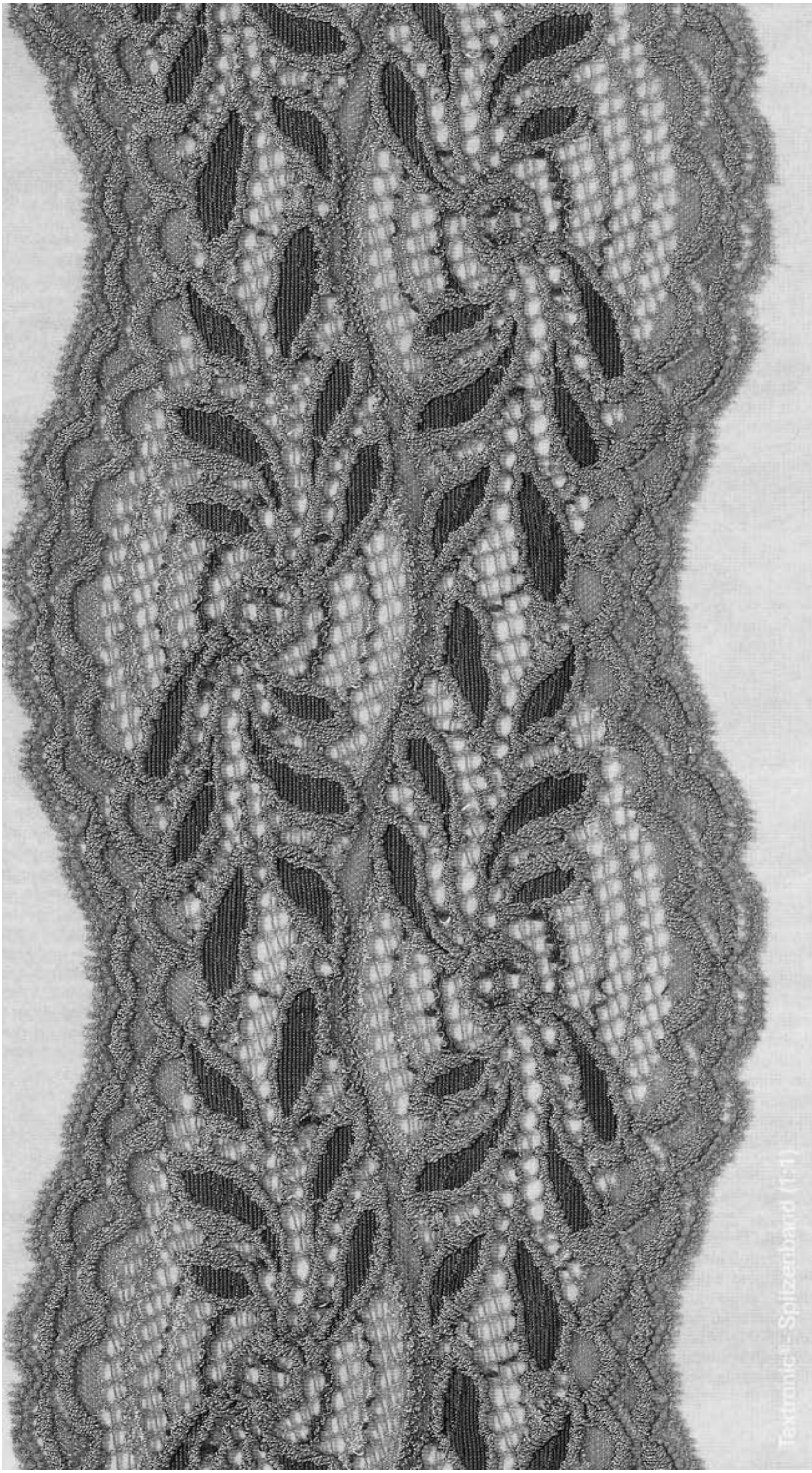



**Fig. 28.16** Leaver's lace effect produced on a Textronic raschel lace machine [Karl Mayer Textronic].

an electrical voltage is applied to a piezoelectric material, it expands or contracts as a function of the polarity. The resultant change in length is directly proportional to the applied electrical voltage. Each jacquard guide has a piezoelectric ceramic strip on either side that positively moves the guide one needle space left or right when required. The possibility of being able to transmit two different control signals during one knitting cycle enables selective displacement of both the overlap and the underlap stitches to be achieved.

With this arrangement, knitting speeds can be increased by up to 50 per cent and power consumption is reduced. There is a quicker reaction and a greater range of guide bar shogging possibilities.

Three MRPJ *Jacquardtronic* machines have been developed with 25, 43 and 73 guide bars in gauges E 18 and E 24. The 43-bar machine has a production speed of 420 courses per minute and a pattern repeat area of 168 needles and 14 000 courses.

The jacquard bar can be positioned behind the pattern bars so that three-dimensional patterns can be produced. On the model MRPJ 73/1 [5], the ground bar is in position 1, there are then 70 pattern bars, a split piezoelectric jacquard bar in position 72, and an elastane guide bar in position 73. The guide bars are divided into 18 shogging rows (displacement lines) of which two can form stitches. By positioning the pattern bars in front of the jacquard bar, three-dimensional relief motifs can be produced.

The guide bars are shogged by two computer-controlled digital pattern drives. The ground bar, jacquard bar and even-numbered pattern bars from 4 are controlled from the right side of the machine. Odd numbered pattern bars from 5 are con-

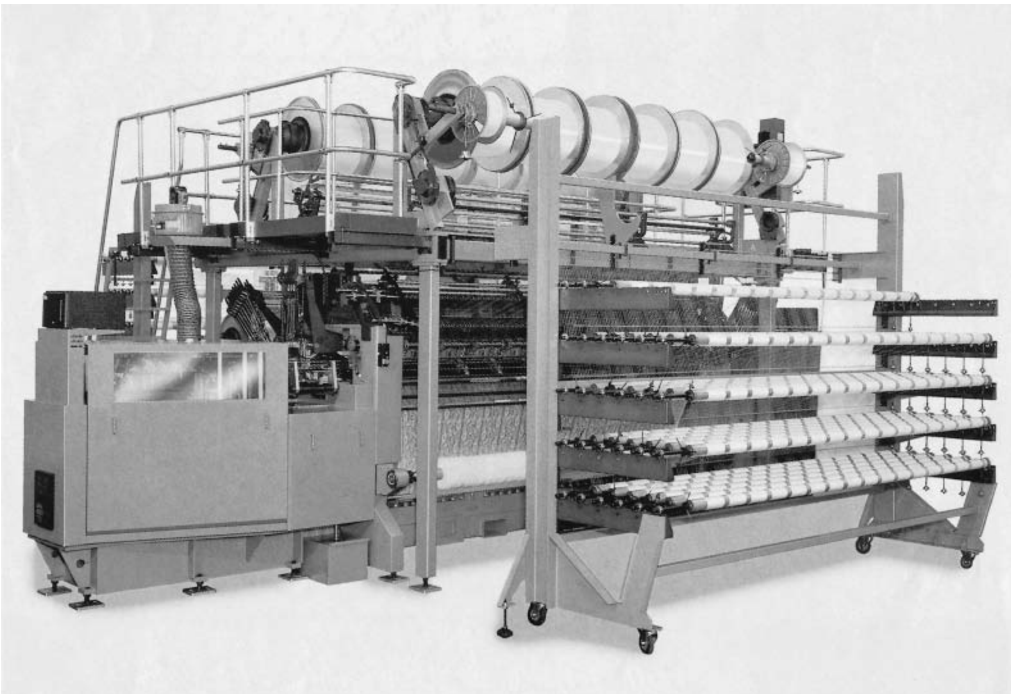


**Fig. 28.17** Textronic MRPJ 59/1/24 raschel lace machine [Karl Mayer].

trolled from the left side. The control for guide bars 2 and 3 via the mechanical overlapping mechanism is located on the left side of the machine.

The latest '*Textronic*' fall-plate multi guide bar raschel lace machines use new technology to produce '*Leaver's lace*' quality fabrics. Shadow and filler yarns can be used as well as thick contour yarns (gimps or liners) (Fig. 28.16).

One of the models, MRPJ 59/1/24 (Fig. 28.17), has 59 guide bars arranged in 14 shogging lines. Twenty-four pattern bars are in 4 shogging lines in front of the fall-plate and are thus controlled by it. There are then two pattern guide bars with mechanical overlaps, a stitch-forming ground guide bar, one piezo jacquard bar for inlay, 30 pattern inlay guide bars in 5 shogging lines and one elastane yarn guide bar.

*Karl Mayer* have an individual yarn selection device that removes yarns when they are not required so that there are no floats carried in the ground between one motif and the next. As soon as the yarns are needed again for patterning, they are reintroduced after having been cut and trapped.

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# 29

# Double needle bar warp knitting machines

## 29.1 Operating principles

*Double needle bar raschels* and bearded needle *simplex machines* are symmetrically arranged, with each needle bar usually having identical facilities and knitting once during the 360-degree revolution of the machine's cam-shaft. The vertical needle bars work back-to-back in line with the fabric being drawn downwards in the gap between them.

Guide bars are thus able to pass between needles in both beds as they swing from the front to the back of the machine and *vice-versa*. The guide bar lapping sequence involves overlapping and underlapping on each bar in turn so it is not possible to achieve the same actions simultaneously on both bars and the production rate is thus approximately halved.

Also, compared with single needle bar knitting, an extra or *triple swing* of the guide bars is necessary after each underlap in order to swing the guide bars over the needle bar that has completed knitting, so that the other needle bar can rise to commence its knitting cycle.

Double needle bar production is thus very much slower than single needle bar warp knitting, and basic double-faced fabrics knitted with two fully-threaded guide bars are heavier and more expensive than equivalent weft knitted double-bar fabrics. To compete, it is therefore necessary for warp knitted double needle bar products to exhibit unique properties.

Twice as many chain links will be required per complete cycle as compared with a single needle bar machine, with the first half of the links of each complete cycle being used for lapping on the front needle bar. When drawing a lapping notation, it is useful to indicate that every alternate horizontal row of points represents the front bed, either by lettering or by a heavier line of points or both. It may also be useful to space the rows in pairs, thus indicating each complete cycle on the two beds.

## 29.2 Double needle bar basic lapping principles

Using only one fully-threaded guide bar, overlapping on one bed only will produce a single-faced structure. Overlapping on both beds will produce a double-faced structure but this will only be cohesive if each guide overlaps at least two different needles in one of the beds during the repeat. To understand the appearance and properties of two-bar structures, it is necessary to consider the lapping movements that occur on each needle bed in isolation, as if produced by two separate guide bars.

Figure 29.1a illustrates a lapping movement which is unsatisfactory because the warp threads cannot hold the double-faced wales of loops together. Although the raschel lapping movement is 2-0,4-6/ the overlapping on the front bed is always 4-6, which is equivalent to a closed lap chain on each bed. Thus the wales cannot be held together in either bed.

Figure 29.1b illustrates the simplest lapping movement that can produce a cohesive structure. In this case the lapping movement is 2-4,4-6/4-2,2-0. On the front bed, upright loops are produced because an open lap pillar stitch notation 2-4/4-2 is lapped, whereas on the back bed the lapping movement is 4-6/2-0, which causes alternate courses to be inclined in opposite directions, but ensures that the wales are held cohesively together (Fig. 29.2).

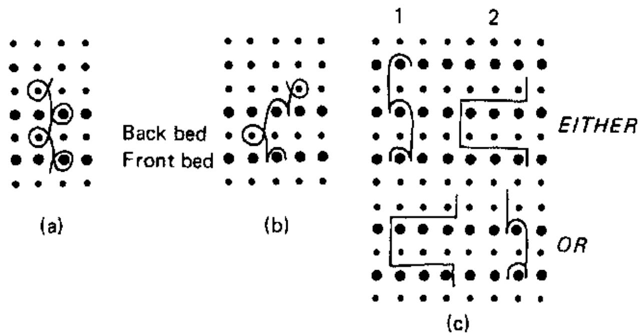


**Fig. 29.1** Double needle bar lapping notations.

## 29.3 Using two fully-threaded guide bars

If the front guide bar overlaps only the front needle bed and miss-laps on the back bed, and the back bar overlaps only the back bed and miss-laps on the front bed, two separate single-faced fabrics will be knitted back-to-back.

If the back bar overlaps only the front bed and the front bar overlaps only the back bed, the two separately knitted fabrics will be connected together by the crossing over of their underlaps.

A fabric of double-faced loops, each composed of a warp thread from each guide bar, is produced if both guide bars overlap both beds.

To understand inlay principles on two beds, it is best to consider each bed as a separate machine with its front (fabric draw-off) on the side remote from the hooks. With inlay, the guide bar nearest to the front overlaps and holds in place the inlay

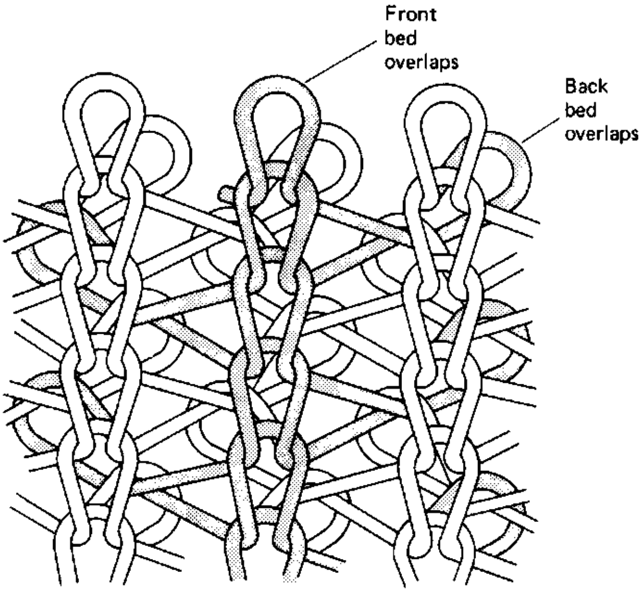


**Fig. 29.2** Loop diagram of double faced double needle bar fabric.

produced by the back guide bar. Thus, for the front bed, the back guide bar can overlap to hold the inlay of the front bar, whilst on the back bed, the front bar can overlap to hold the inlay of the back bar, but not *vice-versa* (Fig. 29.1c).

A double-faced net structure can be produced with two partly-threaded guide bars making a carefully arranged lapping movement so that every needle in both beds receives at least one overlapped thread at every knitting cycle.

## 29.4 The simplex machine

The *simplex* machine knits fine-gauge, high-quality, specialist double-faced fabrics at rather low rates of production. It was originally designed to knit simplex fabric in order to replace duplex glove fabric, which was composed of two single-faced fabrics stuck together back-to-back. It has two guide bars, which overlap and underlap each needle bar to knit plain types of fabric and simple mesh designs on standard lapping movements, usually controlled from pattern wheels. The gauge range is approximately E 28 to E 34, with E 32 being a popular gauge. Cotton glove fabric is still knitted in typical counts of NeB 80/1 to 90/1 but yarns as fine and as expensive as NeB 120/1 have been knitted.

Atlas lapping on a 48-cycle repeat is normally employed to hide count irregularities in the structure and improve the elastic recovery. To obtain the 65–75 per cent width-wise stretch required for glove fabric, the fabric is treated with a 30 per cent caustic soda solution during finishing. This causes an approximate 50 per cent width shrinkage, and it is followed by a mild raising process with emery-covered rollers in order to achieve a suede appearance. Stable print-base fabrics for dress wear are produced with simple repeat movements using 40-denier nylon. A cheaper, lighter-weight fabric may be produced from heavier yarns by causing each guide bar to knit only on one bed and inlay on the other, so that they hold each other together in the double-faced fabric.

Unlike in the tricot machine, the sinkers are not leaded at the front so they can be completely withdrawn from the needles. In order to bring the needle bars closer together, they have no profiled sinker belly and on the newer machines, no throat. The beds converge at an angle of less than 45 degrees. Landing is achieved by taking the needle bar downwards whilst still in contact with the presser which, in order to simplify machine movements, may be mounted on top of the sinker bar and move with it. On simple designs knitting high quality yarn, speeds of 300 courses per minute are possible on each needle bar.

Figure 29.3 shows the knitting action on the front needle bar; an identical sequence occurs afterwards on the back needle bar to complete the machine cycle.

(a) *First rise of the needle bar.* The knitting action has been completed on the back needle bar for the previous machine cycle. The front sinker/presser bar has withdrawn, leaving the back sinker bar to support the fabric. The guide bars have completed their third swinging movement so that they are now swinging towards the back of the machine, allowing the front needle bar to rise with the back needle bar still near to knock-over and thus helping to hold down the fabric. The front needle bar rises sufficiently to enable the old overlaps under the beards to slide down onto the needle stems.

(b) *Return swing, second rise then lowering and pressing.* As the guides swing to the back of the machine, the warp ends are wrapped over the needle beards. The front needle bar is now lifted to a higher position so that the new overlaps slip from the beards to a high position on the needle stems. As the front needle bar is lowered to cover the new overlaps, the front sinker presser bar moves to contact and press the beards so that the old overlaps slide onto the closed beards which descend through them.

(c) *Completion of landing and knock-over, underlap and third guide bar swing.* Whilst the needles descend further to knock-over the old overlaps, the guide bars make their underlap shog behind the front needle bar and then commence their swing towards the front of the machine to allow the back needle bar to rise for the second part of the machine sequence.

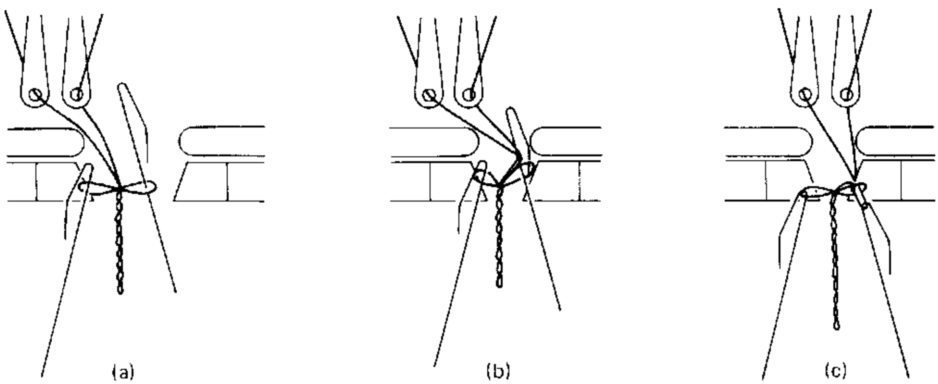


**Fig. 29.3** Knitting action of bearded needle simplex machine.

Simplex fabric is in demand as a result of its smooth surface, soft handle, elegant drape and extensibility, all of which make it suitable for moulded brassiere cups. To meet this demand with up-to-date technology, *Karl Mayer* have produced a double needle bar raschel with two latch needle bars and four guide bars that can knit the fabric at a maximum rate of 500 courses per minute on each needle bar in E 32 gauge and a width of 4318 mm (170 inches). Maximum stitch density is 32 stitches/cm. The machine can also knit ultra-fine spacer fabrics [1–3].

## 29.5 The double needle bar raschel

The double needle bar raschel, as designed by *Redgate*, later developed into a general-purpose machine, mainly knitting shawls and scarves. At first, the needle bars were arranged back-to-back alternately, as on rib weft knitting machines, but they were soon placed exactly behind each other for convenience of guide bar swinging. Between six and eight guide bars were employed, together with various attachments such as a fall-plate, a crepeing motion (which could disengage one needle bar for a pre-selected number of courses), a switching device for moving the guide bar push-rod from one track of the pattern chain to another, and simple weft inlay or insertion. The front needle bar could be replaced with a point bar for making plush and pile structures or removed altogether so that the back needle bar could knit single-faced fabrics driven by a new set of cams, which doubled its knitting speed.

Improvements in weft knitting and single-bed warp knitting machinery left the double needle bed raschel isolated as a slow, coarse-gauge and very cumbersome type of machine until comparatively recently. However, the arrangement of the elements and knitting action of the raschel is less complex than that of the simplex machine, thus offering greater possibilities for adaptation and modification in order to knit special structures at economical speeds, so it is in this direction that developments have occurred.

### 29.5.1 The conventional knitting action

On the conventional double needle bar machine, each needle bar in turn is active only for half of the 360 degrees of the knitting cycle. Holding-down sinkers are therefore unnecessary as the other needle bar is in the low inactive position and will restrain the fabric loops.

Figure 29.4 shows the knitting action on the front needle bar; a similar action occurs on the back needle bar (for simplicity, only one guide bar is illustrated).

(*a*) *The front needle bar rise.* The front needle bar is raised to clear the previous course of overlaps from the latches whilst the back needle bar holds the fabric loops.

(*b*) *The overlap.* The guide bar swings through between the needles to the front of the machine. It is shogged for the overlap and then swings back.

(*c*) *The knock-over and underlap*. As the needle bar descends to knock-over, the guide bar performs the underlap shog.

(*d*) *The third swing of the guide bar.* The guide bar now swings over the front needle bar in order to allow the back needle bar to rise and begin its knitting cycle.

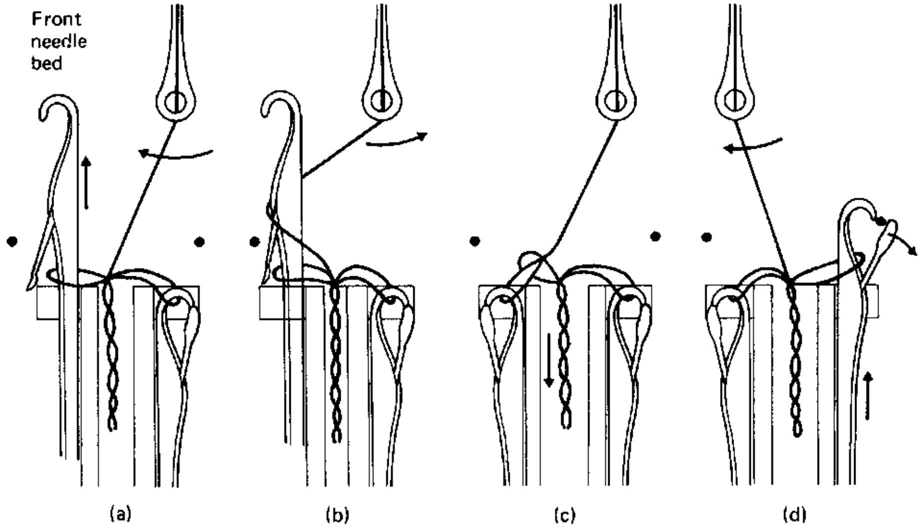


**Fig. 29.4** Knitting action of a double needle bar raschel.

In order to increase knitting speeds on modern machines, the 180-degree dwell period of each needle bar has either been reduced or eliminated. In the latter case, one needle bar is rising as the other is falling so that the two needle bars are almost continuously moving in opposition, thus effectively doubling the knitting speed. Some machines also have a counter needle bar motion so that the needle bars and trick-plates move towards the guide bars and thus reduce the guide bar swing. As the needle bar in these cases has only a short dwell period and sometimes separate fabric sections are being knitted on each needle bar, holding-down sinkers are necessary.

### 29.5.2 Double needle bar raschel products

In the past, double needle bar raschels of 24-gauge and coarser were used to knit fancy fabrics in woollen yarn for baby-wear, nightwear and knitwear. Two such structures were *rib* and *crepe*. In the former, certain needles were never overlapped, whereas the latter is actually a knop fabric produced by taking the back needle bar out of action for between two and four courses to hold its loops whilst the front bar continues to knit. Fabrics of this type have faced increasing competition from the improved design possibilities now offered by flat weft knitting machines.

Two other structures that occasionally achieve a limited success in underwear or outerwear are *waffle* fabric and *Brynje* string vest, both of which were originally developed in the early 1950s as thermal underwear fabrics for US forces serving in cold climates. Both are produced with two half-threaded guide bars although two other guide bars are often also used to produce the selvedge edges for making up. In 24 gauge, 22/1 NeB combed cotton would be a suitable yarn count.

*String vest* is a double-faced net structure with the underlaps hidden inside. Because it is a double needle bed fabric, the net openings are only half as large as the lapping movement representation.

*Waffle* fabric is a solid fabric composed of a series of open pockets alternately placed on both sides of the fabric. Each guide bar makes overlaps over two needles, which draws their two adjacent wales together thus leaving a gap between every two wales. Gaps on one side are opposite the two connected wales on the other. This arrangement would give the fabric the appearance of a $2 \times 2$ rib but after five courses, the lapping movement is changed causing the gaps and connected wales to change positions.

### 29.5.3 Length-sequenced articles

Some raschel double needle bed products are in the form of articles, a number of which can be simultaneously knitted side-by-side across the needle bed. These articles have a length repeat composed of sections of fabric where the lapping cycle of one or more of the guide bars has been altered. The sequence involves a pattern-change device for counting the number of repeat lapping cycles in each section and for initiating a changeover of guide bar push-rod control from scanning links in one chain track on to those in another track, in order to alter the lapping repeat for a particular guide bar. By this method, a guide bar may be controlled from a choice of two or more chain tracks, each having a short, simple repeat of chain links that may be used any number of times, instead of being controlled from one track of an excessively long and expensive chain containing links for every repeat cycle throughout the length of article.

The principle of '*pattern changing*' is used in the production of a scarf with knitted-in fringes on each end. Lapping for the scarf section is taken from one set of chain tracks and lapping for the fringe section from another. Each guide bar shogging lever may be controlled from either of two pattern chain drums; the upper drum chain tracks may produce the simple lapping repeat for the scarf section whilst the lapping for the fringe section is achieved by switching the shogging control to the chain tracks of the lower drum.

The scarf fabric is knitted as a continuous strip of double-faced fabric with the fringe sections composed of two-wale wide strips, each unconnected by underlaps to its neighbour. Each scarf piece is separated from the next by cutting through the centre of the fringe section and seaming the cut ends to secure them. The simple tricot lapping movement produces the width-wise elasticity required for scarves.

### 29.5.4 Tubular articles

A seamless tube of fabric may be knitted on a rectilinear double needle bed raschel in a similar manner to on a V-bed flat weft knitting machine. Each bed knits separate single-faced fabrics that are joined together only by underlaps of other partly-threaded guide bars between the beds at the two opposing selvedge needles at each edge. The underlaps may be arranged to be the same as for the needle beds, thus producing a seamless join to the fabric tube.

Figure 29.5 illustrates the basic principles using a base structure of single tricot lapping and four guide bars. The front bar laps only the front bed, the back bar laps only the back bed, and the two middle bars are threaded with only one thread to each complete one selvedge join.

In the first underlap movement towards the *right*, the warp threads will rotate anticlockwise by one needle space in producing the tube on the machine beds. Underlapping on the front bed will be towards the *right*. The right-hand selvedge

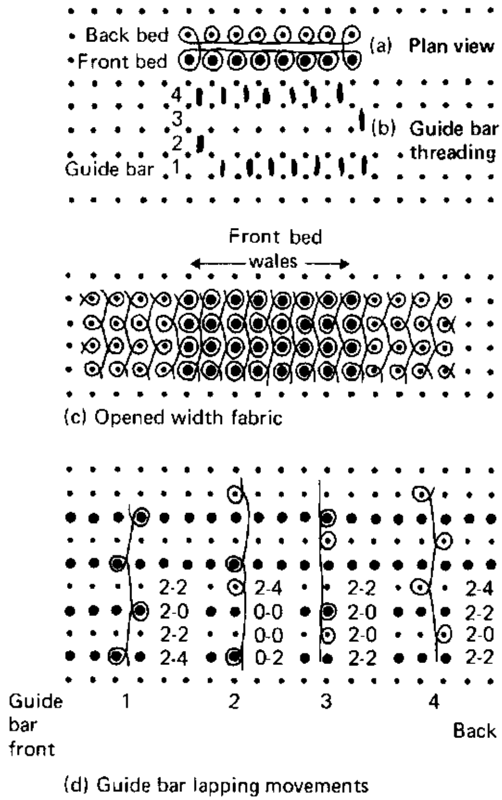


**Fig. 29.5** Lapping diagram and notation of a seamless tube knitted on a double needle bar raschel.

bar will underlap across from the front to the back bed. The back bar will underlap towards the *left* and the left-hand selvedge bar will underlap across from the back to the front bed. In the next underlap movement, the direction of lapping will be reversed for each of the guide bars, by a clockwise movement.

As one selvedge bar is always overlapping one needle in each bed, the threading of the front and back bars must be one less than the number of needles knitting the fabric in that bed. Two selvedge guide bars are required because when one is overlapping the front bed in a particular cycle, the other is overlapping the back bed.

Whilst knitting the tube, no guide bar must overlap on both the front and back beds during the same cycle, otherwise a single-thickness double-faced stitch is produced. If the base movement is a two-needle underlap, two selvedge threads will cross over the beds at each selvedge and each will require a separate guide bar. If the base movement was full tricot, a minimum of eight guide bars would be required, two for each bed and two for each selvedge. Inlay net or part-sett threaded net lapping movements may be used to produce tubes in a similar manner.

Some of the first tubular fabrics produced were for *vests* or for *fishnet stockings*, knitting eight to twelve tubes side by side. In 1967, the American *Kidde Cocker* company introduced the *Fashion Master* machine for knitting panty-hose and body stockings. By changing the lapping movement of an extra four bars that are lapping in the centre of the fabric, the large tube for the body portion can be divided into two smaller tubes with two of the bars joining two opposing needles across the needle beds for the inner selvedge of one leg, and the other two joining the adjacent needles for the other leg, thus knitting a bifurcated article. Graduating stiffening is achieved by infinitely-variable control of the fabric take-down and warp let-off, a shifting control moves the guide bar push-rods onto other chain tracks when required, and reinforcement is achieved by double-needle overlapping. For approximately two years, hosiery produced on these machines was highly popular.

The *Karl Mayer* HDR 16 EEW machine was introduced in 1970 for producing a range of simple garments such as seamless panties, brassieres and pocketings. The technique used, which has undergone continuous development, is to form the tube across the knitting width rather than down the wales. Although this causes the article in use to have its courses in a vertical direction, this is no major disadvantage and the possibilities for achieving simple shaping are considerably improved.

Figure 29.6 illustrates the production of a strip of briefs fabric; it is only necessary to cut through the centre of the connecting joins to separate each article from the next. These joins of short length are, in effect, knitted side seams, so the briefs are turned inside out after knitting to hide this seam. The first side seam is produced by guides lapping across between the two beds to form a solid double-faced fabric section. Guide bars inlaying on the left selvedge form the knitted-in waist band which is produced on each bed because the guide bars lap on the two needle beds separately in order to produce the waist opening on the left and the first leg opening on the right. Half-way through the courses for the sequence, the right selvedge needles are joined together for a number of courses to complete the first leg opening and close the crotch section of the brief. Single-bed fabric knitting then continues for the second leg after which the bars knit between the beds to form the second side seam and then commence the sequence for the next brief.

On a 75-inch (190 cm) wide machine, three brief fabric strips can be knitted side by side giving a production of 360 briefs per hour. It is possible to achieve a cotton terry effect on the inside if desired. Upper and lower pattern chain drums are employed to control the guide bar shogging levers and these drums may have a split drive and chain stop facilities to further economise on links and provide greater versatility in lapping movements. The double needle bar raschel in 12–16 gauge has proved particularly useful for the production of *packing sacks* for fruit and vegetables made from polyolefin in fibrillated tape or mono-filament form [4,5]. The base structure is usually a pillar stitch inlay that provides a secure non-slip construction (Fig. 29.7). The polyolefin sheets may, if necessary, be fed directly into the back of the machine where they are split into separate ends without the need for warping.

The sacks are knitted sideways at a rate of 250 courses per minute on each bed in a similar manner to the briefs. Their depth can thus be varied according to the number of needles knitting in each section. The two fabrics are joined together at the top and bottom to form the side seams and at one selvedge to form the bottom of the sack. At the open end, a draw-thread may be knitted into each side of the fabric and separation of the sacks from the continuous warp knitted strip is achieved afterwards with a hot wire.

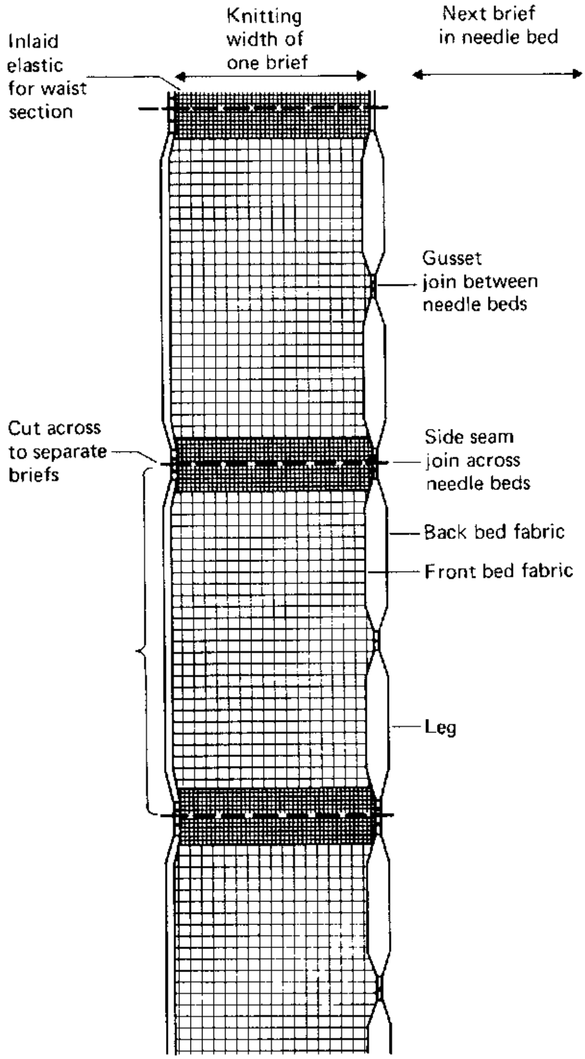


**Fig. 29.6** The principle of knitting tights on a double needle bar raschel.

### 29.5.5 Pile fabrics

There are two main groups of pile fabrics produced on double-bar raschels: cut pile and point pile. *Cut pile* is achieved by knitting a separate base fabric on each needle bed but joining the two together by the lapping movement of the pile, which is later slit to produce the two cut pile fabrics. *Point* or *looped pile* is produced by replacing the front bar needles by a point or pin bar around which the pile yarns are overlapped. For security, the pile yarn may be overlapped in the base fabric on the needle bar or it may be inlaid to economise on yarn and produce a lighter-weight fabric.

Cut pile fabrics are employed for a wide range of high pile end-uses such as simulated fur and skin fabrics, upholstery and coat linings. The *Karl Mayer* HDR 5PLM is designed specifically for this type of fabric. Its raschel gauges range from 18 to

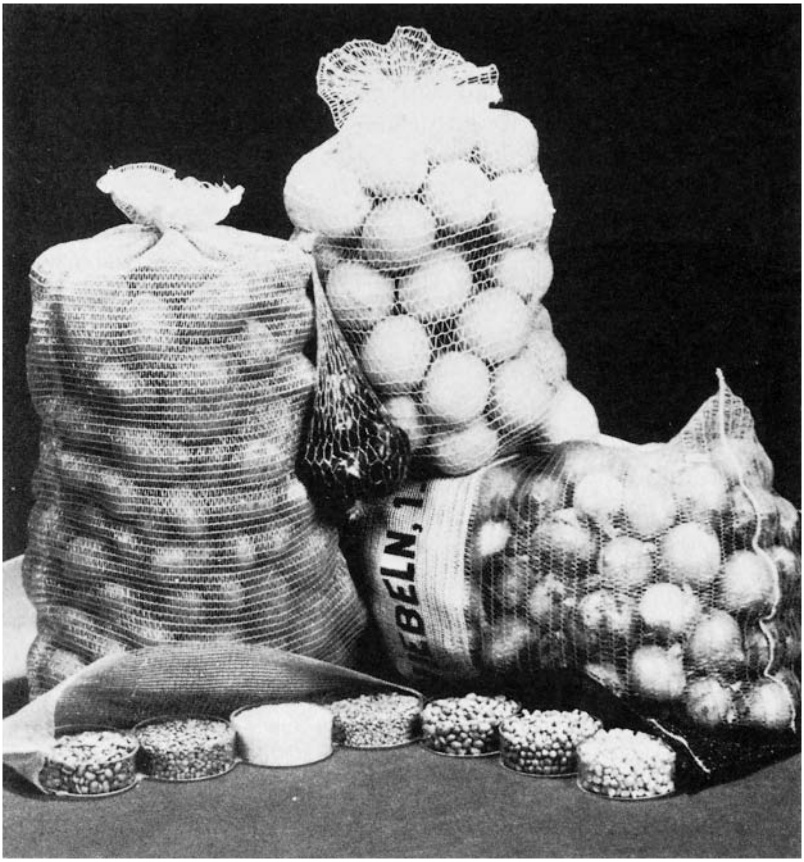

**Fig. 29.7** Fruit and vegetable sacks knitted on double needle bar raschel machines [Karl Mayer].

36, with 32 being most common, in widths of 75–180 inches (190–457 cm) and speeds of approximately 250–300 cpm per needle bar (five-times faster than weaving). The fabric made from polyester yarns weighs between 300 and 600 g/m$^2$ and is particularly used for automotive upholstery.

Each bed knits alternately and has a cam-shaft, needle bar, trick-plate, sinker bar and two guide bars with no swinging action. The needle bar and trick-plate swing through the two guide bars to produce the base structure on that particular needle bed. The middle (pile) guide bar has normal swinging facilities for lapping the pile alternately on each needle bed. As the pile is severed in the centre, its height is half the distance between the two trick-plates; this distance may be altered to give a range of pile heights between 2.5 and 30 mm.

Figure 29.8 shows a simple three guide bar construction and Fig. 29.9, a more popular construction using five guide bars. By lapping the pile yarn into two wales, any irregularity in the yarn is disguised.

The effect produced is determined by a combination of type of fibre, denier, lapping movement and finishing process sequences whose operations may include one or more of the following: raising, cropping, setting, dyeing or printing, and electro-polishing.

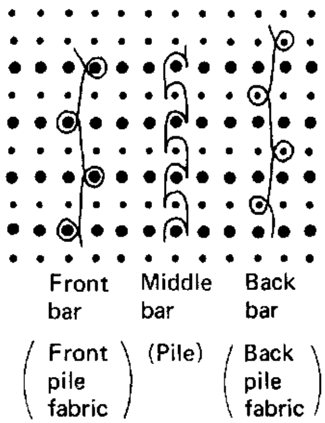


**Fig. 29.8** Notation for a three guide bar cut plush.

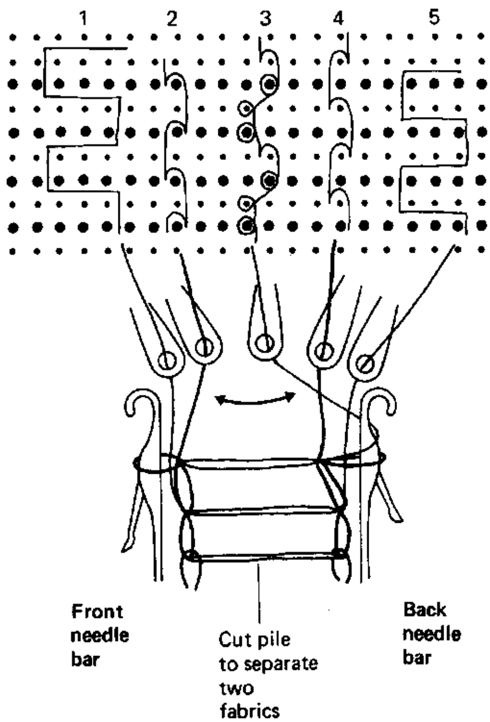


**Fig. 29.9** Notation for a five guide bar cut plush.

In point pile, the loops lie at right angles to the base fabric and on some machines the points are sharpened or contain rotating cutting blades for cutting the pile loops. The structures are particularly suitable for floor coverings and carpeting. On a five guide bar machine in 12 gauge, the front two bars might knit pillar stitches in opposition, threaded with spun polyester; the inlay might be supplied by 2/10 NeK spun polyester from the back bar; whilst the two middle bars might supply 5/400 denier textured polyester for the pile, overlapping the points and laying-in on the needle bar.

Using an eight-link-per-course cycle, the overlap for the points occurs between the first two links, the overlap for the pillar stitches on the needle bar occurs between the second two links, whilst the last four links allow the points and needles to descend for knock-over and for the underlap inlay on the back bar.

An unusual use is three guide bar structure for the artificial turf, *Astro-turf* [6], whose pile is composed of four, six or eight ends of 500 denier dope-dyed nylon ribbon on a nylon polyester knitted and inlaid base fabric.

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# 30

# Technical textiles

A *technical textile* is a textile that has been developed to meet the exacting specified high-performance requirements of a particular end-use other than conventional clothing and furnishings. In many cases, specially developed technical yarns are employed to support and reinforce the fabric properties [1].

## 30.1 Markets for technical textiles

According to Professor S. Anand of Bolton Institute, England, technical textiles account for approximately 21 per cent of all textiles. The main markets are: traditional industrial fabrics, for example, canvas, tents, etc. (43%); transportation and automotive (23%); leisure (12%); geotextiles (10%); medical textiles (10%); and protective apparel (2%).

Two-thirds of *automotive materials* go into 'interior trim' for seat covers, roof and door liners, and carpets, where woven fabrics still dominate [2]. Other uses include tyres, air bags and filters.

Although non-woven and woven fabrics account for the majority of technical textiles, warp knitted and, to a lesser extent, weft knitted structures have captured some special end-use markets. These are particularly where certain properties such as drapability, mouldability, knitting to shape, open-work, extensibility, strength, lightness of weight and cost are at a premium and can be tailored to requirements.

## 30.2 The properties of warp knitted structures

Warp knitting offers:

- Higher production rates than for weaving.
- A wide variety of fabric constructions.
- Large working widths.

- A low stress rate on the yarn that facilitates careful handling of fibres such as glass, aramide and carbon (particularly when using weft-insertion techniques).
- Conventional warp knitted structures that can be directionally structured.
- Three-dimensional structures that can be knitted on double needle bar raschels.
- With weft insertion, uni-axial, bi-axial, multi-axial and composite structures that can be manufactured on single needle bar raschels.

## 30.3 End-uses for technical textiles

Possible specific applications for technical textiles are as follows:

- *Geotextiles* – Drainage, filter, and membrane material, road and tunnel reinforcement, erosion protection.
- *Tarpaulins, coverings* – Air-inflated structures, tarpaulins, roof coverings, temperature-resistant sails, back-lit advertising signs.
- *Safety textiles* – Heat and flame-resistant protective clothing for civil and military purposes, fluorescent safety clothing, inflatable life rafts, bullet-proof vests, helmets, sun protection blinds, radiation protection, parachutes, oil trap mats. (Bullet-proof vest fabric can be knitted on a *Karl Mayer* E 18 raschel machine with a magazine weft insertion and three guide bars. The front bar is threaded with 80 dtex polyester guide bars and laps 1–0/2–3. The other two bars 'interweave' with the front bar using the evasion technique 00/11/00/22 and

**Fig. 30.1** EQT full-body competition swimsuit [Adidas].

00/22/00/11 (Chapter 27). These, together with the weft insertion mechanism, are threaded with 840 dtex aramid.
- *Industrial Textiles* – Filter fabrics, conveyor belts, adhesive tapes.
- *Medical Textiles* – Plasters, tapes, gauze, artificial arteries, bandages, dialysis filters, elastic net bandages, blankets and covers. (Small-diameter, single cylinder machines are ideal for weft knitting tubular stretch bandages from cotton yarn with inlaid elastic yarn [3]).
- *Composites* – Composites for buildings, aerospace, automobiles, boats.
- *Active Sportswear* – Clothing and equipment (Fig. 30.1).
- *Nets* – Fabrics for construction, agriculture, for safety, weather and pest protection, blinds, fences, storage nets, sacks, fish nets [4].

## 30.4 Geotextiles

*Geotextiles* are polymer fabrics used in the construction of roads, drains, harbour works, and breakwaters, and for land reclamation and many other civil engineering purposes (Fig. 30.2).

The geotextiles market requires bulk quantities of material. Warp-knitted weft-insertion geotextiles offer the following advantages when compared to woven geotextiles:

1 Strength-for-strength, they are lighter than woven geotextiles using the same yarn. This makes for easier handling and laying on site; thus transport and labour costs are less in real terms.
2 Knitted geotextiles have exceptional tear strength. Additional strength can be designed and built-in to the weft direction such that a bi-axial high tensile, high strength warp/weft geotextile becomes a reality; e.g. 500 k Nm warp and 500 k Nm weft.
3 Knitted geotextiles can incorporate an additional fabric to form a true composite geotextile, the fabric being simply knitted-in.
4 The individual yarns in the warp knitted weft-insertion geotextile are straight when incorporated, so they are able to take-up the strain immediately on loading. Those in woven geotextiles are interlaced [5,6].

## 30.5 Knitted wire

*Rhodius GmbH* of Bavaria specialise in the knitting of yarns or fibres composed of metal and of speciality material such as glass and aramid [7]. In the car industry, knitted wire components are used as filters in air-bag systems, as vibration dampeners, and for thermal insulation and noise reduction purposes. Knitted wire fabrics prove very efficient particularly in terms of elasticity, corrosion, thermal resistance and long service life.

## 30.6 The advantages of warp knitted nets

Warp knitted nets have knot-free joints giving greater strength and lower weights; extremely open fabric uses very little yarn; fabric density is adjustable and can be adjusted to the requirements of sunlight.

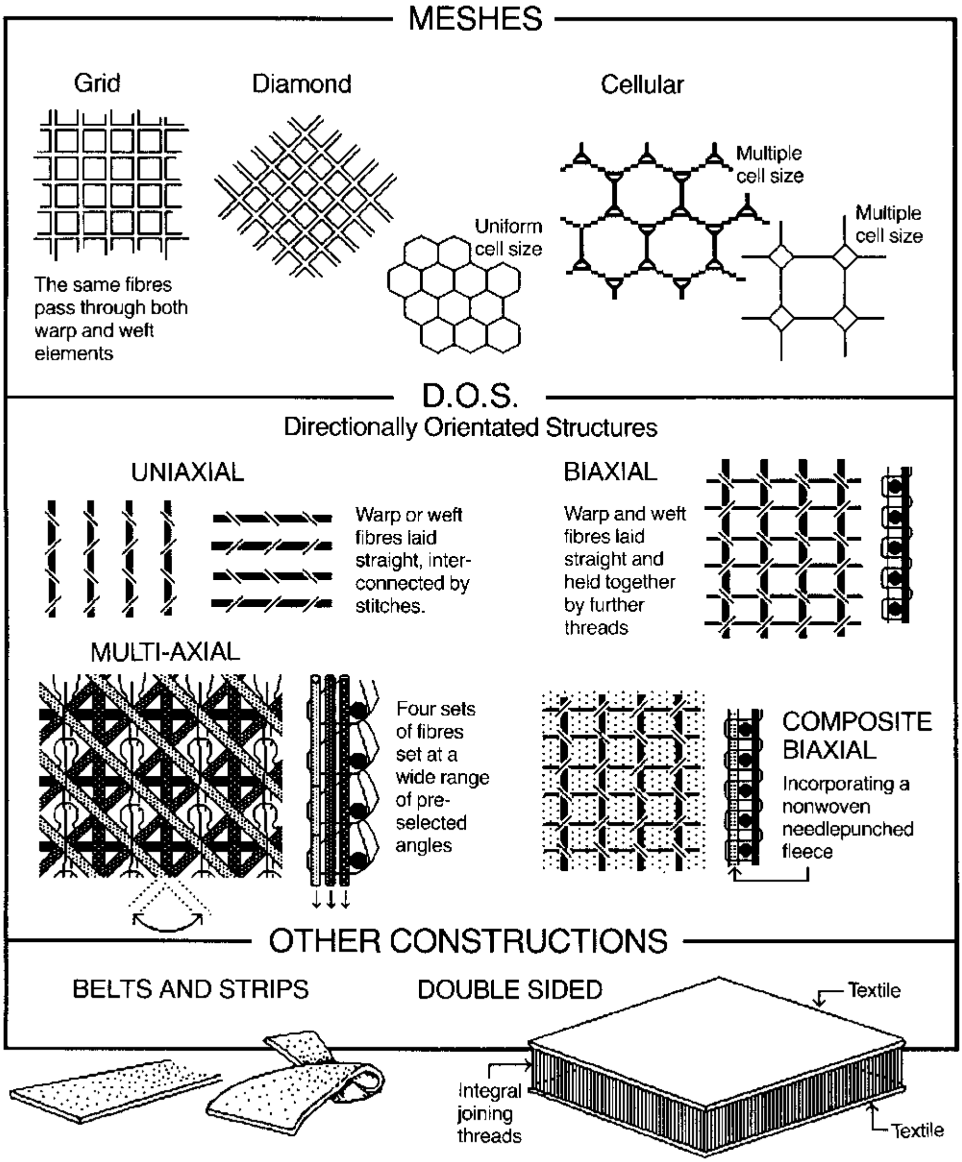


**Fig. 30.2** Directionally-structured fibre (DSF) geotextile constructions [*The Karl Mayer Guide to Geotextiles*, P R Ranilor and S Raz (1989), Karl Mayer, Germany].

Warp knitting technology is more versatile than any other fabric producing technique for manufacturing nets. Different sizes and shapes of net openings can be produced. They are dimensionally stable, slip-resistant, and do not require a stabilising finish.

*Karl Mayer* have an eight-guide bar raschel for knitting medium-weight nets in E 6 to E 9, in a yarn count range of dtex 3000 to 6000, at a speed of 400 to 500 courses per minute. It has six stitch-forming bars (4 ground, 2 selvedge, and 2 inlay guide bars).

## 30.7 Composites

*Composites* are products formed by combining two or more discrete physical phases, usually a solid matrix and a fibrous reinforcing material. The reinforcing component often consists of or is made up from high–tenacity fibres as the strain-resistant structure, and is surrounded by a polymer matrix that acts as a rigidising adhesive holding the fibrous component(s) in place.

Such composites are used for high-performance parts having low specific weight. One objective is to replace metallic materials. Fibres with high tenacity can be used simultaneously with low-stretch, high-modular filament yarns. These include glass fibres, carbon, and aramide. The strength of the composite is also determined by the position of the yarns and the angle at which they are inserted into the matrix.

## 30.8 Warp knitted multi-axial weft insertion fabrics

*Multi-axial layered fabrics* are structures fixed by a stitch system retaining the several parallel yarn layers (Fig. 30.3). The yarn layers may have different orientations, differing yarn densities of the individual layers, and may include fibre webs and fleeces, film tapes, foams, etc.

Due to the drawn and parallel yarn layers, multi-axial layered fabrics are particularly suitable for bonding by resinous or polymeric materials to produce fibre-polymer composites.

The *Liba Copcentra* tricot machine has a multi-axial, magazine weft-insertion. It has been developed to stitch bond composite fibre mats at high production rates. The feeding conveyor is approximately 15-metres long and is located at the back of the machine. Each creel-supplied yarn sheet layer is laid across or along the width of the conveyor at a specified angle. The continuous mat of yarn layers is conveyed

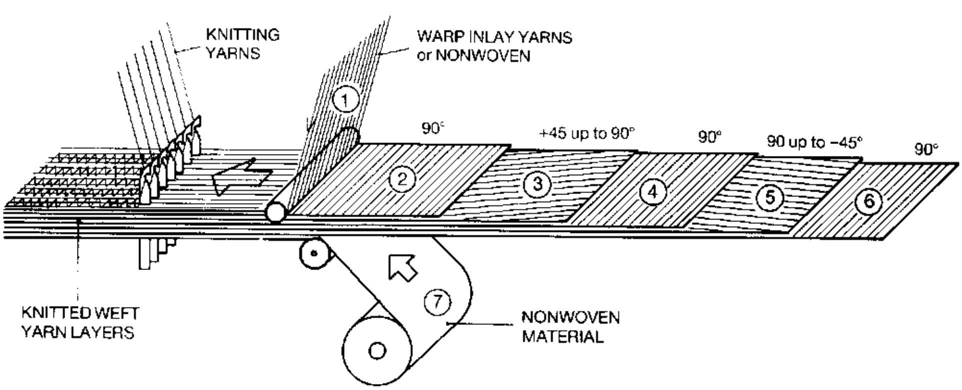


**Fig. 30.3** Principle of the LIBA multi-axial magazine weft insertion warp knitting machine. Up to 6 yarn layers and one fleece layer are possible [LIBA].

through the knitting machine where the compound needles, supplied with warp threads, stitch through and stabilise the structure.

The standard arrangement uses 5 weft-insertion systems of which 3 systems supply parallel weft and 2 systems supply diagonal weft. Each diagonal weft thread layer can be laid at any adjustable angle from 60–45 degrees (or 90–45 degrees on request). The density of each layer can be varied and is not dependent upon the gauge. Non-woven webs can be fed into the knitting zone above or below the yarn conveyor; two guide bars can be used for stitch forming. The machine has a working width up to 245 inches (622 cm) in a gauge range of E 6 to E 24, and has a production speed of 1200 courses per minute.

## 30.9 Stitch bonding or web knitting

Warp knitting machine builders *Karl Mayer* build a range of *Malimo* stitch bonding machines (Fig. 30.4) [8]. Whereas warp and weft knitting construct fabrics from yarns, stitch bonding constructs fabrics from a medium such as a fibrous web using purely mechanical means. It is therefore a highly-productive method of producing textile substrates for industrial end-uses.

Using horizontally-mounted compound needles, the medium can be pierced by the pointed needle heads, so it is ideal for the production of textile composites. It is stitch-bonded either right through the structure or only on one surface in order to stabilise it. Dependent upon the model, additional yarns or fibres may or may

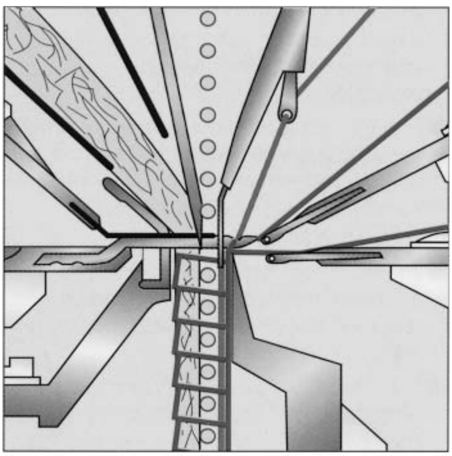


**Fig. 30.4** Malimo stitch bonding machine knitting head [Karl Mayer].

not be supplied to the needles. Yarn layers, webs, films or materials such as glass fibres, rockwool, or re-cycled products can be processed

*Malimo* web processing techniques include *Maliwatt*, *Malivlies*, *Kunit*, and *Multiknit*. The *Malimo* machines operate with one or two guide bars and offer parallel weft and multi-axial alternatives. Pile and fleece can be produced on the *Malipol* (pile yarn feed) and *Voltex* (pile web feed) machines.

The *Karl Mayer Maliwatt* stitch-bonding machine is a high-performance machine for plain stitch-bonding of loose or pre-bonded fibrous webs, as well as of substrates of various materials within a wide range of thicknesses and weights per unit area.

The advantage of mechanical bonding is that it occurs in a single process without the use of chemicals. The resultant fabric can be used in a moulded resin laminate for boats, cars and sports equipment.

A special version of the machine for processing fibreglass into a web has now been developed. The fibreglass is fed to a chopper behind the machine. This cuts the glass fibres into pre-determined lengths (25–100 mm). The chopped strands are randomly arranged in the form of a mat on a conveyor belt that feeds to the stitch forming area where they are bonded by means of a quilted seam. The mat is used to make reinforced plastic mouldings such as safety helmets and vehicle bodywork.

Working widths range from 2900 mm to 6150 mm and gauges from E 3.5 to E 22.

## 30.10 Spacer fabrics

A *spacer fabric* is a double-faced fabric knitted on a double needle bar machine. The distance between the two surfaces is retained after compression by the resilience of the pile yarn (usually mono-filament) that passes between them.

One reason for the development of spacer fabrics was an attempt to replace toxic, laminated-layer foam with a single, synthetic fibre type fabric, thus facilitating future re-cycling (Fig. 30.5).

Spacer fabrics are manufactured according to their function and have three variable components: fabric construction, yarn material and finishing. The hollow centre of the fabric may be filled with solid, liquid or gaseous materials (air can be used for insulation). Yarns with good moisture transportation properties may also be employed.

Partly-threaded guide bars can produce open-hole structures on each surface and air circulation can occur in the two millimetre space between the two surfaces. An important advantage is the low weight in proportion to the large volume.

The compression resistance can be adjusted by using different yarn counts in the rigid, synthetic mono-filament spacer yarns that connect the two surfaces of the fabric. Additional spacer yarns can be used where the choice of type of yarn determines properties such as moisture transport, absorbency, compression resistance, drapability, and thermal conductivity. The spacing can be up to 60 mm and widths up to 4400 mm. Fine fabrics knitted on E 32 raschels range in thickness between 1 and 4 mm.

End-uses for spacer fabrics include moulded bra cups, padding, and linings [9]. Medical applications are also being investigated [10].

**Fig. 30.5** Raschel-knitted spacer structure used for car seat covers of the Daihatsu Move 'Aero Down Custom' model. The front is formed as an openwork mesh structure and the back as a dense structure, so that the air circulates freely in the space between, and the driver and passengers are guaranteed an optimum microclimate [*Kettenwirk-Praxis* (3/99), 40].

## 30.11 Circular warp knitting

Tubular, seamless, extensible nets for fishnet patterned stockings, fruit sacks, and medical support bandages can be knitted on simple, small-diameter circular warp knitting machines. The vertical latch needles are fixed to the needle cylinder, collectively rising and falling with it. They are in a conical arrangement so the hooks form a smaller circle than the stems. The warp yarn is supplied through guide-eyes drilled in a ring. The ring turns to overlap the hooks when the needles are raised and produces underlaps at the back of the needles when they are lowered. For a simple balanced net, two full rings are used.

For more complex designs, up to 4 additional patterning rings may be employed. *Tritex* (Barwell, Leicester, UK) are supporting the development of a new prototype machine [11].

The rings can be cam-driven or electronically-controlled. At 80 per cent efficiency, approximately 100 metres of fabric will be knitted per hour. The stitch length is controlled by the positive warp let-off mechanism.

## 30.12 V-bed technical fabrics

In *v-bed weft knitting*, the *Stoll* approach emphasises made-to-measure quick prefabrication of complex two- or three-dimensionally shaped articles (Figures 30.6 and

**Fig. 30.6** Tube connection with rectangular cross-section [Stoll, from *Knitting Technique,* Vol. 13 (1991), 2, 124].

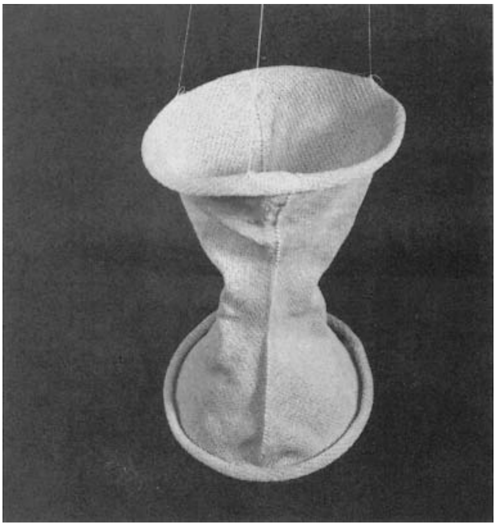

**Fig. 30.7** Funnel-shaped tube connection in Kevlar [Stoll, from *Knitting Technique*, Vol. 13 (1991), 1, 123].

30.7), including the knitting of a wide range of materials such as metals in fibre or filament form. Examples of end-uses include upholstery for office furniture, one-piece seat-heating circuits, helmets, catalytic converters, pressure tanks made of composite materials, and support bandages that are knitted to size and shape [12,13].

There is no doubt that when used as a type of reinforced material, weft knitted fabrics have their disadvantage in mechanical properties (low resistance and modulus) due to the loop construction used, but in cases where elasticity, flexibility and high energy absorption are required, weft knitted fabrics have their advantages.

Compared with other techniques that have been used for the production of 3D fabrics, the advantages of flat knitting are as follows:

- It is a flexible manufacturing process.
- The change of fabric structures and forms is very fast.
- The change of yarn types in the same structure is also possible.
- Possibility of knitting to shape without cutting waste or making-up time.
- Complicated shapes can be developed [14,15].

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