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# The development of 3D shaped knitted fabrics for technical purposes on a flat knitting machine

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The use of a new electronic flat knitting machine (Shima Seiki SES 122FF) for producing three-dimensional shaped fabrics for technical purposes is described. The three methods which can be applied to knit to shape, i.e. using different structural combinations, using different loop lengths, and altering the number of knitting needles and knitted courses, are discussed. Further, the different knitted elements (tubular forms, spherical forms, box forms and car seat covers) developed on the SES 122FF machine are described in detail.

**Keywords:** Flat knitting machine, Knitted fabrics, Loop structure, Technical textiles, Three-dimensional shaped knitted fabrics

## 1 Introduction

Technical textiles have been applied in different fields such as protection clothing, transportation related textiles (cars, planes and space crafts), geotextiles, building construction related textiles, packaging materials, military related textiles, medical textiles, sports related textiles, etc.

For many years, technical textiles were considered as very high-modulus fabrics, exhibiting extremely high structural stability and made of high-tenacity, low-elongation yarns. With the further development of new end uses, it has been realized that each technical product requires a different technical textile, with a different set of characteristics and some of these characteristics might be found in "loop based" structures.

Flat knitting machines are traditionally used for producing pullovers and other outerwear garments. One of the main advantages is the facility of these machines to knit fabric pieces to a particular shape or form. The combination of the individual needle selection technique and the use of the presser foot or holding down sinkers on the new generation of computer-controlled flat knitting machines increase this ability a great deal. By using the new flat knitting machines,it is possible not only to knit the new loop structures which are not possible on the conventional flat knitting machines, but also knit fully fashioned garments. This is very important to reduce the waste of expensive materials during cutting as well as in eliminating the additional making up operation. If the ability of knitting to shape of the flat knitting machines is used to produce 3D knitted technical textiles, it is not difficult to foresee their new end uses in the future.

This work describes the use of the new flat knitting machines to knit 3D structures by using different techniques in the Shima Seiki SES 122FF flat knitting machine. It is thought that these knitted shapes can be interesting as technical textiles and may also stimulate the imagination towards new applications.

## 2 Short Description of the Shima Seiki SES 122FF Flat Knitting Machine

The SES 122FF machine is one of the new generation of computer-controlled flat knitting machines. The main features of this machine are as follows:

- the double cam system for knitting and transfer facilities at each cam system in which 31 different stitch lengths can be set;
- the combination of holding down sinkers and presser foot is the machine facility which enables the knitting of fancy stitch effects and knit to shape;
- the belt drive system gives smooth and high-speed carriage travel which enables the yarn to be picked-up or not, as required;
- the set-up device and finely tuned take-down system for added take-down requirements; and
- the machine controller which is programmed for knitting and shaping from a micro compu-

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ter with floppy disc drive, and has a screen resolution of 1024 × 1024 pixels.

The major advantage of this machine is that it has overcome former restrictions in knitting design and shaping, thus enabling the development of 3D knitted structures for technical purposes.

## 3 Techniques for Knitting to Shape

On flat knitting machines, it is possible to use the following techniques for knitting to shape:

- —using different structural combinations;
- —using different loop lengths; and
- —altering the number of operating needles from course to course.

### 3.1 Using Different Structural Combinations

It is not difficult to reach the objective of knitting a 3D shape by using different loop structural combinations when knitting a technical course, because the different loop structures have different geometrical shapes under conditions in which the yarn counts and the loop lengths are the same. The new flat knitting machine can knit most weft-knitted structures, and so the combinations of different structures for knitting to shape are easily realised. However, it is necessary to bear in mind that this technique is not suitable in cases in which a technical product requires homogeneous properties in all parts, as the parts knitted with different structures present different properties.

### 3.2 Using Different Loop Lengths

Fabrics knitted with the same knitted structure but using different loop lengths have different geometrical dimensions. If one fabric is knitted with different loop lengths in different courses, shaping can take place. One simple example is circular jersey fabric knitting in separate needle beds. It is not difficult to change the circumference by changing the loop length from course to course. On the new flat knitting machines, the stitch cams can be automatically adjusted during knitting and so changing of loop length is very easy. It offers the facility of knitting to shape by changing loop lengths.

### 3.3 Altering the Number of Operating Needles from Course to Course

This technique is widely used in flat knitting for the production of fully fashioned panels. Two operations can be performed: increasing and decreasing the number of operating needles. On the new flat knitting machines, these two operations are very easily realised due to electronic single needle selection.

It is necessary to note that during the increasing (widening) or decreasing (narrowing) operations (Fig. 1), some needles are rendered inactive for a long time while retaining their loops. The tension applied to the fabric by the take-down rollers is, in this case, transferred solely to these needles, distorting the loops and subsequently breaking the yarn. For this reason, the use of the presser foot is necessary.

The presser foot (Fig. 2) is a metal wire which is securely fixed to the carriage by the presser foot mechanism, and moves across the machine with the carriage. During knitting, the presser foot precedes the needles which are rising. The wire

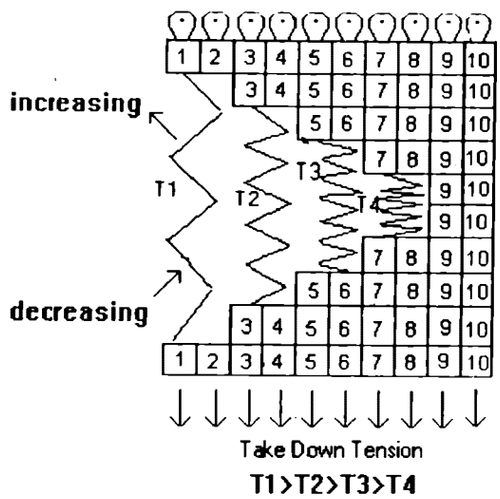



**Fig.1** - Fashioning operation: decreasing and increasing the number of knitting needles in one needle bed

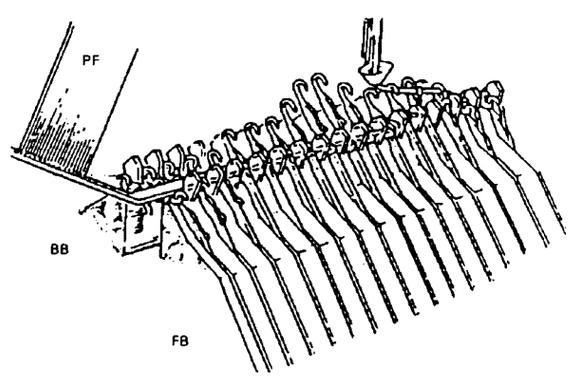



**Fig.2** - PF - Presser Foot
FB - Front needle bed
BB - Back needle bed

slides just underneath the crossing or intersecting opposing needles on both needle beds and presses against the stitch laying between the two needle beds. As a result of this the take-down tension given to the fabric by the take-down rollers becomes unnecessary.

The absence of take-down tension allows stitches to be held on idle needles which are temporarily inactive, while neighbouring needles continue to knit normally. This is just one of the requirements of knitting to shape.

When this method is used to knit three-dimensional structures, the main technique consists in transferring the three-dimensional form to two-dimensional patterns, because the fashioning operation (increasing or decreasing the number of knitting needles) is only determined according to two-dimensional patterns. The three-dimensional shaped knitted fabrics presented in this work are all knitted by using this technique.

## 4 Three-Dimensional Shaped Knitted Fabrics Developed on the Shima Seiki SES 122FF Machine

### 4.1 Tubular Forms

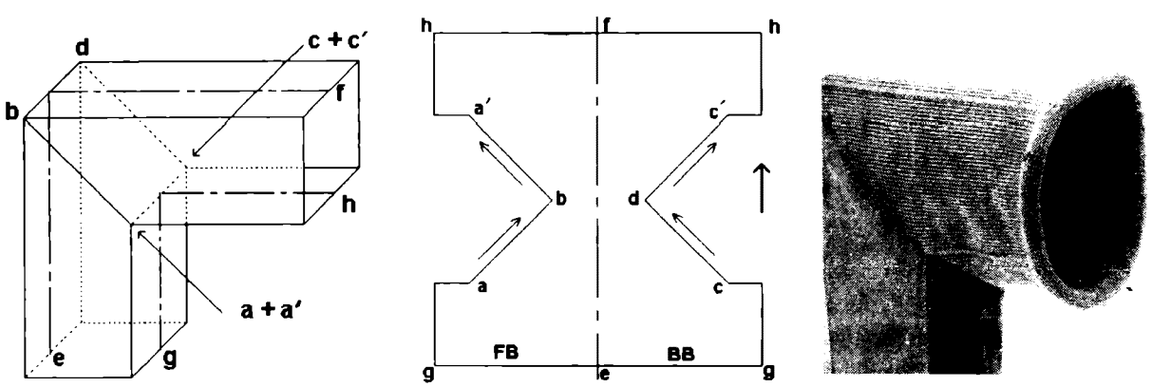
The tubular forms are knitted on both needle beds. When the number of operating needles in one bed is changed, a "knee" form is developed. The different tubular forms knitted on the SES 122FF flat knitting machine are shown in Figs 3-6. These types of structures can be used as tube connections for reinforcing purposes to enhance flexibility and strength, while preventing fatigue and cracking.

The tubular form in Fig. 3 is one version at right angle with the rectangular cross-section. The knitting operation for this, which is very similar to knitting a hose, is shown in Fig. 3(2). The ab and cd lines represent the operation of decreasing the number of operating needles, while ba′ and dc′ represent the operation of increasing the number of operating needles. During these operations, the needles which are temporarily inactive hold the stitch on them so that the decreasing and increasing lines become one connecting line after knitting. When the decreasing and increasing lines are at a 45° angle with the wales, a right angle is formed.

Fig. 4 shows another right angle tubular form but in this case with a circular cross-section. The radius $R$ of the "knee" can be chosen according to the application requirements. For knitting this form, first of all it is necessary to determine the decreasing and increasing knitting curvature [Fig. 4 (2)], i.e. establishing the relation between the number of operating needles and the number of consecutive knitted courses produced with those needles ($C$). This relation can be determined by the following equation:

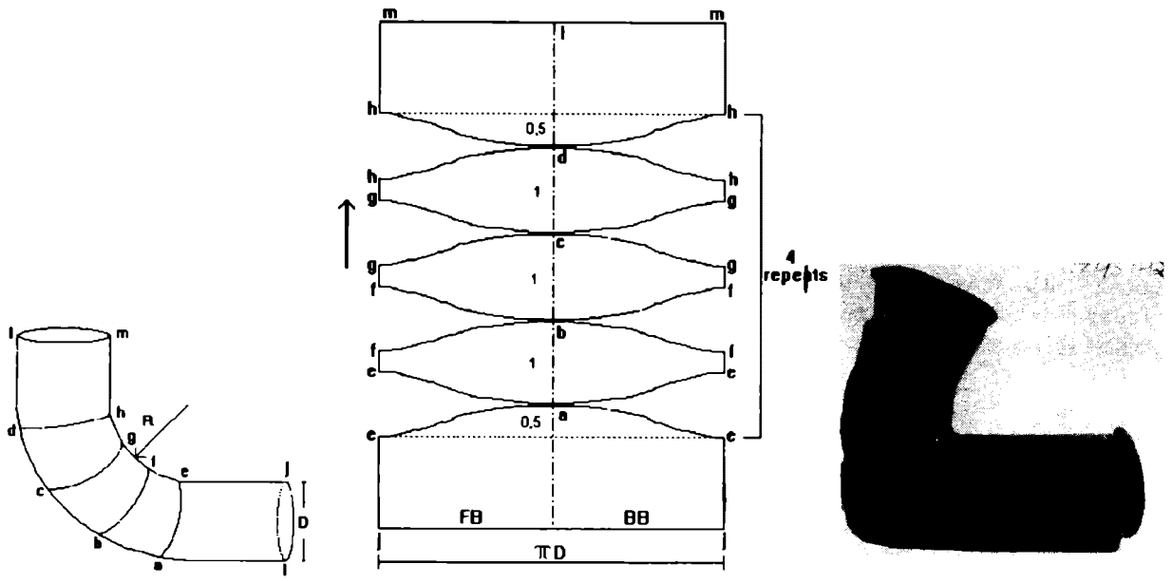
$$C=\frac{N[1-\cos(\pi n/N)]}{4aM} \qquad \ldots(1)$$

where $C$ is the number of knitted courses; $N$, the total number of active needles in one needle bed (depends on the required diameter of tube); $n$, the number of operating needles during an increasing (widening) or decreasing (narrowing) operation;



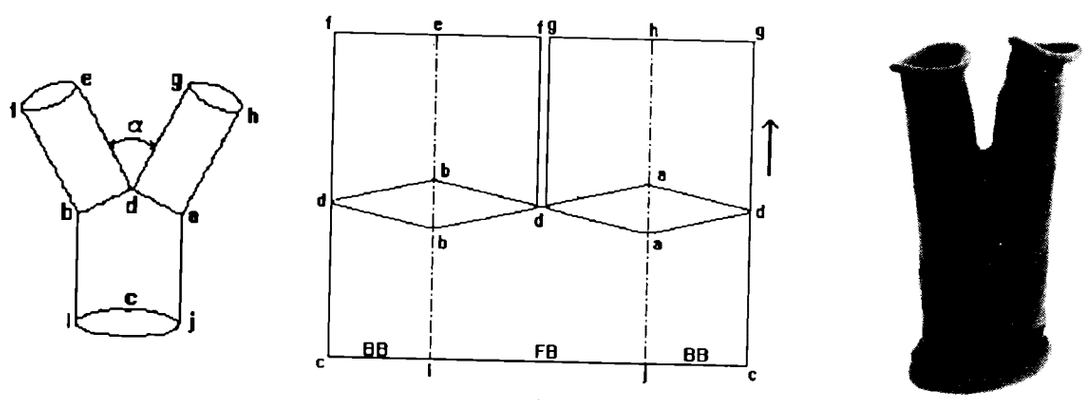

(1) 3D Theoretical Form (2) 2D Pattern (3) Knitted Fabric

**Fig.3** - Tubular form with rectangular cross-section
( ↑ - Take-down direction )
FB = front needle bed
BB = back needle bed




(1) 3D Theoretical Form (2) 2D Pattern (3) Knitted Fabric

**Fig.4** - Tubular form with circular cross-section




(1) 3D Theoretical Form (2) 2D Pattern (3) Knitted Fabric

**Fig.5** - Tubular form : one main tube connected to two smaller tubes

$M$, the number of increasing/decreasing repeats; and $\alpha$, the loop shape factor (Poisson ratio).

The tubular forms shown in Figs 5 and 6 have the required shape to connect one larger tube to two smaller ones in a "Y" shape. The angle $\alpha$ between the two smaller tubes can be changed according to the requirements. During knitting, the two smaller tubes are separately knitted with two cam systems.

#### 4.2 Spherical Forms

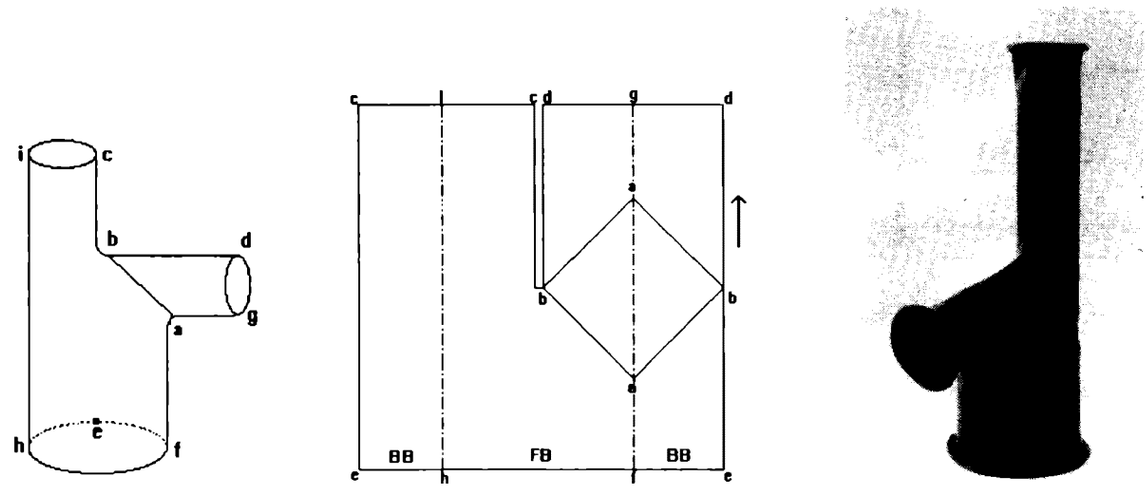
It is not difficult to knit a spherical form in the SES 122FF flat knitting machine. To knit a spherical form with a radius $R$, it is necessary to start by transferring the three-dimensional concept to a two-dimensional pattern, as shown in Fig. 7, and then establishing the relation between the number of operating needles and the number of knitted courses as follows:

$$C=\frac{N\sqrt{1-\sin^2(\pi n/N)}}{2\alpha M} \quad \ldots (2)$$

For knitting this type of article, a double knitted structure is normally used. In this case, it is possible to introduce a weft inlay thread to enhance the dimensional stability of the fabric.

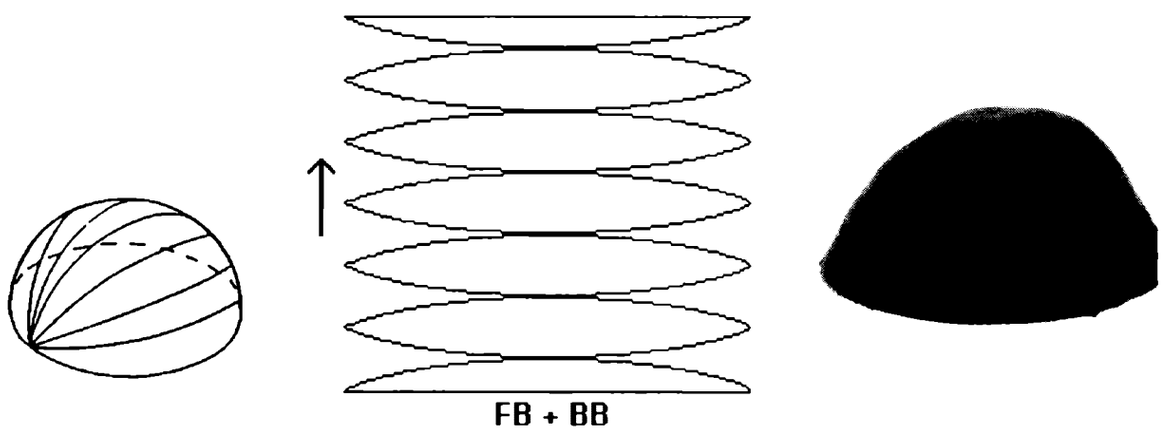
#### 4.3 Box Forms

The box form (Fig. 8) is another example of




(1) 3D Theoretical Form (2) 2D Pattern (3) Knitted Fabric

**Fig.6** - Tubular form : one main tube connected with two smaller tubes




(1) 3D Theoretical Form (2) 2D Pattern (3) Knitted Fabric

**Fig.7** - Spherical form

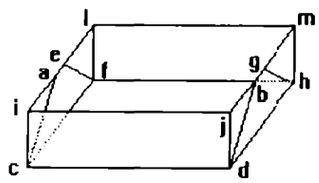
three-dimensional knitted fabric on the SES 122FF machine. As shown in Fig. 8(2), the increasing and decreasing lines are linear at 45° with the direction of knitting (wales direction). This type of form is also knitted with a double knitted structure introducing a weft inlay thread.

#### 4.4 Car Seat Covers

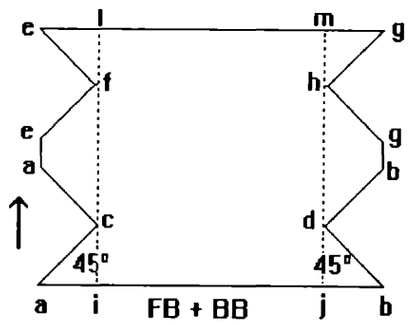
Knitted fabrics have been widely used in the automotive industry. At present, the most used knitted fabrics are circular weft knitted and warp knitted fabrics. In the last few years, however, the flat knitted fabrics have also been used for this purpose. The advantages of using the flat knitting machine to produce car seat covers are as follows:

- knitting directly the 3D shapes can overcome fabric waste and diminish the labour cost inherent to the use of two-dimensional fabrics which have to fit the variable geometry of a three-dimensional seat bum. Automation, despite several attempts, has not been as successfully applied to this sector as it has to others, using two-dimensional fabrics.
- the capability of electronic flat machines can be used to produce fabrics in greater structural and pattern variety than in any other type of knitting machine.

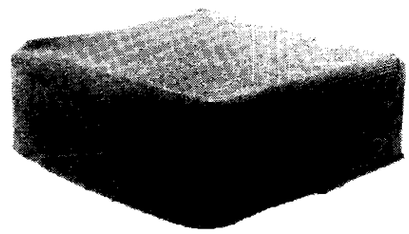
There are different types of seat covers. In order to knit a complete cover, the knitting process might be extremely complex. The conventional electronic flat knitting machines have difficulties in producing this type of fabric. For this reason, a simple form of car seat cover (head rest) developed on the SES 122FF is presented (Fig. 9).




(1) 3D Theoretical Form

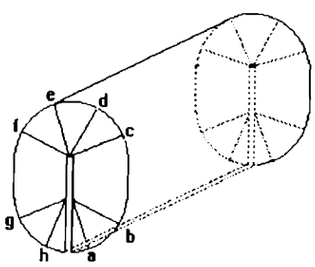



(2) 2D Pattern

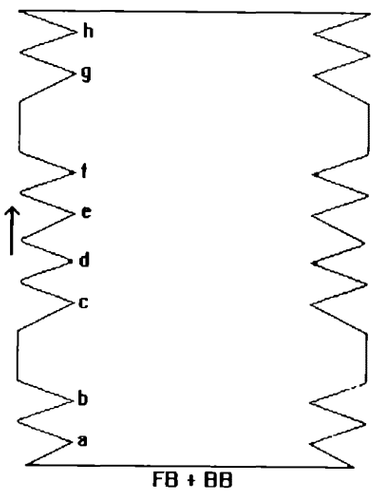


(3) Knitted Fabric

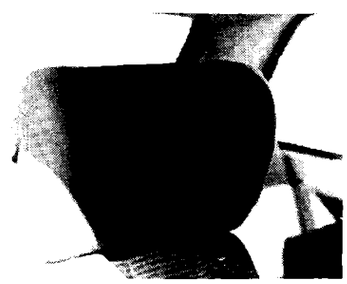
**Fig. 8** - Box form




(1) 3D Theoretical Form




(2) 2D Pattern



(3) Knitted Fabric

**Fig. 9** - Car seat cover (head rest)

## 5 Conclusions

The three-dimensional shaped knitted fabrics presented in this paper are only examples which have been developed on the SES 122FF flat knitting machine. By exploiting the capacity of this machine, it is possible to knit more types of three-dimensional knitted fabrics. The properties of fabrics knitted on the flat knitting machine are different from those of other types of textiles. Woven and multiaxial fabrics are stiffer than conventional weft knitted fabrics and so more suitable when high tenacity/low strain is required. If weft inlay threads are introduced, the stiffness of these fabrics can be increased at least in one direction.

If it is required to produce technical textiles (or parts) on flat knitting machines, the end-products should be able to exploit at least one specific advantage of the machine. For the production of large pieces of fabrics for technical textiles, weaving machine, warp knitting machines or even the circular knitting machines may be more suitable.

The flat knitting machine is more suitable for small shaped pieces and it is in this area that it will find its uses in the future.

## References

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