Chapter 2

LITERATURE REVIEW

2.1. INTRODUCTION:

Woven fabrics produced are mostly 2 dimensional (2D). However in actual use of fabrics, mostly they are required in 3D shapes, e.g. garments like trousers or a shirt are 3D forms. Thus the use also may be technical. Making-up is widely used method of producing 3D shapes from 2D woven fabrics. However this method has some limitations. Therefore other solutions are sought to overcome these limitations.

2.1.1 Limitations of producing 3D shapes from 2D woven fabrics by making-up:

Making-up is widely used technique of getting desired 3D shape from 2D woven fabrics. Making-up is advantageous (1) as it offers high flexibility in terms of materials and shape, reliability and performance of the shapes created, and seams can be a feature of style. This technology is simple and fully developed. But some debatable aspects related to making-up are high labor cost, quality deficiencies of visual and technical nature, a large number of potential sources of defects in lay planning, cutting and sewing, minimum cycle times due to high manual labour content and the ease with which the technology can be relocated. Reproducibility is also a major problem as human sensory system can give better reproducibility when job cycle time is minimum, which is difficult to achieve in real practice.

In making-up pattern breaks at seams and seam itself act as a thick line which may give discomfort or poor appearance in apparel application. The texture is also disturbed at the seams. For technical applications, seam act as a weaker place. Producing certain shapes satisfactorily, e.g. a convex shape is difficult.

2.1.2 Proposed solutions to over come drawbacks associated with conventional making-up :

Following solutions are proposed to over come drawbacks associated with conventional making-up.

2.1.2.1 Thermal molding:(1)

Molding systems are employed both in apparel sector (hats, bras and trousers) and in technical textiles (glass fiber reinforcement in composites. But the extent to which molding can be applied is limited. It cannot be employed to cotton and wool fabrics as break occurs at extension of 20 % to 30 %. Fabrics woven in glass, aramid and carbon fiber are virtually non-extensible. Molding comes against the obstacle of drape capacity, i.e. local thread displacement and compaction phenomena. The performance of set at molded sites is also questionable. Where a plastic matrix is not incorporated, shape-retainer coatings for the fabric are suggested.

2.1.2.2 Automation of making up:

Manual labour requirement in making up is very high. After lay planning and cutting, the product passes through several work stations requiring manual labour involvement. Manual labour is also involved in transporting goods from one work station to another. Therefore this method is not affordable, especially to high wage countries. Only option to make high wage countries competitive in this business is introducing automation at various stages of making up so that labour cost is reduced. With aid of computer technology, robotics, automatic transportation systems and intense research, attempts are being made currently to reduce manual labour requirement in making up (1). Alongwith saving in labour, distinct improvement in reproducibility of product may be expected. However this option in principle retains the seam and problems related with it as well as two-dimensional textiles.

2.1.2.3 3D Shape Weaving:

The third solution of shifting the task of shaping to weaving is a completely different approach. Developments in this direction were initiated in the beginning of the 20th century. In this a tubular double cloth is woven on a shuttle loom with jacquard shedding. As the weaving proceeds, ends are progressively eliminated from taking part in weaving. Weft is inserted in form of spiral. As ends are progressively eliminated, say along a curve, effective width of fabric goes on reducing. On opening such construction a 3D shape is formed. The shape so formed is free from seams but warp threads, which are eliminated, are to be cut subsequently. Some non-uniformity can be expected at this place. Many prototype machines were developed and could weave various 3D shapes like hats, radome fabrics, perform for helmets etc. However with introduction of shuttleless weaving machines, this technology passed in to oblivion.

A large variety of 3D woven textile structures (17) have become a part of technical textiles. They are produced to cater specific needs of the end products. Structures such as 3D woven performs, shape woven fabrics, unfoldable woven fabrics, circular woven fabrics, multilayer fabrics, double velour fabrics, multilayer circular woven fabrics, profiled woven layer fabric etc. Development of shape weaving basically began for its potential application in technical textiles.

In shape weaving desired seamless 3D shapes are directly woven on loom. The structure produced is seamless and there is no need of thread cutting. Development of weaving machine for shape weaving began in the beginning of 1990s at the Aachen University in Germany. Since then this technology is under continuous development. Radical changes are brought about in shedding, beat up, take up and other motions on a rapier weaving machine in which warp is fed through a creel. Jacquard shedding is employed to select interlacement in such a way that it assists shape formation. Many shapes are woven having application in aeronautical engineering, automotive engineering, apparels etc. Later shuttle weaving machines were also developed to develop unique tubular structures as well as seamless garments. Though shuttle-weaving technology is internationally considered as a 'Frozen Technology', it is the only picking system that gives continuous weft insertion. Therefore in weaving tubular structures or structures based on tubular structures, there is no other better option than shuttle weaving.

In this chapter literature concerning production of 3D shapes directly on weaving machine is reviewed.

2.2. Unfoldable type 3D shape weaving with progressive elimination of ends:

In his patent literature, H. Hill (2) describes the invention that relates to improvements in the manufacture of tubular woven fabrics for the foundations of incandescent mantles, more particularly of the inverted type in which one end is closed up in the process of manufacture.

In weaving these fabrics, the warp threads are disposed in two sheds, upper and lower, and the weft thread is carried through each alternately so as to form two distinct breadths of fabric, (i.e. a double cloth), which are connected at their edges by the weft thread so as to form a tube.

In order to form lengths of tube with closed ends of the shape required, the upper and lower breadths of fabric comprising the tube are connected on an approximately semi-circular line extending from one edge of the said fabric to the other, by moving certain of the warp threads as is required out of one shed into the other, so as to set up the necessary connections and thus form the semi- circular joining. When making a semi-circular joining such as described, the weft thread is only incorporated in that portion of the work which lies within the circular line of the joining, the warp threads outside that line being left free or floating. The result is that the weft thread is only carried to and fro within the line of the joining, the distance over which it is carried being gradually reduced until the joining is finished. Later the eliminated ends are cut. On unfolding tube, woven fabric for the foundations of incandescent mantles is obtained. (Figure 2.1)

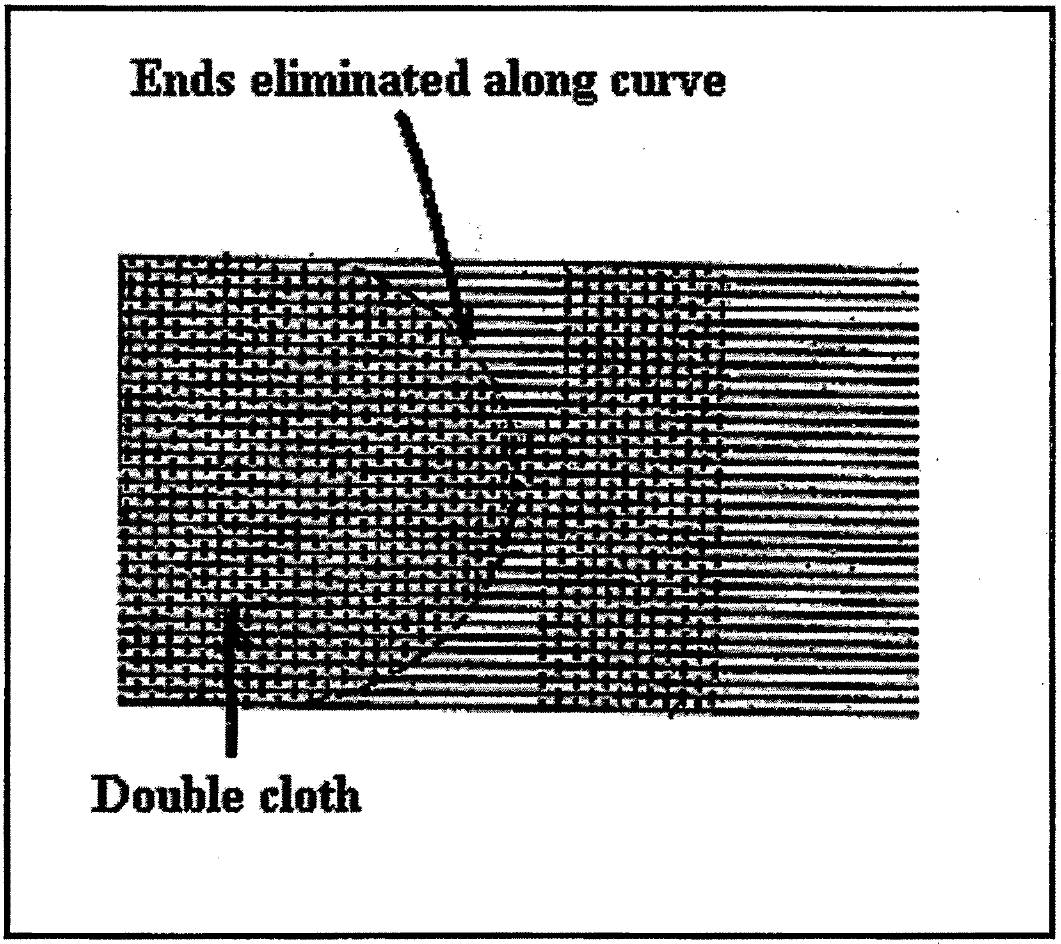

Figure 2.1

Patent of C. Lipper (3) is regarding method of making hats on loom directly without need of stitching. The principle employed is similar to that of H. Hill (2). The hat produced is claimed to have appearance similar to that made by hand but is manufactured continuously on loom one after the other. So cost of production is greatly reduced. The additional feature in this work is use of reed, like that of fan reed. The reed position is changed vertically during weaving so that fabric can be narrowed down or expanded. It is narrowed down while weaving crown of the hat so that warp threads are crowded. Top of the hat is closed by stitching double cloth. Figure 2.2 indicates principle of this work.

J. Felix in his patent (5) describes a loom for weaving non-cylindrical fabrics. This weaving machine can manufacture in a continuous run bodies or articles of hollow seamless non-cylindrical shapes or of non-uniform cross section. Lamp sheds (Figure 2.3), baskets, filters, strainers, endless inserts for reinforcing carcasses of vehicle tires in a shape according to the finished tire and certain articles of weaving apparel can be produced using this technique. Weaving is basically based on weaving of double cloth. Reed (Figure 2.4) is long like a fan reed, i.e. dents converge from one end to the other.

Other typical thing is that reed is non-planar so that its line of beat up is not straight like a usual reed but curved. Therefore weft is not beaten up at right angle to take up direction but curved depending upon shape. As reed is not planar it cannot guide shuttle during its flight. So a row of pins is provided to guide the shuttle during its flight through shed. Reed is moved vertically by a special mechanism so that ends are crowded or scattered, at the same time beat up curve also changes. Special catches are provided to give extra length of weft demanded due to expanding fabric.

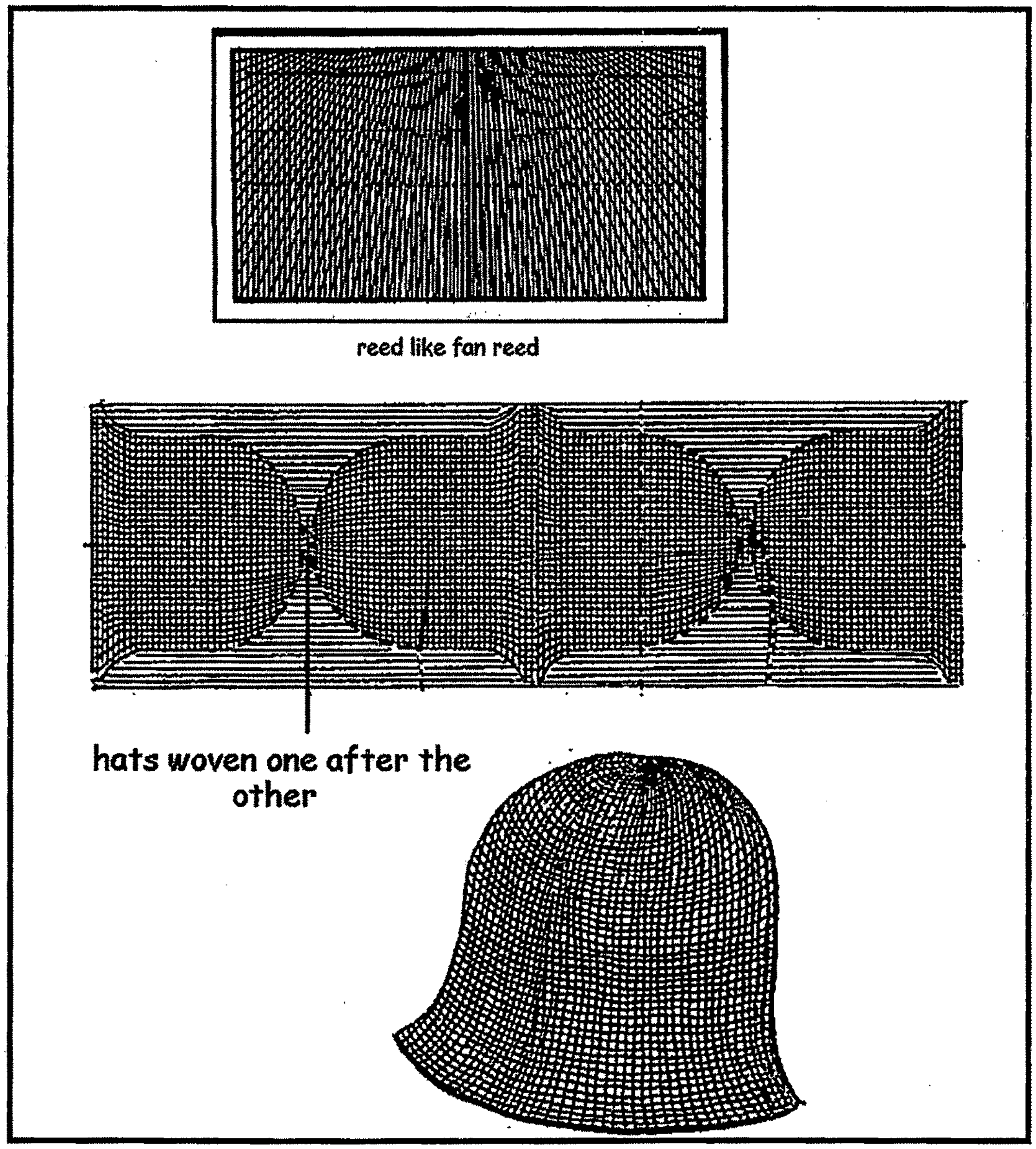

Figure 2.2

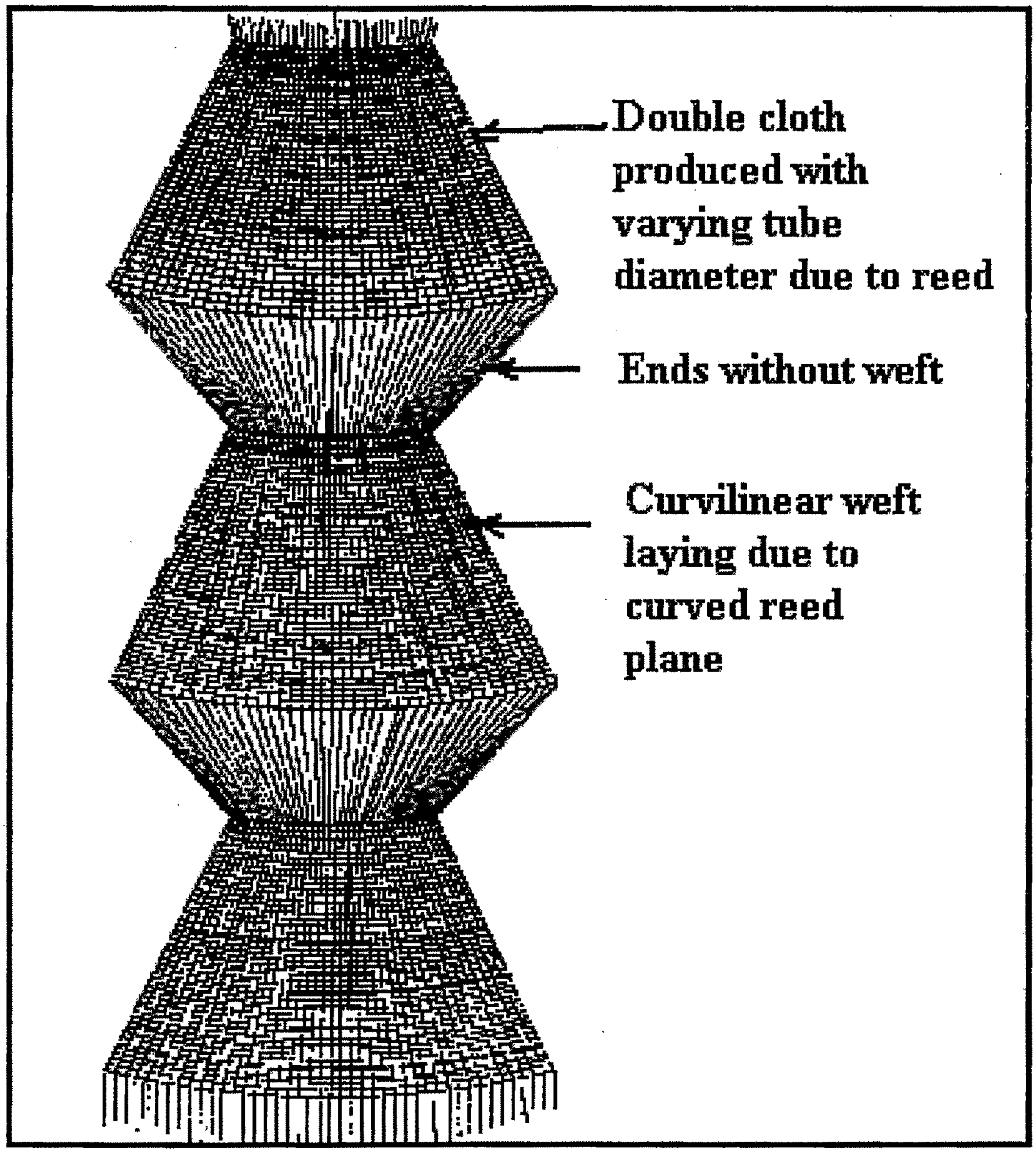
Double cloth produced with varying tube diameter due to reed
Ends without weft
Curvilinear weft laying due to curved reed plane

Figure 2.3

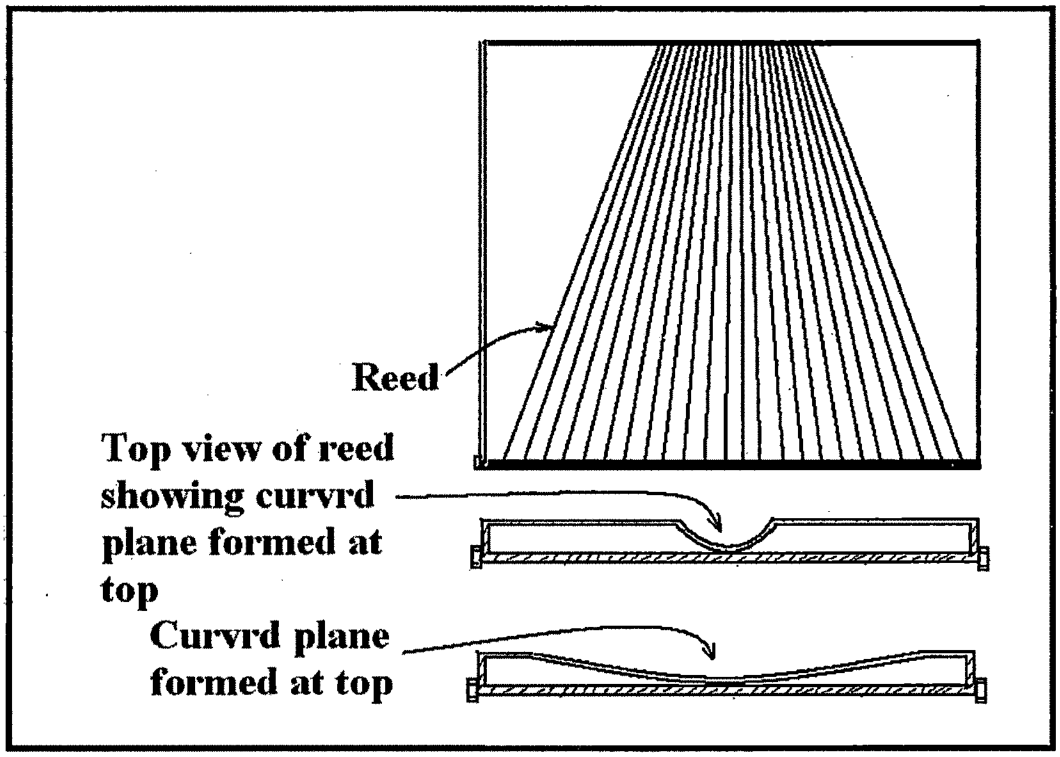
Reed
Top view of reed showing curvrd plane formed at top
Curvrd plane formed at top

Figure 2.4

E.Koppelman et al. (4) in their US Patent describes method of and apparatus for weaving shaped fabrics and articles woven thereby. The principle of shape generation is similar to patents described above but with many improved features. This invention produces shaped, woven fabrics which may be made to conform closely to any desired surface contour and to fit smoothly upon a shaped mandrel without cutting or skilled fitting operations and so are very advantageous in composite production. In this invention too, like previous methods, three-dimensional shape is woven in folded form on loom and warp threads are progressively eliminated.

A 3D shape may be developable or non-developable. A developable shape can be folded without any puckers, whereas a non-developable 3D shape forms puckers on folding. In most of prior methods, weft threads were straight. But if we consider weaving of a right circular cone, it can be appreciated that warp threads can weave straight, but weft threads must be curved during weaving the shape in folded form.

Figure 2.5 shows elevation of an object having a portion of ogive shape, illustrating one surface contour that may be readily fitted by fabrics woven.

Figure 2.6 shows plan view of a fabric according on flat on loom in collapsed state, but unfoldable to fit the shape shown in figure 2.5. In weaving situation is created such that weft shall follow a curved path at cloth fell instead of straight, according to 3D shape.

This is done in three ways:

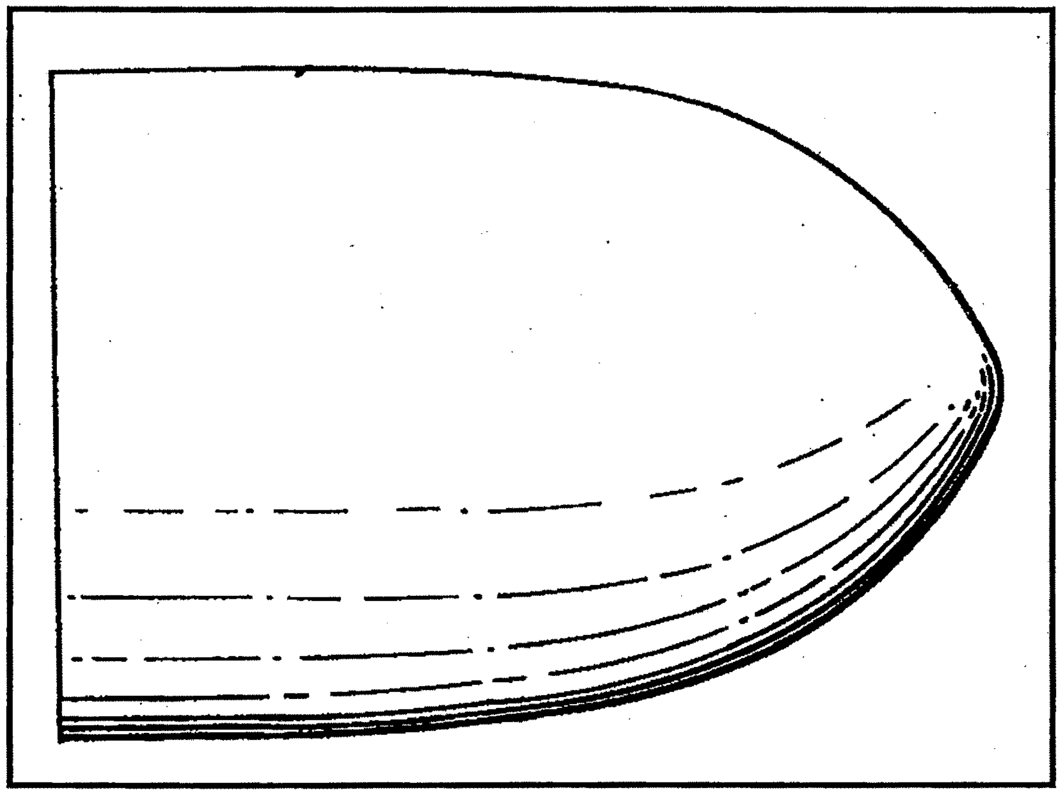

Figure 2.5

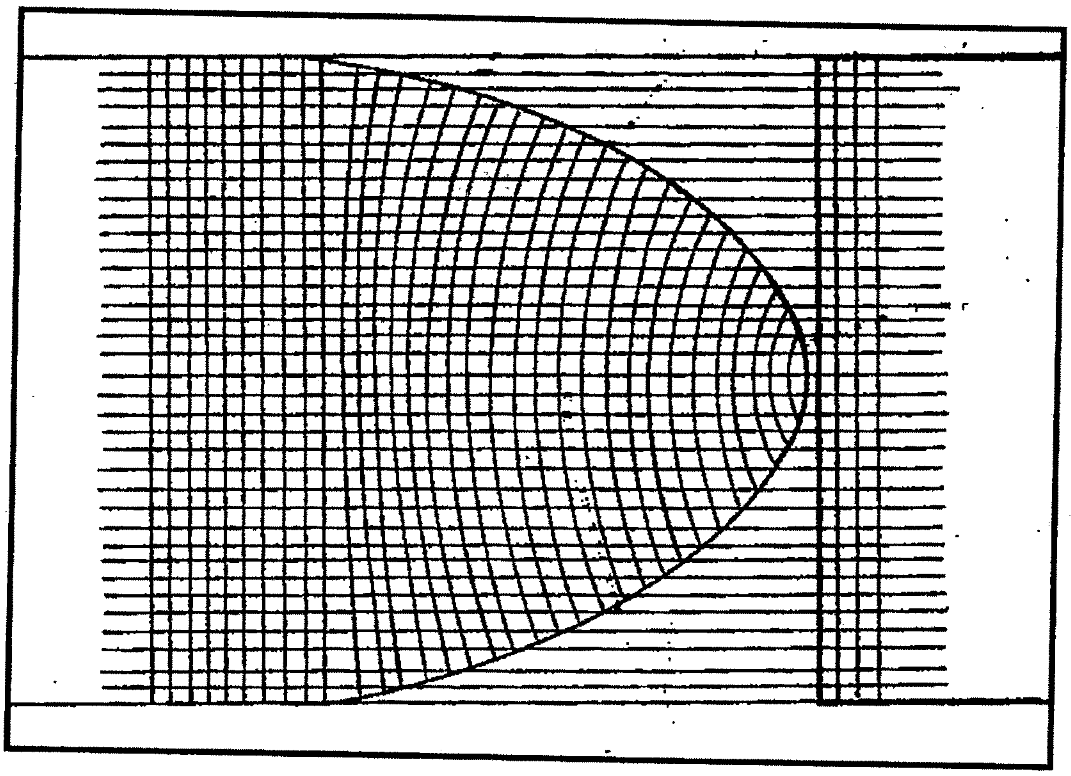

Figure 2.6

i. By providing cam shaped take up roll figure 2.7 that gives variation in feed rates of selected warp threads. The patent describes in detail the basis of designing the profile of this roller according to shape.

ii. By providing a modified form of conventional bent bar take up roll assembly (figure 2.8) which varies take up rates of warp threads as required.

iii. By providing reed with pivoted dents in which reed dents are swung on their pivot towards fell or away, on successive picks at beat up by means of a shaped back up roll. Due to reed with pivoted dents plane of individual dents changes which gives particular curvilinear position to successive picks. The shaped back up roll is to be designed according to shape. (Figure 2.9)

When picks are made to assume curvilinear position spacing between warp thread becomes non-uniform. To maintain uniform end spacing a novel fan reed with specially shaped dents is provided. Patent describes fundamental base of designing these elements according to 3D shape to be produced. Thus Koppelman's patent is a very significant development in producing desired 3D shapes. But this method is based on progressive elimination of ends so it does not produce a purely seamless structure but eliminated threads need to be cut and some irregularity will be present.

John A. McGrath, Walter A. Rheaume and Arthur R. Campman (6) have reviewed the weaving of three dimensional fabrics for the aerodynamic industry. They have described several developments in weaving related to the requirements of the aerospace industry including weaving of fabrics with 3D shapes or contours based on progressive elimination of ends and

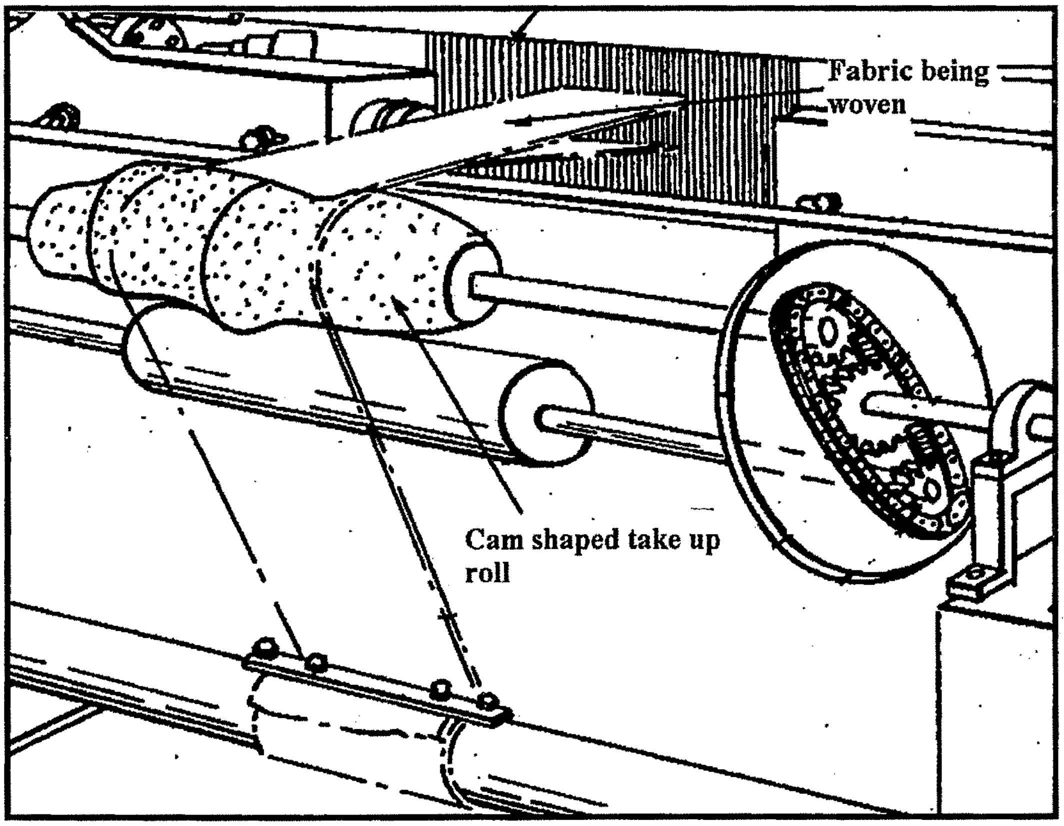

Figure 2.7

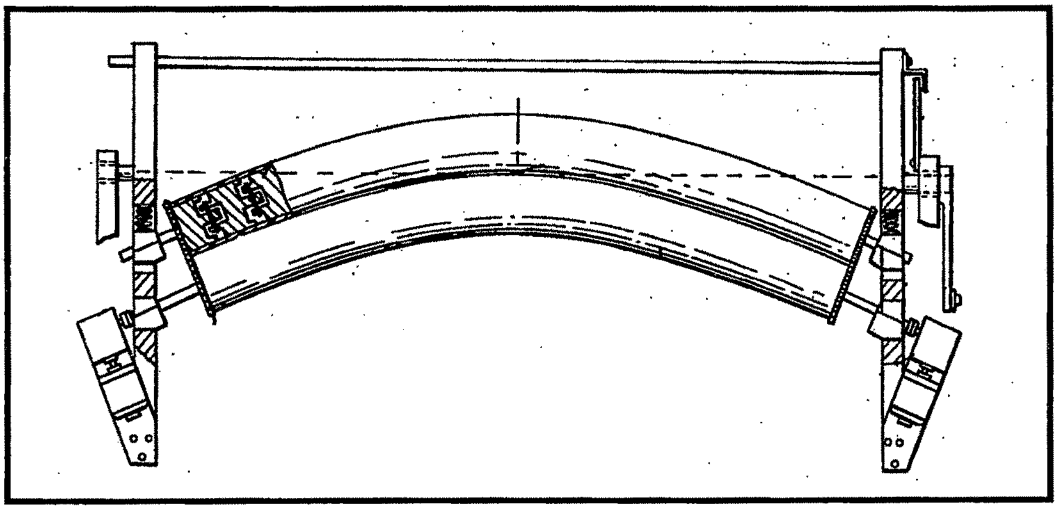

Figure 2.8

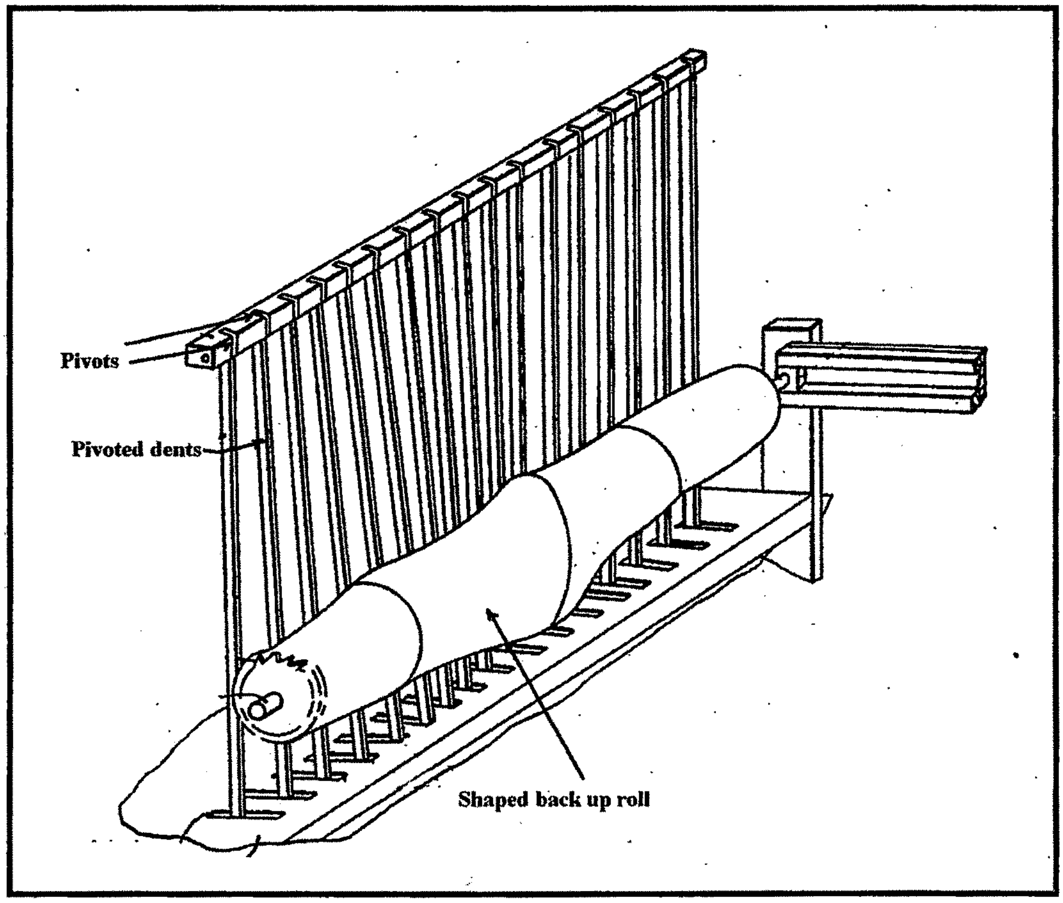

Figure 2.9

weaving 3D shape in folded form. Method of weaving a hemisphere, wedge shaped radome, arctic antenna cover; aircraft radome etc. has been described.

As the method described necessitates progressive elimination of ends, it is required to cut the eliminated ends. These cut ends protrude out and give irregularity to the profile.

2.3 Weaving machines producing seamless 3D shapes:

The weaving machines for producing required 3D shapes described so far are shuttle weaving machines in which 3D shapes are woven in folded form. Ends are progressively eliminated. Desired 3D shape is obtained by unfolding the shape and it is necessary to cut the eliminated ends. Developments further include even rapier weaving machines; developed to produce desired seamless 3D shapes in which shape is produced in unfolded form without need of eliminating ends.

Fleury et al. (7) in their patent an apparatus for weaving spheriodially contoured fabric on a needle rapier weaving machine which is used in the formation of shims for spherically shaped rocket nozzle parts, in the construction of parabolic antennae and bases for radar domes made of resin or like woven from high performance fibers like carbon which are difficult to weave. Here fabric woven is not planar, i.e. 2D, but has contour of that of a sphere (Figure 2.10). Thus this development is basically aimed at catering specific need of technical textile. Warp yarns are supplied from creel. Taking up of cloth is done by a shaped mandrel (Figure 2.11). Therefore take up rate of ends take place at different rate.

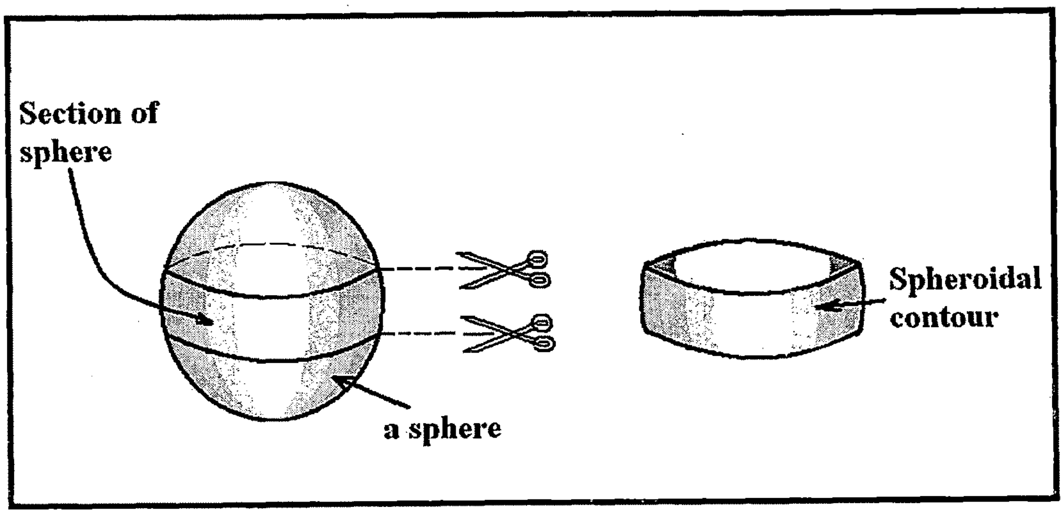

Figure 2.10

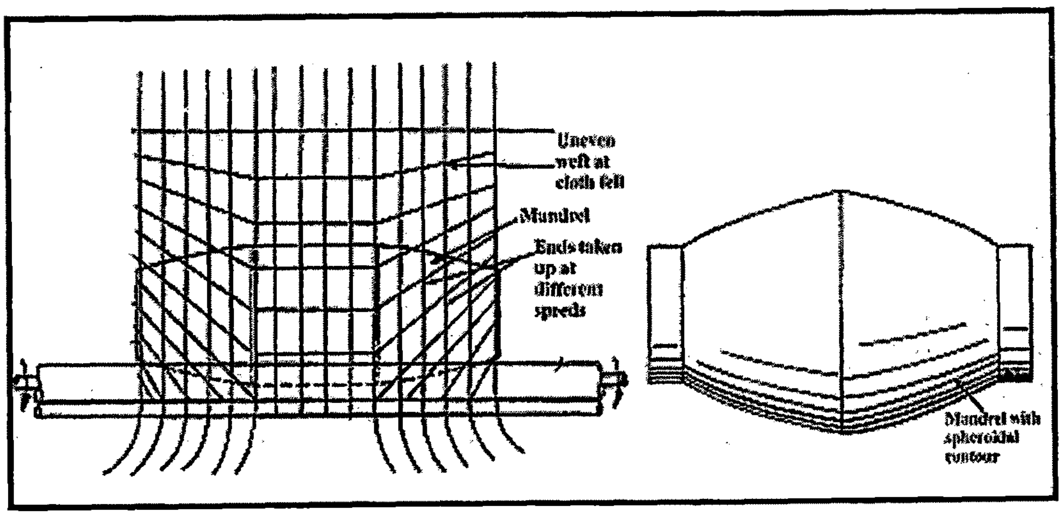

Figure 2.11

The profile of mandrel is designed in such a way that take up over it would form the fabric having a spheriodal contour. The development also includes a set of profiled members in the form of curved bars (Figure 2.12). These bars create differential lengths of ends taken up between beat up point and nip rolls. The combination of mandrel and curved bars produces a spheriodially contoured fabric without need for thread cutting..

Here warp yarns in the finished fabric will be in the positions corresponding to latitudinal lines on a sphere and will be at equal distance from each other. Weft yarns on the other hand, will correspond to longitudinal lines on the sphere and will converge toward the pole of the sphere. Therefore yarn density increases towards the poles.

At the start of the 1990s very development of a weaving machine began at the Aachen University in Germany that would permit three-dimensional hollow shells to be woven without seam and without the need for thread cutting (1). A pioneering systematic fundamental detailed approach was followed and developed for producing any desired 3D woven shape. Subsequently a company 'Shape3 Innovative Textiltechnik GmbH" was established in Wuppertal in Germany which developed a prototype rapier weaving machine for weaving 3D shapes. Since then the development has been going on continuously and many interesting new applications of this technology are developed. Prof. Dr. Alexander Buesgen of this company has played a key role in these developments and has several patents to his credit. For developing products, which are based on tubular construction, shuttle loom is employed as continuous weft insertion is possible only in shuttle weaving.

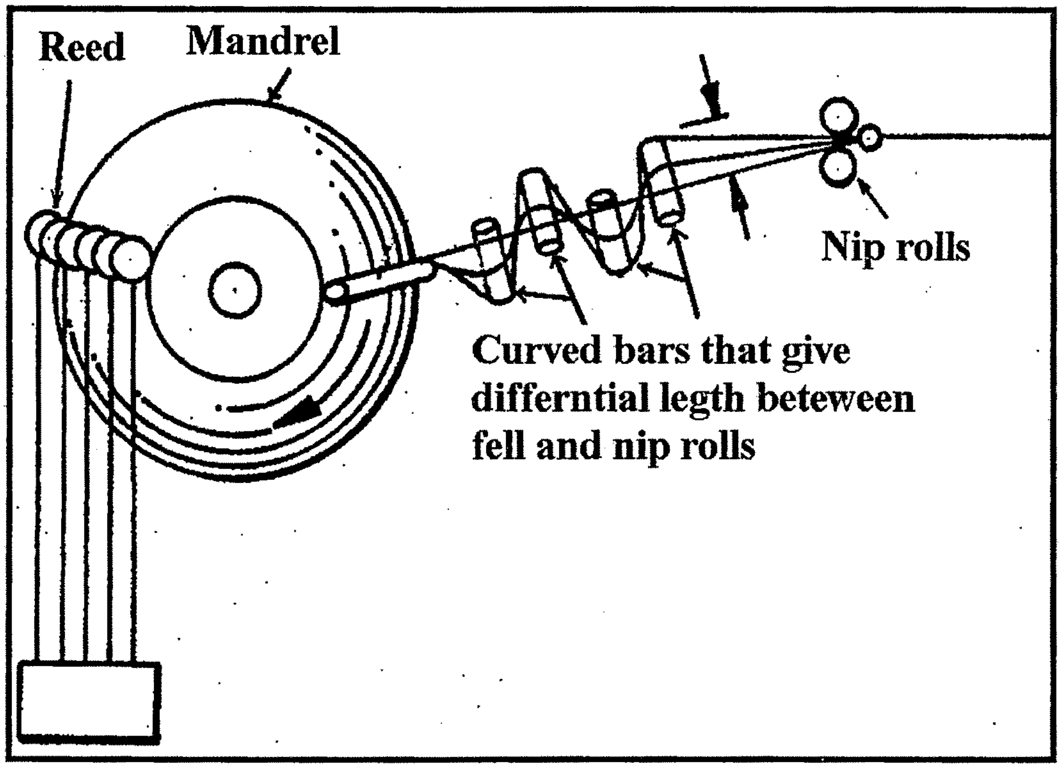
Reed
Mandrel
Nip rolls
Curved bars that give
differntial legth beteween
fell and nip rolls

Figure 2.12

2.3.1 A rapier loom for producing directly 3D seamless woven shapes:

Several patents [(8), (9), (10), (11)] describe the technology of weaving desired seamless 3D shapes on a rapier weaving machine.

2.3.1.1 Rapier weaving machine producing 3D shapes by changing spacing of warp and weft threads:

Buesgen's German patent (8) describes development on a rapier weaving machine to produce 3D shapes. Figure 2.13 shows a weaving machine with elements necessary for producing 3 dimensional shapes. As shown in figure warp threads are supplied from creel individually, passes through individual tensioning system which maintains desired tension, then passes though warp positioning system whose function is to expand or contract space between mail eyes according space changed by reed so that warp threads remain parallel between mail eyes and reed dents, the fabric at fell is taken up by a segmented take up that pulls warp at differential rate. Weft is inserted by rapier. Combination of reed and segmented take up forms 3D shape. The shape is realized after fabric leaves segmented take up. Figure 2.14 shows photograph of the machine weaving seamless 3D hollow shells (18).

Two approaches for 3D shape weaving are adopted. In first case modification in reed and take up brings about change in spacing of ends and picks to develop desired shape.

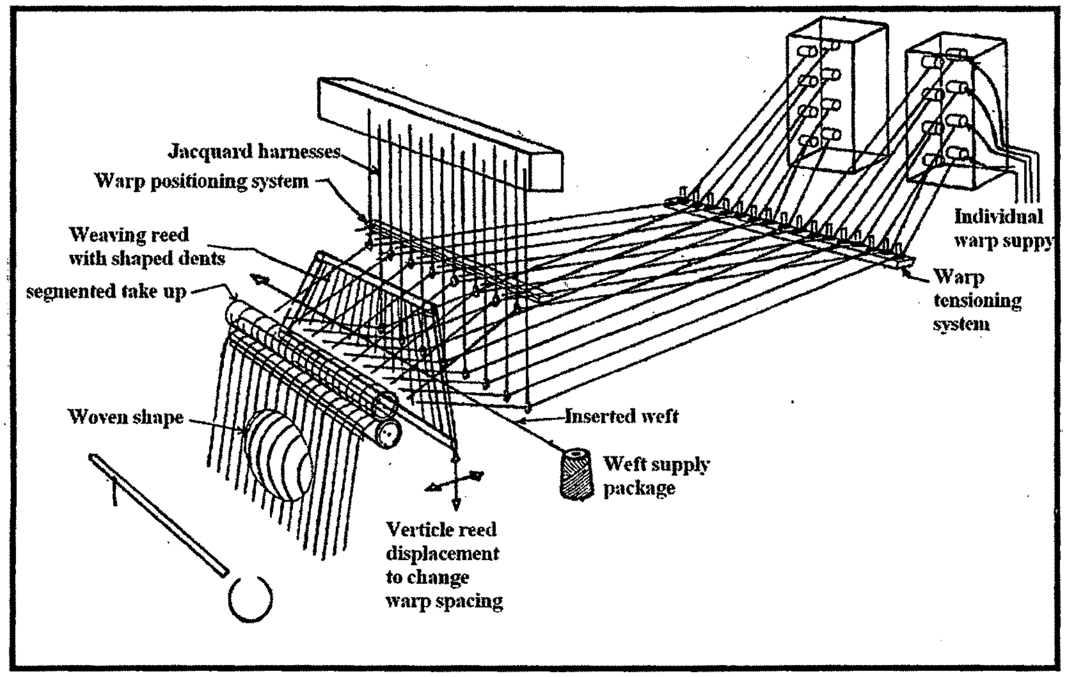
Jacquard harnesses
Warp positioning system
Weaving reed
with shaped dents
segmented take up
Woven shape
Inserted weft
Weft supply
package
Verticle reed
displacement
to change
warp spacing
Individual
warp suppy
Warp
tensioning
system

Figure 2.13

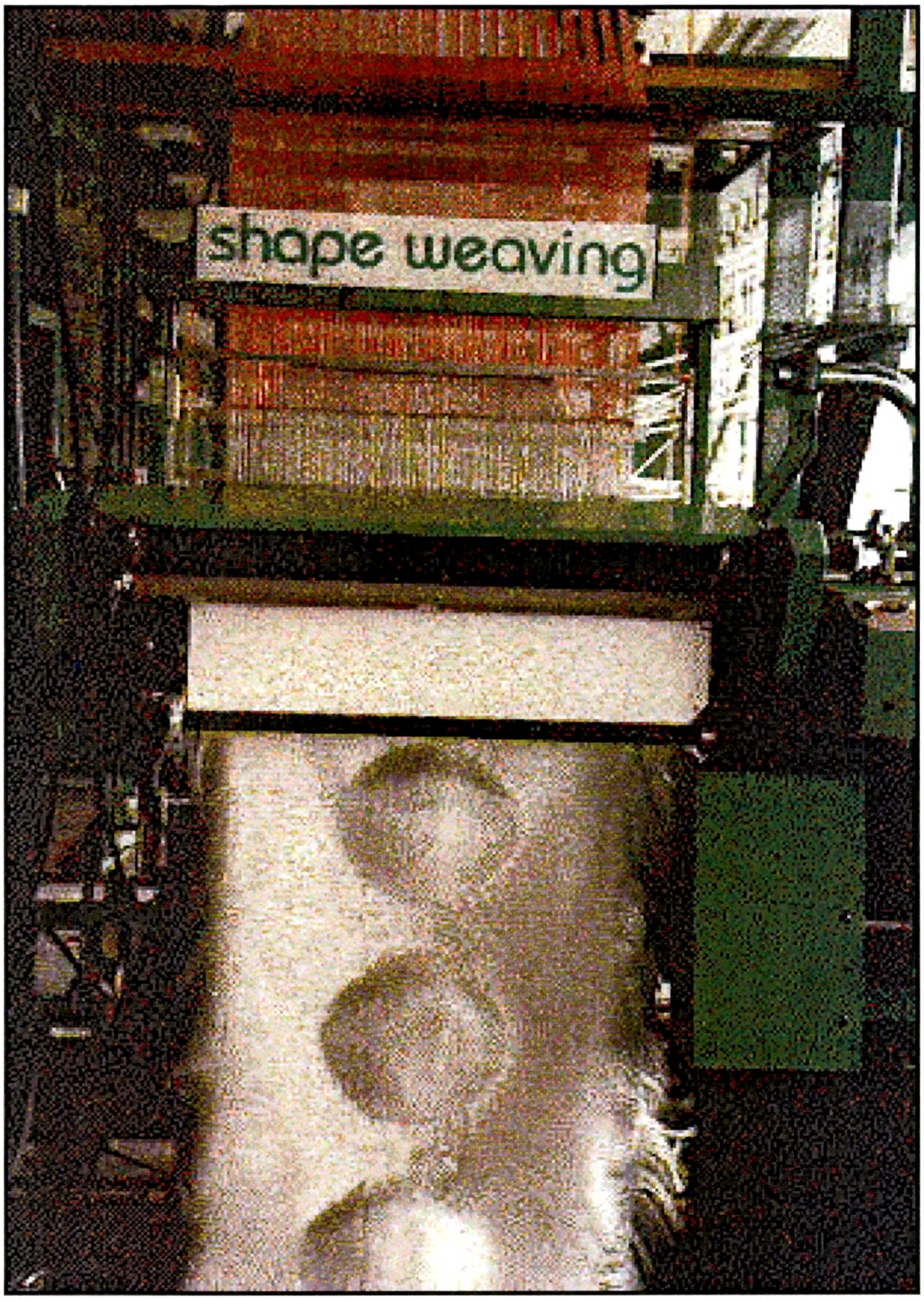

Figure 2.14

2.3.1.1.1 Changing warp thread distances:

2.3.1.1.1.1 Changing warp thread distances using reed with curved dents:

Prof. Dr. Buesgen's patents [(8), (9), (10), (11)]describes means to change warp thread distances. As per one of the methods, special reed is developed that has curved dents (Figure 2.15). Each dent is curved specifically depending upon shape profile. The distance between two successive dents varies along reed height. If reed is moved vertically the warp thread distances can be changed. Curve shapes of individual dents and relative vertical position of reed determines the change in warp thread distances. Thus lifting or lowering of reed can change warp thread distances. In this method for every 3D shape, a separate reed is required to be designed and fabricated.

2.3.1.1.1.2 Changing warp thread spacings by reed with displaceable dents:

In another method, instead of keeping fixed reed dents, reed dents can be made to slide and displaced laterally along length of reed. This changes warp thread distances. In this method dents remain parallel to one another.

As shown in figure 2.16 movable dents can moved laterally through connecting rods or push cable mechanism whereby stepless or gradual lateral dent displacement can be done through a programmable drive with suitable electronic system[(8), (9)]. This system is quite flexible but costly.

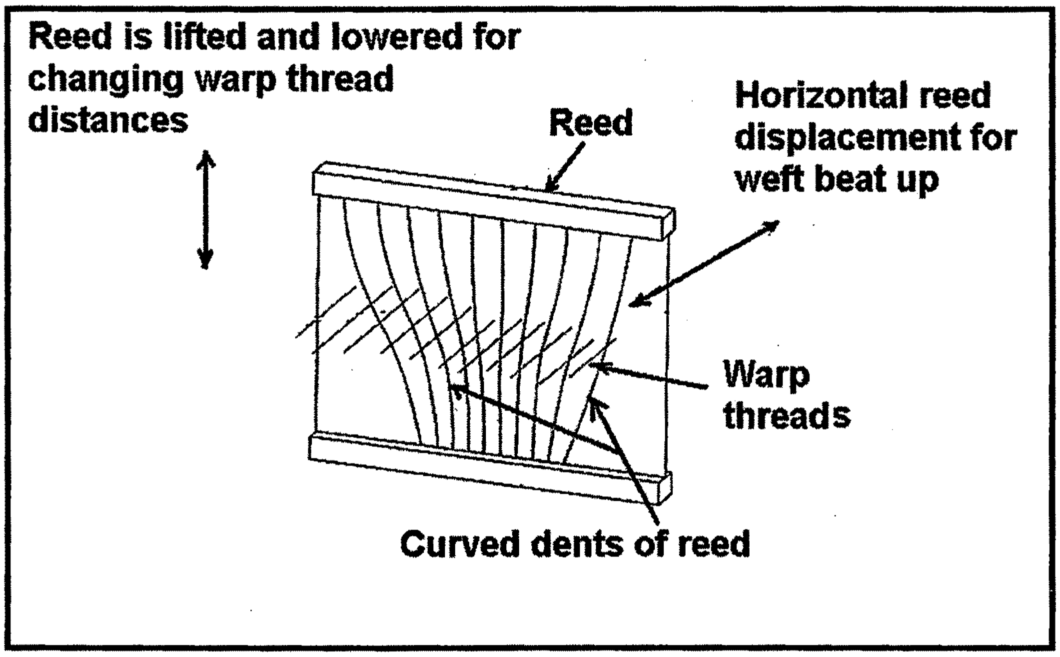

Figure 2.15

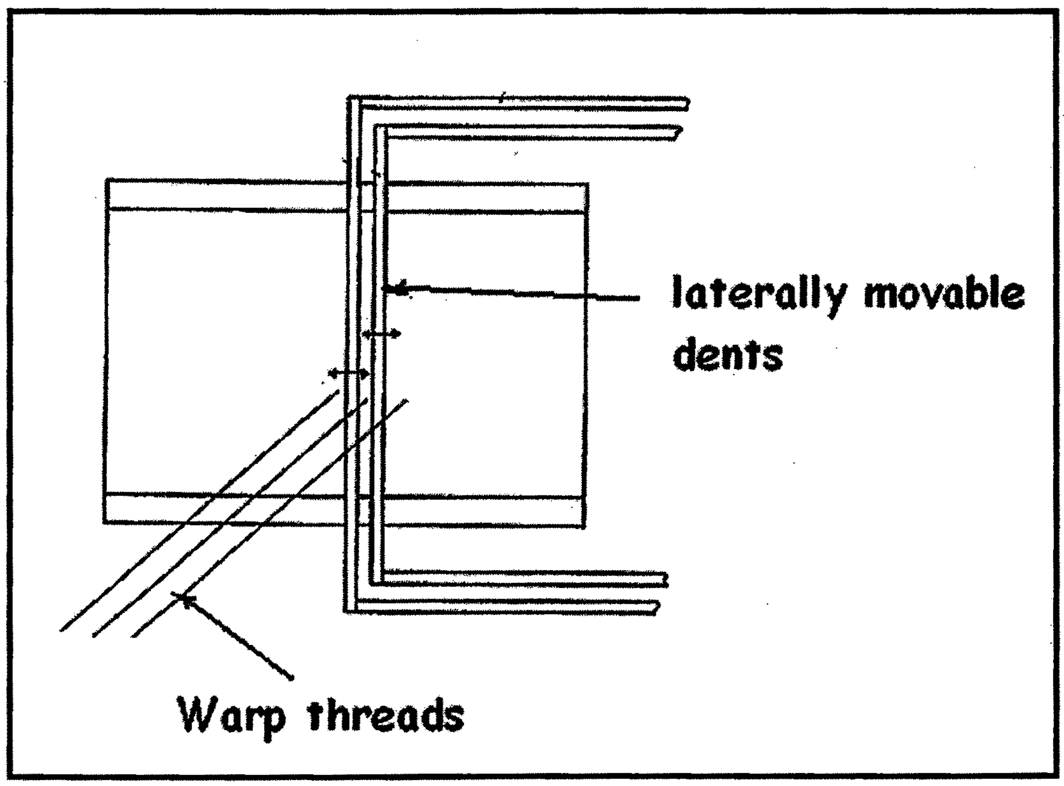

Figure 2.16

Figure 2.17 shows another arrangement in which dents follow grooves of a grooved cam. Each dent has its own groove. Groove design depends upon shape profile. Dents can be displaced by rotating grooved cam. Here for each shape a different grooved cam is required to be designed and fabricated.

2.3.1.1.2 Changing spacing of picks with segmented take up:

To produce desired seamless shapes, alongwith varying warp thread distances, weft thread distances are also to be changed according to shape profile, through a suitable arrangement on loom. Weft thread distance is determined by rate of take up. Therefore if distance between two consecutive weft threads is to be varied across fabric width (which is determined by shape profile), ideally take up rate of each warp should be adjustable on successive picks. Buesgen's patent (8) describes such arrangement. Here take up roll is not made in one piece but is compounded from several individual disc, i.e. take up roll is segmented (figure 2.18).

On successive picks, each disc can be driven at different rate. These discs are driven individually through a suitable electronic configuration and programmable drive. Thus combination of changing warp thread distanced through reed and weft thread distances through segmented take up produces 3D shape.

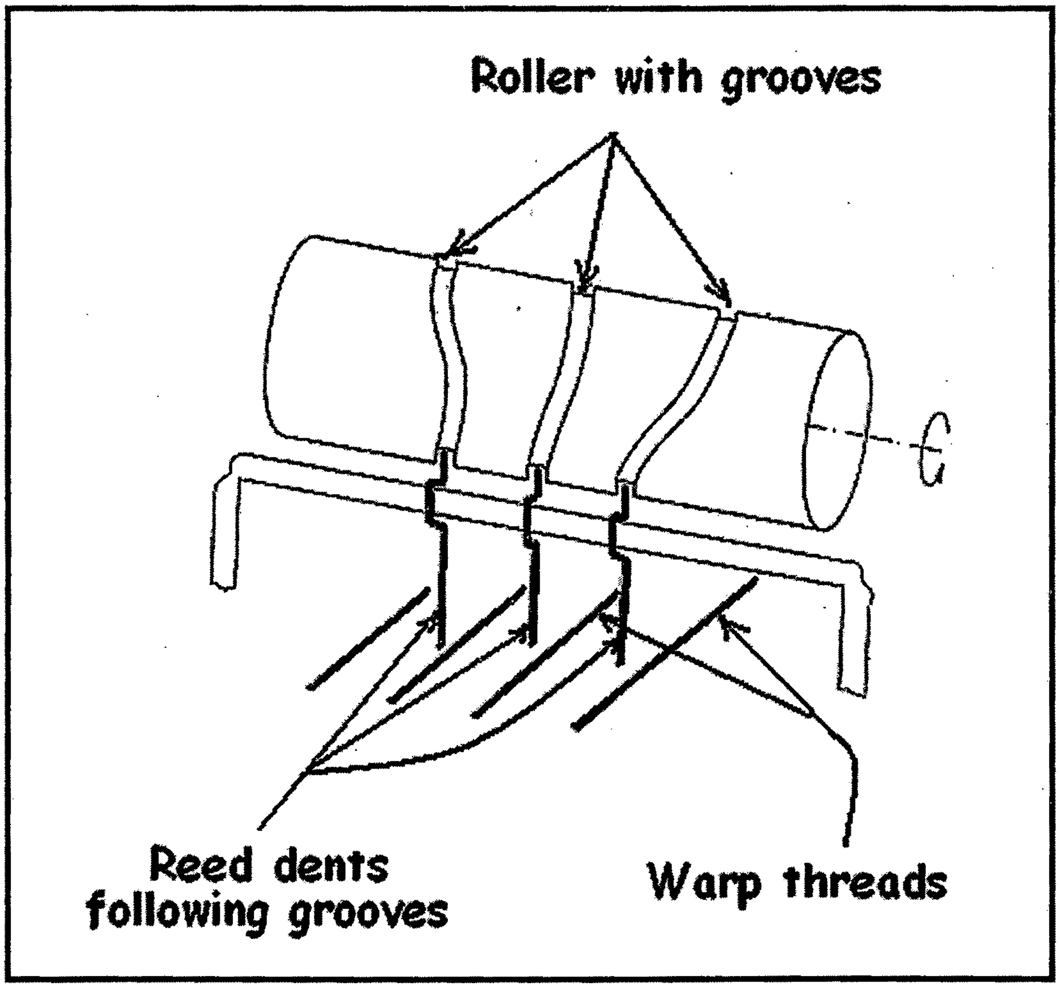
Roller with grooves
Reed dents
following grooves
Warp threads

Figure 2.17

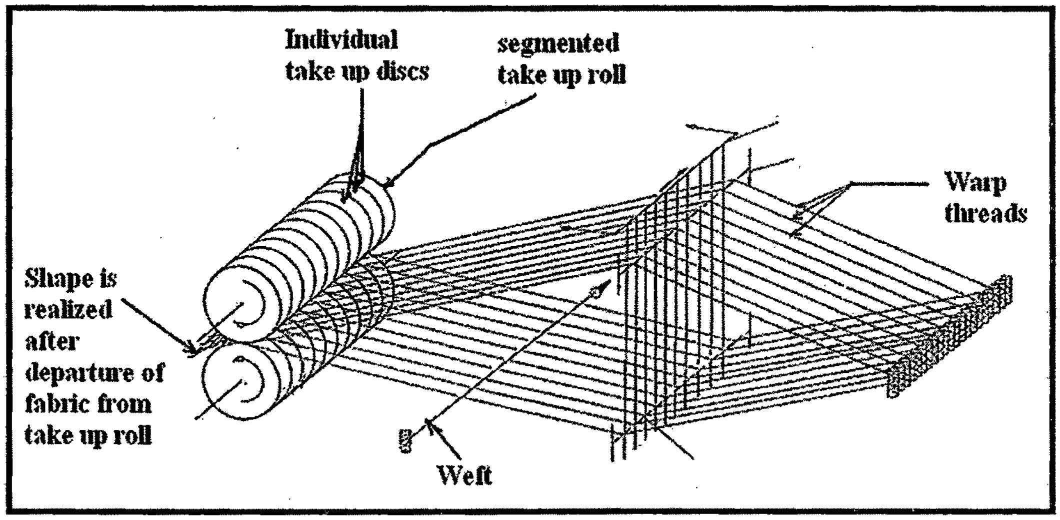
Individual take up discs
segmented take up roll
Warp threads
Shape is realized after departure of fabric from take up roll
Weft

Figure 2.18

2.3.1.1.3 Warp brake (Tensioners) for individual warp threads:

As length requirement of warp threads is different, warp has to be supplied through a creel. Also each warp thread has to be provided with a system that applies desired tension to individual warp threads, which should be maintained at different phases of weaving. Each warp thread is provided with an individual brake (tensioner). As shown in figure 2.19, each brake consists of a lower plate and an upper plate (10). Each warp is passed through an individual brake. The lower plate is fixed while the upper plate is attached to the rod of an electromagnet and can be pushed against the lower plate with a force, which can be preset.

The electromagnets are individually by braking means and braking program. Thereby braking force and warp tension can be adjusted differently. The thread tension is also function of thread speed. In this weaving take up speeds of warp threads is different from one another while weaving shape region. This can cause tension differences among warp threads. To even out the tension, tension applied by brake is varied during weaving through a program as a function of take up speed.

2.3.1.1.4 Arrangement for keeping warp threads in line with reed dents:

As discussed in section **2.3.1.1.1.1 and 2.3.1.1.1.2,** shape weaving method in which warp thread distances are changed by reed with curved dents or with laterally movable dents, effective pitch of reed keeps on changing in shape weaving region. One of the requirements for trouble free jacquard shedding is that number of ends per unit length in comber board has to be equal to those in reed so that warp threads pass around

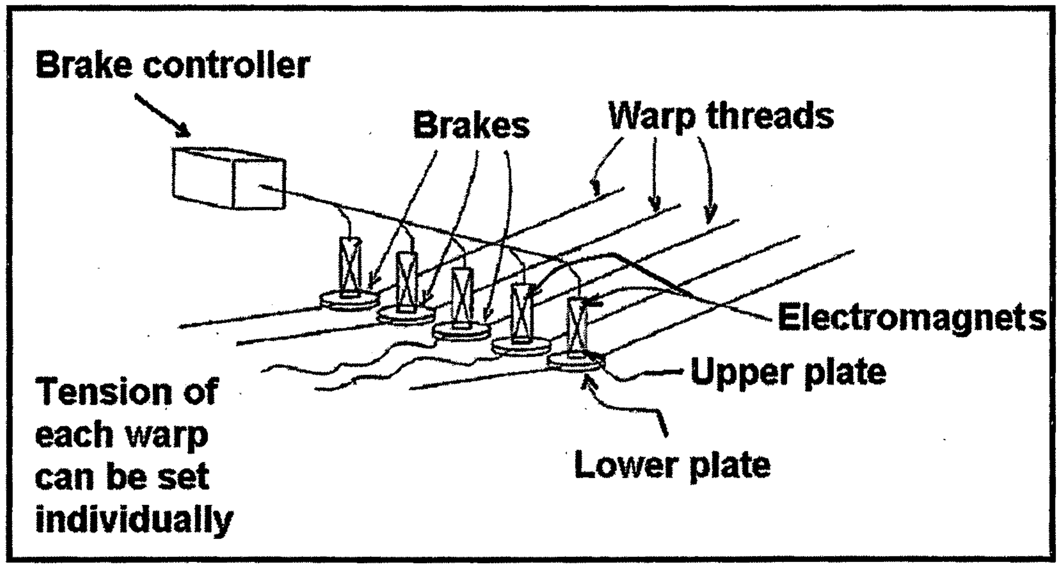
Brake controller
Brakes
Warp threads
Electromagnets
Upper plate
Lower plate
Tension of
each warp
can be set
individually

Figure 2.19

reed dents without deflection / deviation. In shape weaving, when reed causes change in warp thread distances, this condition will not be satisfied. An uneven warp thread tension will be built up in the set of warp threads. This is found to cause deviation in 3D shape from the precalculated form. This also increases abrasion and wear of warp threads (10). Therefore a warp thread positioning system is developed which causes change in distances of healds in synchronization with change in dent spacing at reed.

Figure 2.20 and figure 2.21 show the positioning of the warp threads before being guided into the weaving reed in detail. Only the frame and two representative dents of the reed are shown. The dents run outward from the upper edge in the shape of a fan. Furthermore, only one warp thread is represented running through the space between the represented dents.

A set of parallel guiding rods extending substantially parallel to the warp serves for positioning the heddles with eyelets and harness cords, respectively. For the sake of clarity, only the one guiding rod is represented in figure 2.20, which serves to guide the represented heddle and the represented warp thread. As do all of the guiding rods, this guiding rod also projects into the same space between two dents through which the corresponding warp thread to be guided runs as well. The other end of each guiding rod is held by an individual elastic band in the warp direction as well as by an elastic band in the weft direction shared by all the guiding rods. The shared elastic band can be expanded elastically by the positioning control to a more or less great extent. Thereby, the distance of the fixation points of the guiding rods on the elastic band changes.

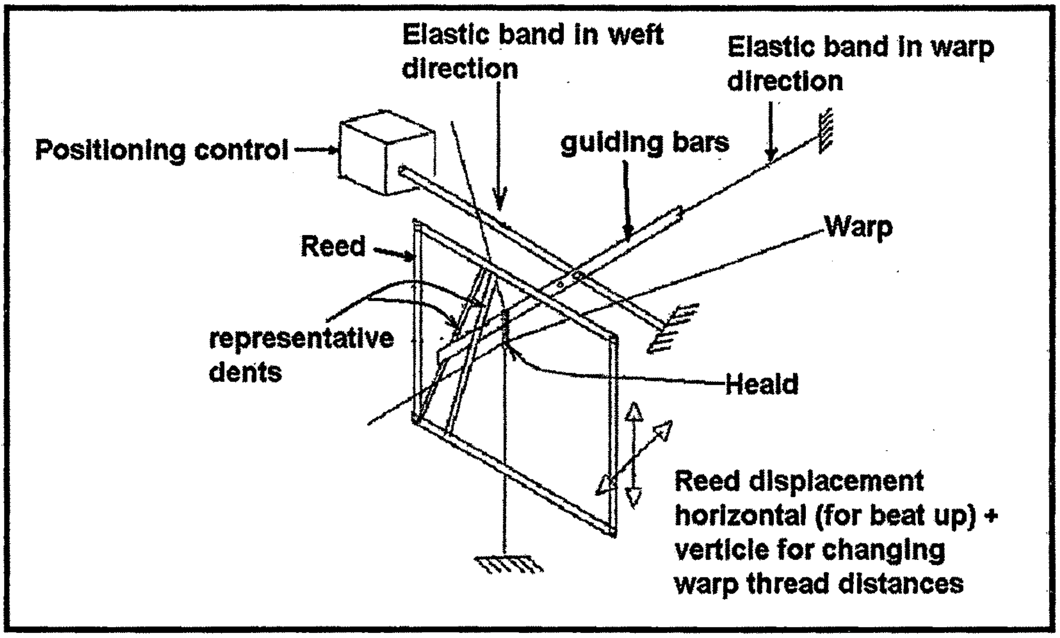

Figure 2.20

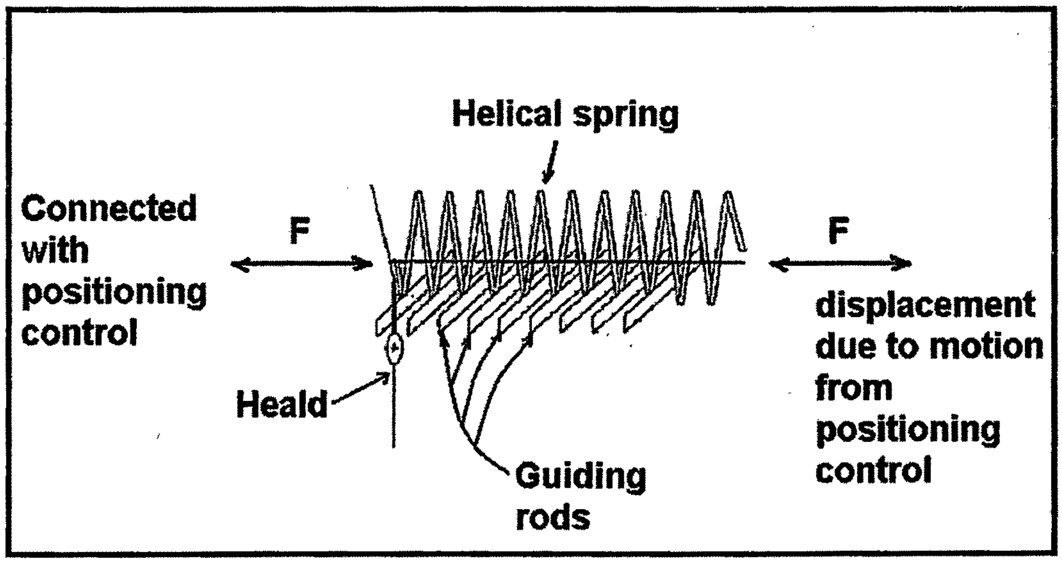

Figure 2.21

As an alternative, the shared elastic band can be replaced by an equally (in the weft direction) directed guiding ridge whereon the guiding rods slide. In this case, the guiding rods are positioned with sufficient precision only by the horizontal distance or the dents guiding the leading ends of the guiding rods. Thus, the horizontal distance of the guiding rods is only determined by the vertical position of the weaving reed without a further positioning control being necessary.

The shared elastic band can also be replaced by a helical spring (figure 2.21). The helical spring extends in the weft direction. Its coils engage between adjacent positioning rods. The helical spring is tensed by the positioning control with a force F to a more or less great extent. Thereby, the pitch of the coils and thus the distance of the rear end of the positioning rods change.

The distance of the leading ends of the guiding rods is predetermined by the respective vertical position of the weaving reed. Both distances are aligned with each other by the vertical weaving reed control on the one hand and the positioning control on the other hand.

As any guiding rod bears on a heddle, guiding it laterally, the heddles are given the distance of the dents. Thereby, the warp threads run through the weaving reed without a significant deviation. Friction and production of undesired thread tractions are avoided. The thread traction force can only be predetermined by braking and by the take-down device.

The method of producing 3D shape, described above is based on changing spacing of threads. Buesgen's patent (8) also describes a method in which plane of cross over points is shifted by an amount depending upon shape profile.

2.3.1.2 Weaving 3D shapes using multi-part shapers:

Here the planes of cross over points are elevated on loom by special multipart shapers introduced one after the other at cloth fell. Fabric is confined to weave in hollow space between these shapers.

As shown in figure 2.22, unlike usual weaving, multi part shapers are inserted one by one at cloth fell. Shapers are essentially inserted from bottom but wherever necessary they are inserted from top also. These shapers result into a sort of 'mould' in which fabric is confined to weave as it is woven. Thus shape to be woven is to be divided in to number of shapers. The lower shaper profiles can be provided with needles so as to prevent slipping of warp threads and fabric.

For shedding a jacquard is employed. For usual weaving jacquard form a shed for weft insertion. Here also jacquard forms shed for weft insertion as per its usual function (figure 2.23).

In second phase unequal lifting of warp threads is caused in such a way that warp threads form the outline of shape profile of shaper. This can be seen in figure 2.24. Thus here instead of reed, healds bring about change in warp thread distances. Thus a desired 3D shape is obtained by elevating cross over points from usual plane of weaving using multi part shapers.

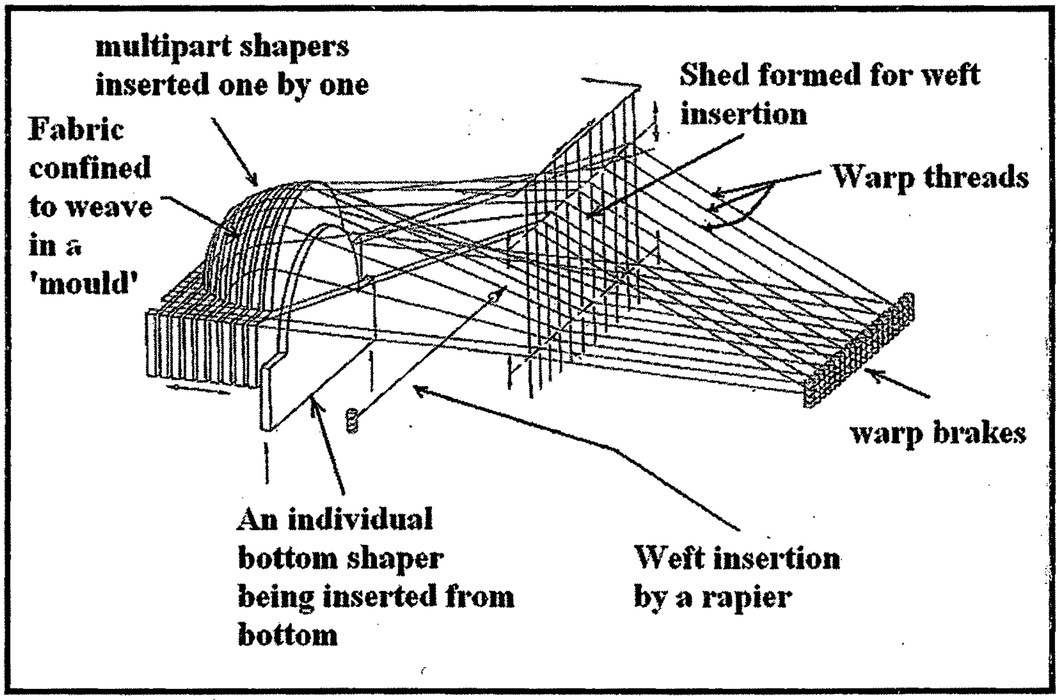
multipart shapers inserted one by one
Fabric confined to weave in a 'mould'
Shed formed for weft insertion
Warp threads
warp brakes
An individual bottom shaper being inserted from bottom
Weft insertion by a rapier

Figure 2.22

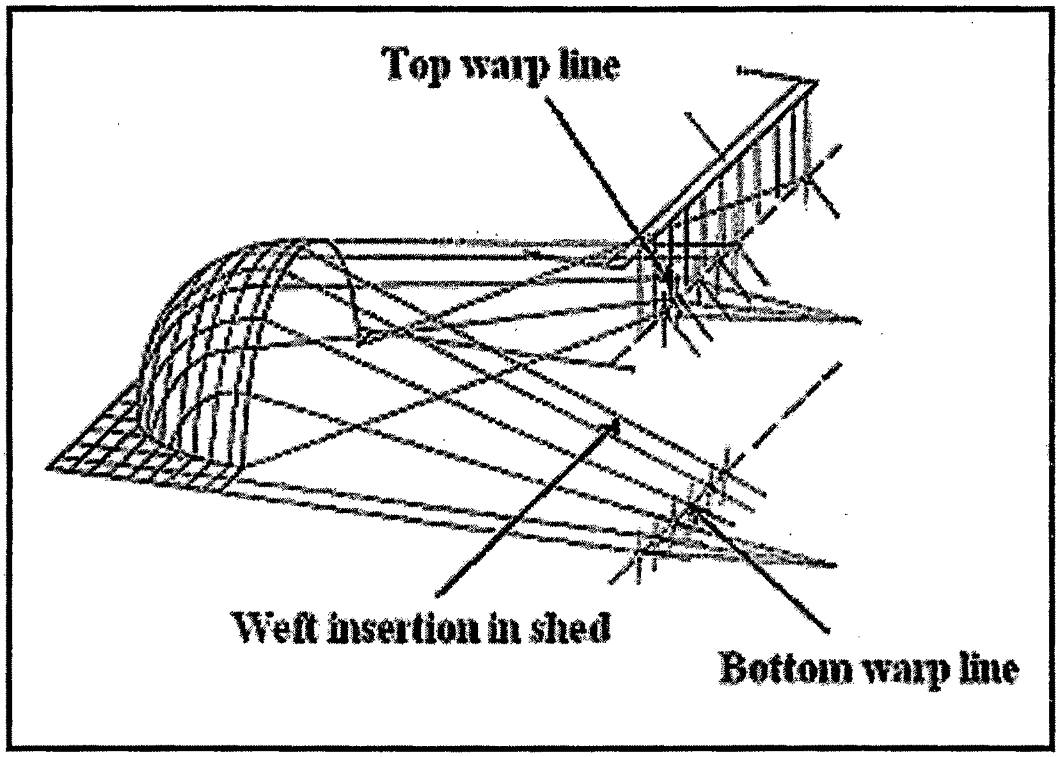

Figure 2.23

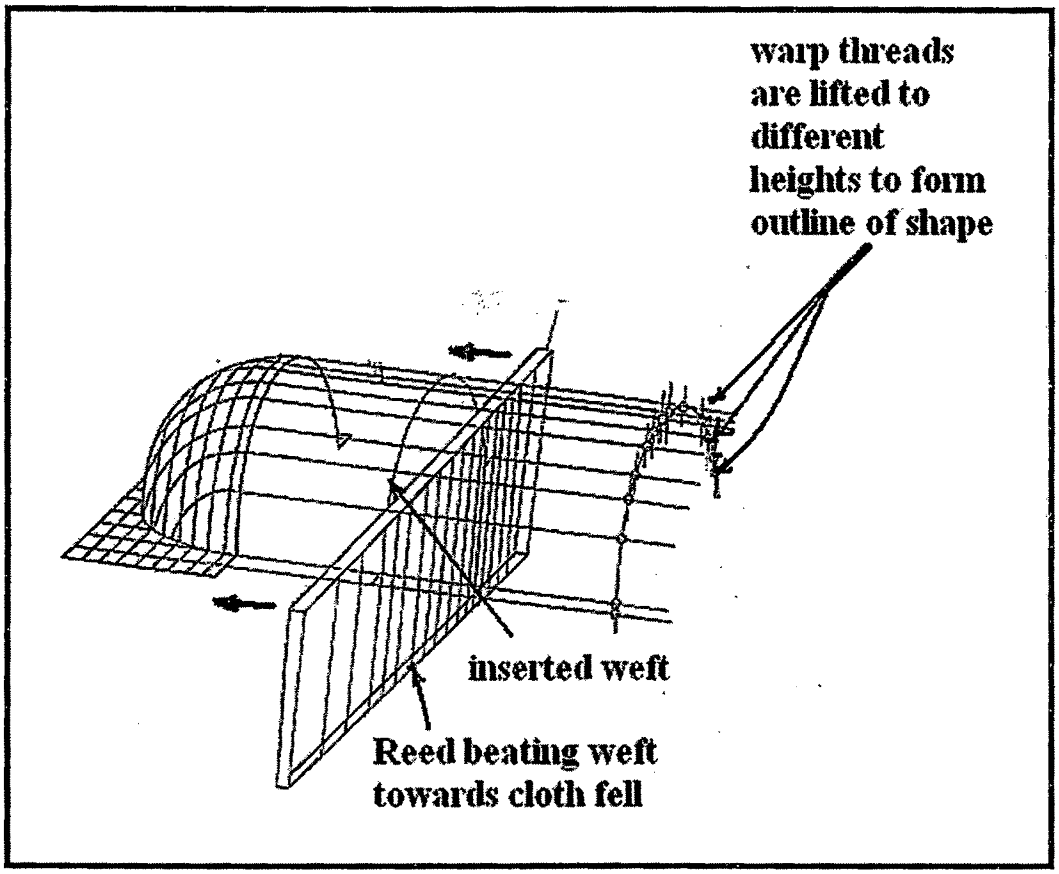
warp threads
are lifted to
different
heights to form
outline of shape
inserted weft
Reed beating weft
towards cloth fell

Figure 2.24

Photograph of a hemisphere woven with this development (18) is shown in figure 2.25.

As described above, Buesgen has done exhaustive basic work on shape weaving. Subsequently, he has filed several patents, which are further extension of this work, directed towards applications in various areas.

In Buesgen's patent (11), method of producing tubular structures with varying diameters as well as having desired bend is described.

2.3.1.3 Role of weave in 3D shape weaving:

Buesgen's patent (10) describes role of weave in shape weaving. In 3D woven shape spacings of ends and picks tend to increase. If same weave is employed throughout, there will be looser regions in shape portion, as fabric area tends to widen. Therefore interlacements are to be selected in such a way that degree of firmness is maintained. Also if spacing of ends or picks widen excessively, it would be difficult to obtain a stable shape as threads would tend to slip and shift due to looseness. This problem can be resolved with the following approaches while selecting interlacements between warp and weft.

The weave in the ground portion, i.e. 2D portion around shaped portion, should be selected with less number of binding points (i.e. a looser weave) but with greater number of ends and picks per unit space. In shape portion interlacements of warp, weft or both should be increased depending upon expansion of area in shaped region. Thus increased binding points in shaped regions cover up increased spacings created between warp and weft.

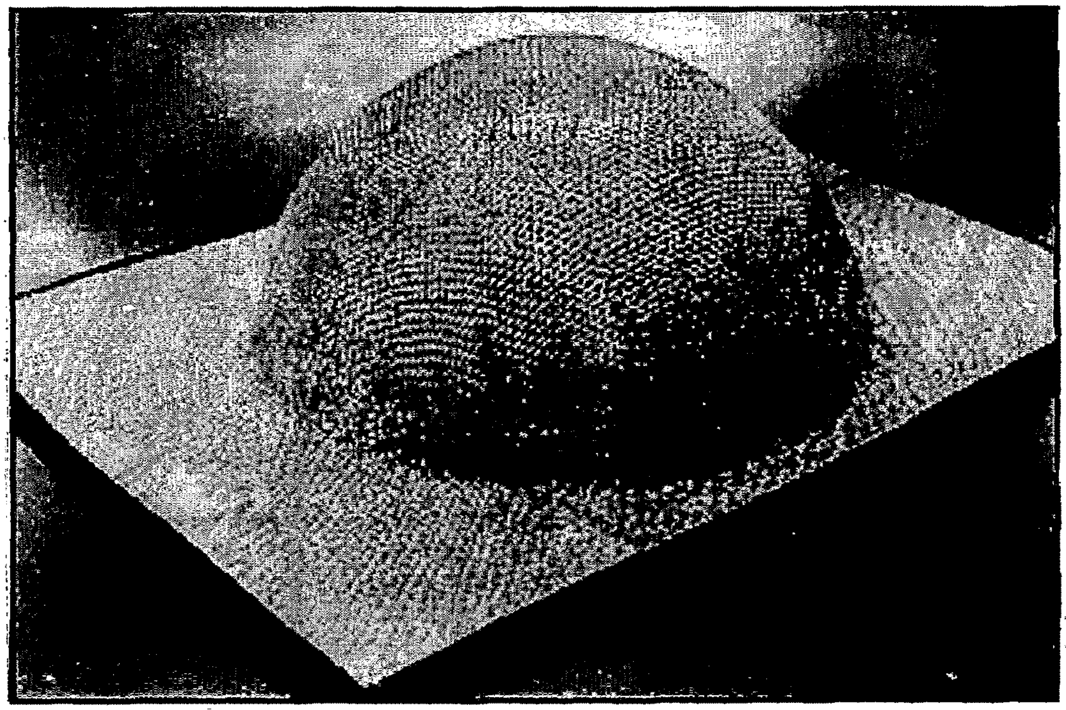

Figure 2.25

In other approach weaves with multilayer cloth construction base, preferably with wadding threads, can be selected in ground portion can be selected. Thus threads of back fabric/s as well as wadding threads act as "reserve" threads. These threads can be brought to face in shape region to compensate for increased spacing of threads.

In some regions in shape, especially when shape profile takes a steep rise, there is excessive widening of thread spacing. To cover up gap in such regions some threads (warp or weft) can be taken which interlaces only in such regions. In other regions they float. Such threads can also be employed to give increased strength to some regions of shape depending upon technical requirements of its end use.

Thus apart from shaping elements like reed and segmented take up; employing weave structure with varying degree of firmness assist in creating a 3D shape.

As described above Buesgen did fundamental developments in 3D shape weaving. Subsequently his work is extended further towards applications of 3D shape weaving in various areas and has filed several patents (12, 13, 14, 15). Relevant ones are described below.

2.3.2 Producing fabric with variable width:

Buesgen's US Patent (11) describes method of producing a fabric with variable width. The development concerns weaving tubes of varying diameter as well as bends as desired or a band of fabric with varying width. Weaving of tubes fabrics require double cloth construction, therefore a shuttle loom is advantageous as weft is laid in continuous form.

Figure 2.26 shows various elements of development. Shedding is by a jacquard. A fan reed is employed, which if displaced vertically, changes fabric width. As fabric width changes during weaving, a specially developed spreader device, keeps fabric stretched, and thereby under tension widthwise. The spreader device displaces width way, according to expansion or contraction carried out by reed displacement. Pick insertion is with a shuttle. Thus a tube with varying diameter is produced. Expansion and contraction of fabric causes changes in warp thread distances. Therefore suitable weaves can be selected that increases crossover points in expanded region and vice versa. If necessary warp threads, weft threads or both can be concentrated in certain regions. If necessary some warp threads can be taken those interlace only in expanded regions and float in constrictions. Tube can be given a bend at required places by having conical take up rolls (Figure 2.27). Instead of a shuttle loom a rapier loom can also produce such fabrics. In a rapier loom weft laying is not continuous. Therefore a double cloth construction stitched at selvedges is used. The stitches cause a joint and thereby form a tubular construction. On a wider rapier loom number of fabrics can be woven side by side (Figure 2.28). The adjacent fabrics are separated by cutting weft threads. These tubular constructions can be used as reinforcement material in producing composite tubular structures.

2.3.3 Weaving tubular garments directly on loom:

Buesgen's patent (12) describes method of producing garments made of tubular components directly on loom without any transverse seams.

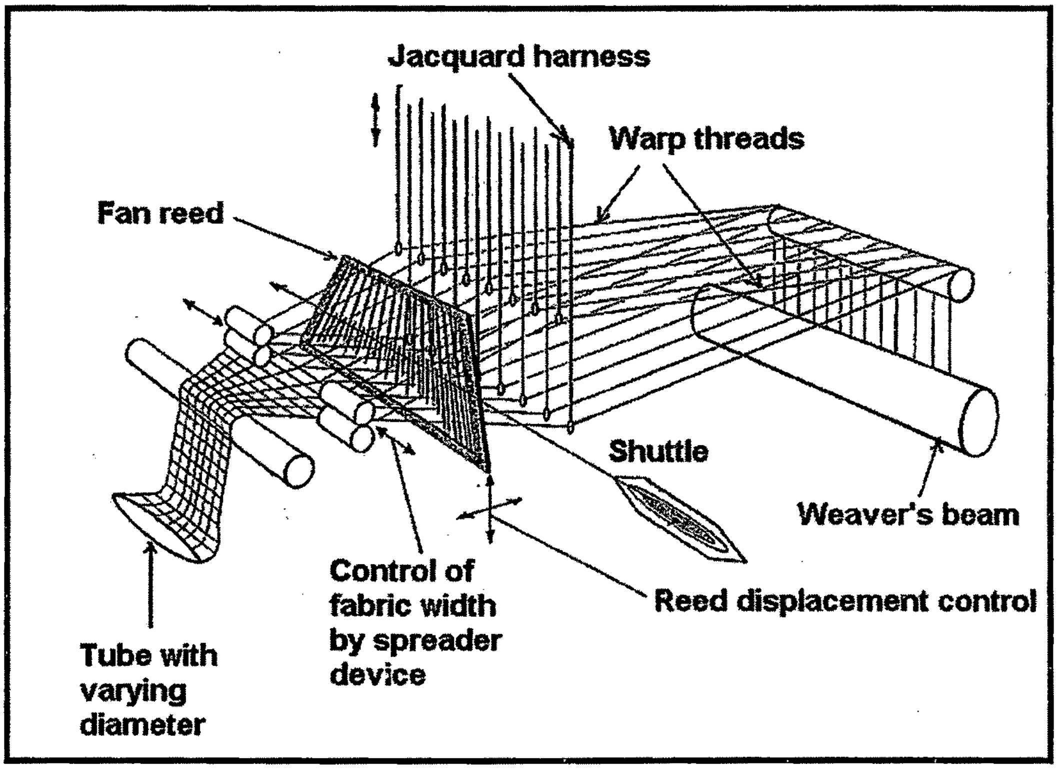
Jacquard harness
Warp threads
Fan reed
Shuttle
Weaver's beam
Control of
fabric width
by spreader
device
Reed displacement control
Tube with
varying
diameter

Figure 2.26

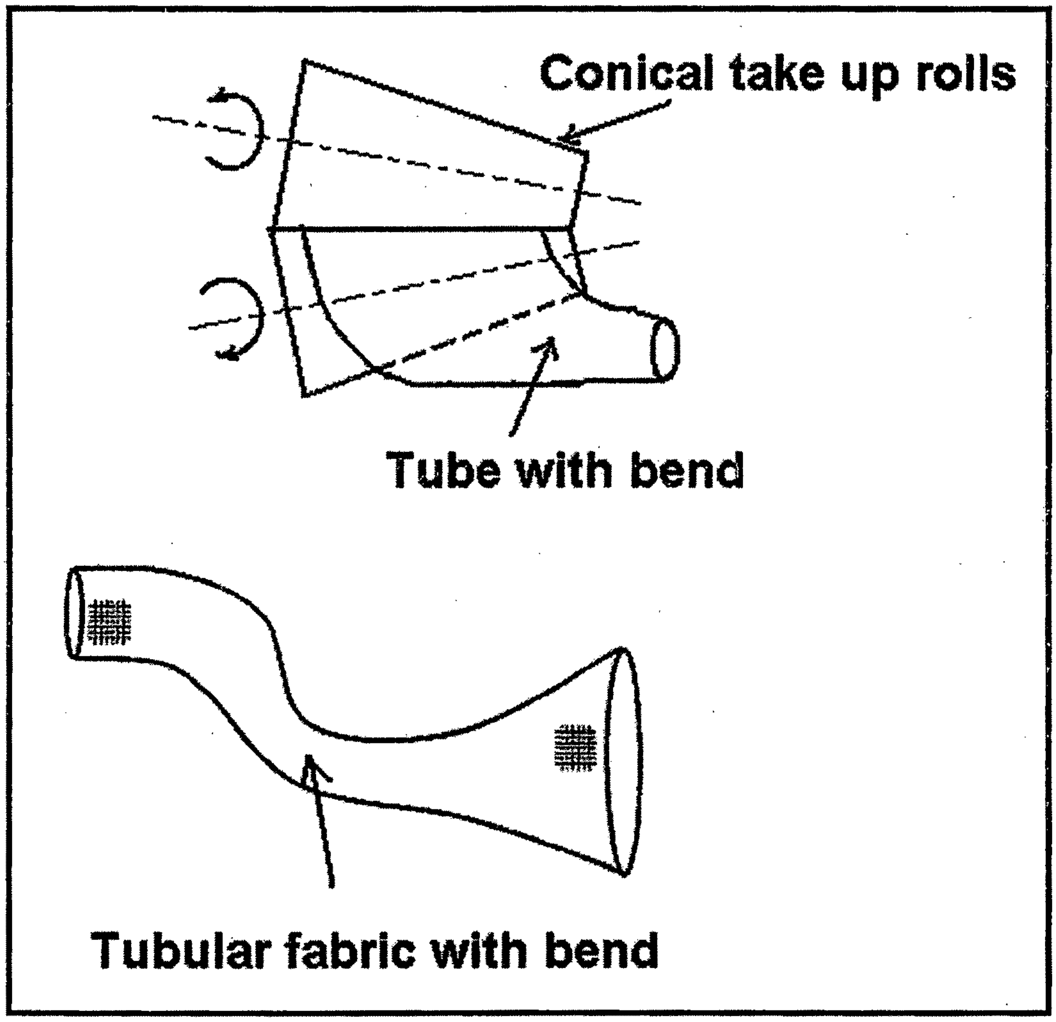
Conical take up rolls
Tube with bend
Tubular fabric with bend

Figure 2.27

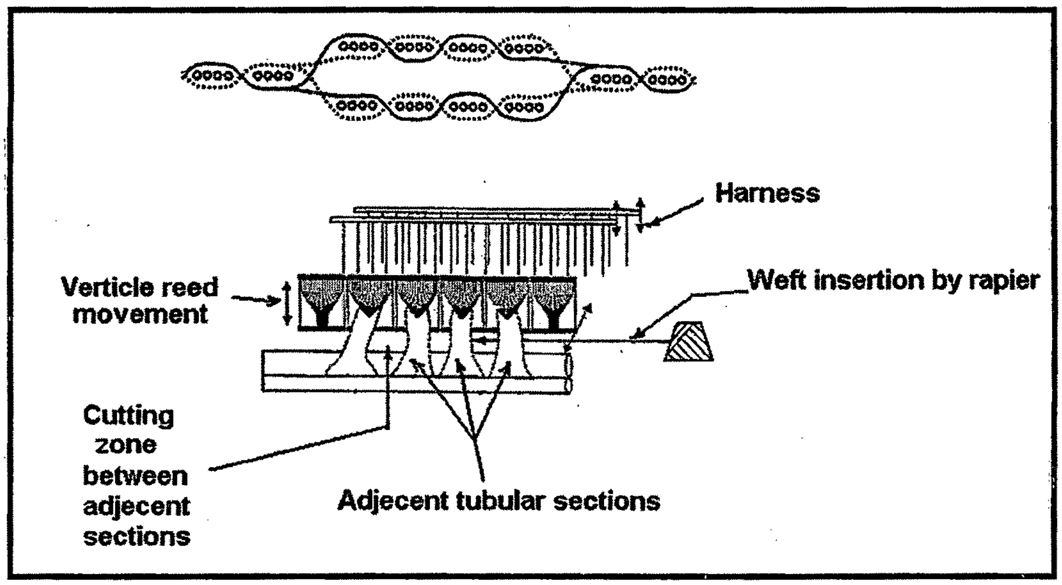
Harness
Verticle reed movement
Weft insertion by rapier
Cutting zone between adjecent sections
Adjecent tubular sections

Figure 2.28

These developments necessitate use of a shuttle loom. Clothings such as trousers, dresses, shirts, blouses that consist of tube pieces are woven without any seams.

Principle is shown in figure 2.29. A trouser is woven as a four layer cloth. Initial top part is woven with single shuttle. Insertion of weft is shown at 'I'. On unfolding a cut is produced that is required for zip. Subsequent portion as indicated at 'II' produces a tubular cloth. Last portion, as indicated at III where legs are produced, two shuttles are required. It weaves two separate tubes. For creating tapering effect, a fan reed is employed.

Xiaogang Chen and Ayse Ebru Tayyar (17) have described a method of manufacturing 3D domed woven fabrics economically on loom with an add-on device. The add-on device is a combination of a roller, a profile chain that is engaged on a roller and a frame holding the roller and chain. This frame can be easily mounted on and taken off the loom. The profile shape taken was spherical but can be varied to other shapes. For flexibility instead of profile roller a profile chain was taken. Figure 2.30 shows the take-up system after the add-on device is mounted. The add-on device lengthens the fabric path before reaching cloth roll. The main part of this device is the profile chain. Warp was supplied from three beams for compensating warp tension variation. Fabrics with different weaves, i.e. single layer, multi-layer and angle interlock weaves, were woven and dome effect was evaluated. However this method doesn't seem to be suitable and versatile for producing any desired shape.

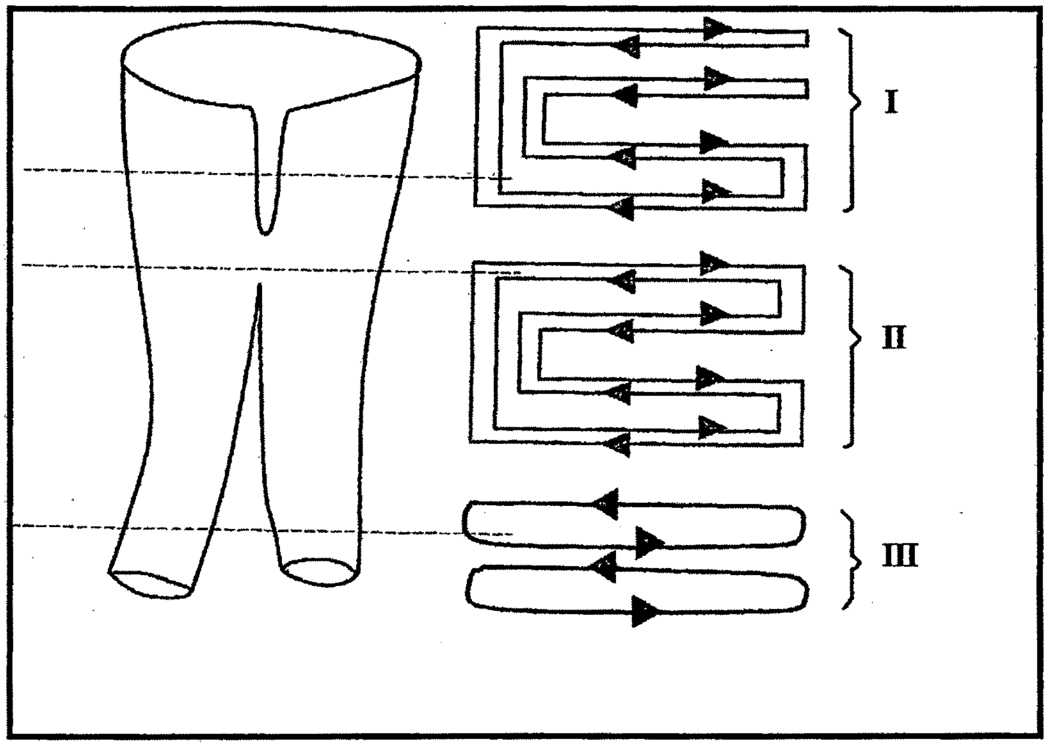

Figure 2.29

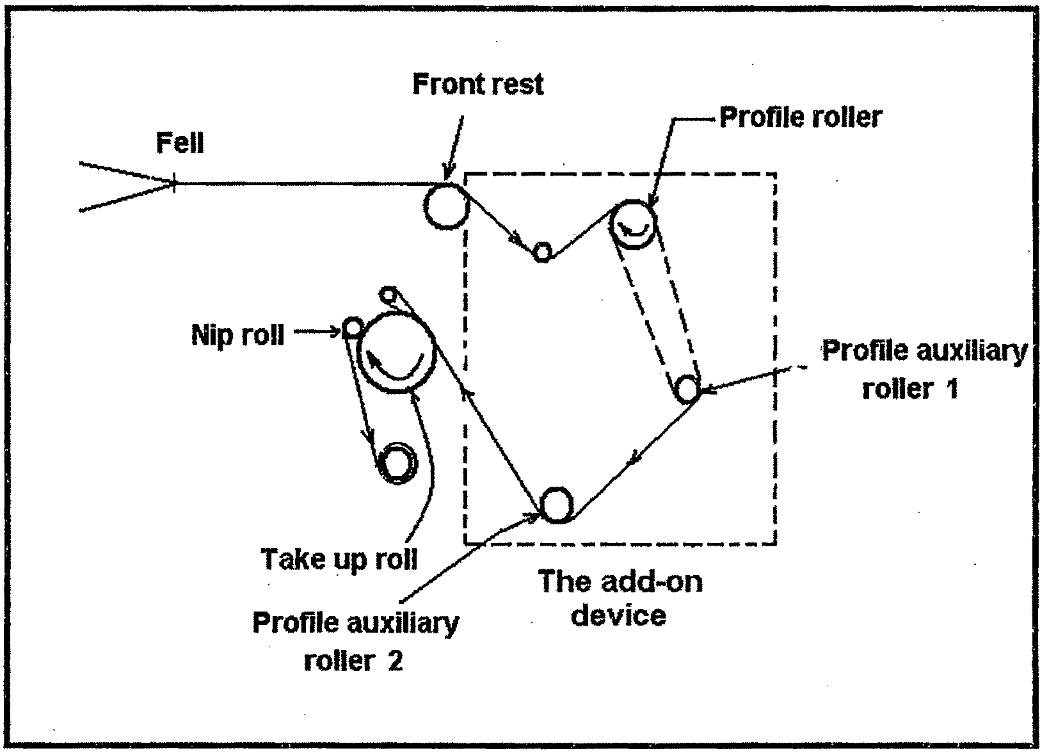
Front rest
Profile roller
Fell
Nip roll
Profile auxiliary
roller 1
Take up roll
The add-on
device
Profile auxiliary
roller 2

Figure 2.30

K.Anderson and A.M.Seyam (16) have woven seamless 3D shapes on conventional looms. On ordinary loom narrow tubes were woven with three variables, viz. pick density, weave and filling yarn shrinkage. These variables were strategically manipulated to cause different width shrinkage within the fabric structure during the finishing process. Additional weaving trials were conducted to investigate the correlation between fabric width shrinkage and a given set of fabric construction parameters in order to create inherent shape within the fabric.

It has been shown that seamless woven products with inherent shape can be produced continuously on conventional loom selecting optimum above mentioned fabric parameters. Thus this method is fundamentally based on weaving tubes and developing 3D shape on finishing owing to differential shrinkage of threads. However this method seems suitable mainly to create tubular structures with varying diameters.