Chapter 4
RESULTS AND DISCUSSIONS

4.1 Introduction:

Producing desired 3D woven seamless shapes directly on loom offers distinct advantages over those produced by making up or thermal moulding. To produce desired woven 3D shapes directly on loom; modifications are necessary in primary, secondary and auxiliary mechanisms of loom.

The work undertaken started from weaving a 3D hemispherical shape by manual means. Subsequently; after passing through several stages of development, overcoming several hurdles, evolving newer techniques in weaving, developing suitable methods for fabrication of components, developing mathematical tools for designing some components etc.; it became possible to reach a stage of weaving 3D shapes on a power loom.

This chapter describes stage wise results as well as discussions of the entire work.

4.2 Producing 3D woven shape manually:

As described in section 3.2 (Page 60) a 3D hemispherical shape was produced manually.

Half cut rubber ball used in this method shaped a hemisphere. The ends and picks laid manually were made to follow the shape profile of the ball using pins. The tension in ends and picks cause them to slide down the slope of the ball and cause difficulty in maintaining their position. Tension in yarns give them natural tendency to lie straight, instead of following a curve, as required in generating a 3D shape.

4.3 Producing 3D shape on handloom:

4.3.1 Producing hemispherical shape using shaped rods:

Attempt of weaving a hemispherical shape (described in section 3.3.1, page 60) using shaped rods ***did not succeed.***

4.3.1.1 Reason for why 3D shape could not be produced:

It was expected that shaped rods would change the plane of cross over points and a hemisphere would be produced. The change in planes of all cross over points does not take place simultaneously and by equal amount. Tension in warp and fabric does not allow this to happen. Therefore this method failed to produce a hemispherical shape.

4.3.1.2 Out come of attempt of producing hemispherical shape using shaped rods:

Although this attempt failed it inspired subsequent method of weaving 3D shapes with shaped fins in which planes of cross over points is changed according to shape profile and is retained even against tension in warp and fabric.

4.3.2 Producing 3D shapes using shaped fins:

As described in section 3.3.2 (page 63) pyramidal and hemispherical shapes were produced successfully using shaped fins.

4.3.2.1 Dimensions of shapes woven:

However this method is suitable for producing smaller shapes. Dimensions of '*mould*' in which pyramid was to be woven was length and breadth of 8 cm and height of 4cm. Pyramid woven after contraction measured about 7 cm in length and breadth and 3.5 cm in height. Hemisphere woven had radius of 4 cm in mould which on contraction became about 3.7 cm in fabric.

4.3.2.2 Limitations of weaving 3D shape using shaped fins:

The slots in fins together form a mould cavity in which fabric should be confined to weave. In this method, planes of cross over points are shifted vertically depending upon shape profile. To do this, force must be applied on cross over points. This force is applied by slotted shaped fins.

Figure 4.1 shows one of the shaped fins for weaving a hemispherical shape. Weaving commences from point 'a'. During weaving from portion 'a' to 'b', the cross over points lie in the plane of ground non-shape portion. As can be seen beyond point 'b' and up to 'c', cross over points will be lifted by semi-circular slot. The lifting force is applied by face indicated by solid face from 'b' to 'c' as warp tension tends to keep fabric formed pressed against this face.

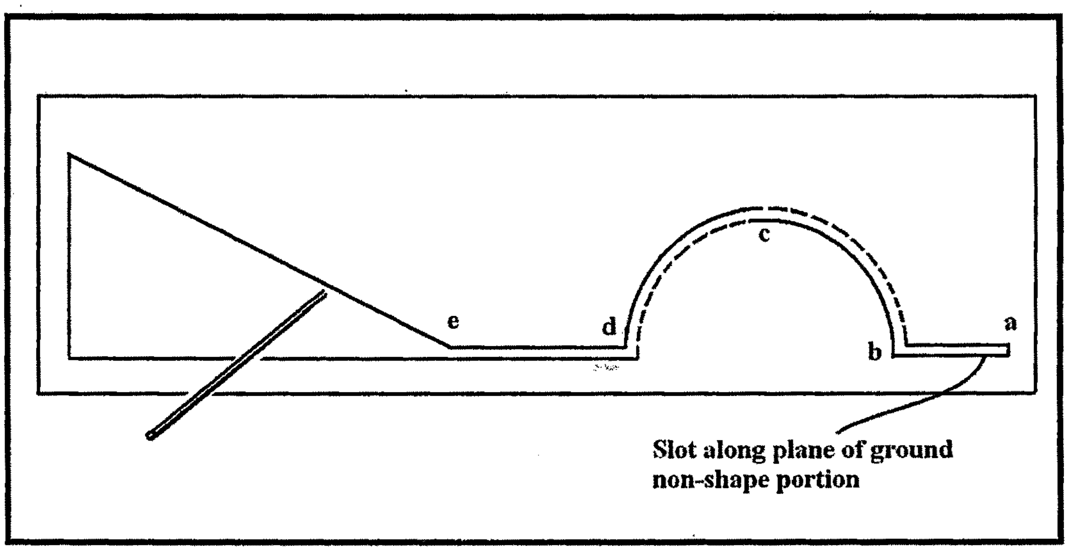


Figure 4.1

Beyond point ‘c’ up to ‘d ’, cross over points will be lowered. Force for the same is applied by face indicated by solid line from ‘c’ to ‘d’ because warp tension tends to keep fabric formed remain pressed against this face. Beating of weft and getting exact additional weft length while weaving shaped region also becomes difficult. During beat up, friction between weft and slot faces causes wearing out of slots in the fins as fins are made of card board. Fabric tension tends to distort fins. Fabricating fins from metal sheet could be better by will be expensive as creating slots of exact shapes would need expensive process like EDM wire cutting.

Therefore following is concluded for the method of producing 3D shapes using shaped:

i. This method is suitable for producing smaller shapes.
ii. This method is suitable only for weaving on handloom and is not suitable for adoption on a power loom.

4.3.2.3 Out come of weaving using shaped fins:

Close observation of 3D woven shapes enabled further understanding and analysis 3D woven shapes and inspired further development. This analysis revealed the fundamental requirements for weaving 3D shapes.

4.3.3 Fundamental requirements for weaving 3D shapes:

A 3D woven shape can be viewed from two angles and weaving process can be modified accordingly as discussed in 3.3.3 (page 66).

4.3.3.1 Producing 3D shape by shifting planes of cross over points:

In a 2D woven fabric, all cross over points practically lie in same plane whereas in a 3D woven shape cross over points do not lie in same plane. Taking this as the base, weaving process should be modified in such a way that planes of cross over points are shifted depending upon profile of 3D shape.

This principle is employed in the method of producing 3D shapes using shaped fins. To employ this principle on a power loom, similar means has to be provided that would shift the planes of cross oven points and retain them in that position against the weaving stresses. In this principle, the cloth fell would not lie in same plane but would follow a curve depending upon shape profile. Therefore, this principle was felt unsuitable for application.

4.3.3.2 Producing 3D shape by changing spacing of ends and picks:

Looking 3D shape from other angle, it can be observed that spacing of ends and picks in shaped region does not remain the same but keeps on varying depending upon shape profile. In 2D weaving the spacing of ends and picks almost remain the same. Therefore, instead of modifying weaving process in which planes of cross over points are shifted, approach can be of bringing modification that changes spacing of ends and picks depending upon shape profile. During weaving, the fell of the cloth would remain in straight line instead of curvature and shape would be developed subsequently.

Viewing from this angle, therefore, factors those influence spacing of ends and picks are identified as follows:

(a) Spacing of ends is influenced by:

i. Space between successive wires of reed.
ii. Interlacement between ends and picks
iii. Weft contraction

(b) Spacing of picks is influenced by:

i. Rate of take up
ii. Interlacement between ends and picks
iii. Warp contraction

Next job was implementing these factors in actual weaving so as to produce a 3D shape.

4.3.3.2.1 Changing spacing of ends by reed:

As mentioned in 3.3.4.1 (page 69), spacing of ends remains unchanged using reed with parallel fixed reed wires. To change spacing of ends, two designs of reed were found possible. One is reed with displaceable dent wires, as mentioned in 3.3.4.1.1 (page 69), and the other is reed with shaped dent wires as mentioned in 3.3.4.1.2 (page 72).

4.3.3.2.1.1 Reed with displaceable dent wires:

In spite of spending considerable time and effort in developing possible design of reed with displaceable dent wires, it did not materialize due to following reasons.

i. This method seems ***less suitable*** as maintaining firmness of dent wires during beat up would be difficult.
ii. Designing and fabricating cam with ***finer pitch*** would also be ***difficult.***
iii. Uniformity of depth and width of groove of cam was not assured.
iv. Estimated fabrication ***cost was also exorbitant.***

4.3.3.2.1.2 Reed with shaped dent wires:

As described in 3.3.4.1.2 (page 72), use of reed with shaped dent wires was found more feasible. Instead of parallel fixed dent wires, each dent is shaped to a specific curve which depends upon shape profile. The out come of efforts towards developing reed with shaped dents is as follows.

i. The basic principle of determining shape of dent wires for a given shape was worked out. Fundamentally, shaped dent wires have to bring about change in spacing of ends as required in 3D shape.

The length of weft between any two consecutive threads remains almost the same in 2D fabric. In 3D fabric, the changing space between two consecutive ends causes variation in lengths of picks between these ends. Thus dent wire should be shaped in such a way it can bring about variation in lengths of picks depending upon shape profile.

It appeared that it would be more convenient to weave a 3D shape in folded form from the point of view of controlling cloth fell. The dent wire shape determination is illustrated for pyramidal and hemispherical shapes as described in 3.3.4.1.2.1 (page 75) and 3.3.4.1.2.2 (page 82) respectively.

ii. A mathematical tool for generating curves of shapes of individual dent wires for pyramidal and hemispherical shapes with given dimensions and parameters, is developed as described in 3.3.5.1 (page 88) and 3.3.5.2 (page 101). Using this tool, curve shapes of dent wires can be generated on computer. Print out of the same is utilized for fabricating reed.

iii. The equation developed for generating curves of shapes of dent wires for a hemisphere is as follows.

Required parameters are:

r = radius of hemisphere

n = number of reed wires in reed to produce hemispherical shape, i.e. number of reed wires in width equal to ‘r’. Therefore reed wires those produce hemisphere can be numbered from 1 to n.

d = dent number for which shape of curve is to be generated. ‘n’ number of curves have to be generated.

$$q = 1 - \sqrt{1 - (1 - \frac{d}{n})^2}$$

Y = distance measured along reed height starting from a reference point on bottom baulk of reed

X = distance measured along reed length from reference point

Curve for each dent starts from bottom baulk, for d^{th} dent at distance $\frac{dr}{n}$. The initial portion is straight along direction of reed height up to distance $= rq$.

Mathematically,

for $0 \le y \le rq$, value of x remains constant, i.e. $\frac{dr}{n}$

Beyond rq, for $rq \prec y \le r$,

values of y are,

$y = q + r(1-q)(\frac{f}{m})$, where m is any natural number. Value of m should be taken as a larger number (e.g. m=200) to generate more points for the curve so that curve obtained is smoother. Number 'f' is a natural number such that, $1 \le f \le 200$, for m=200. Thus 200 values of y are obtained when values of 'f' are substituted in equation $y = q + r(1-q)(\frac{f}{m})$.

Corresponding values of 'x' are given by equation,

$$x = \frac{dr}{n} + r(1-\frac{d}{n}) - [r\sqrt{1-(1-q)^2(1-\frac{f}{m})^2}] + [r\sqrt{1-(1-q)^2(1-\frac{f}{m})^2}][\cos^{-1}\frac{(1-\frac{d}{n})}{r\sqrt{1-(1-q)^2(1-f/m)^2}}]$$

On plotting x-y graph of these values curve of d^{th} dent is obtained.

Using these equations, curves of all dents are obtained. By plotting these curves together, shapes of curves for all dents is obtained.

Initial straight portion of the curve is to be extended by few centimeters towards negative y – direction to obtain beat up line for weaving ground portion without shape where all ends are uniformly spaced.

Similarly from end point of the curve, i.e. when f = m, a stright line is to be extended in positive y – direction to obtain space for shed formaion when reed is lowered in its downmost position. This is illustrated in figure 4.2.

In this equation crimp is not considered. Actual values of 'x' will be influenced by crimp percentage. Crimp percentage in a 2D fabric can be constant and is considered for fabric calculations. While weaving a 3D shape thread densities vary in shaped regions. Therefore crimp percentage would be different in different regions.

iv. The equation for generating curves of shapes of dent wires for a pyramid is as follows.

Required parameters are:

W	=	width of pyramid
L	=	length of pyramid
H	=	height of pyramid
D	=	dent/ unit length

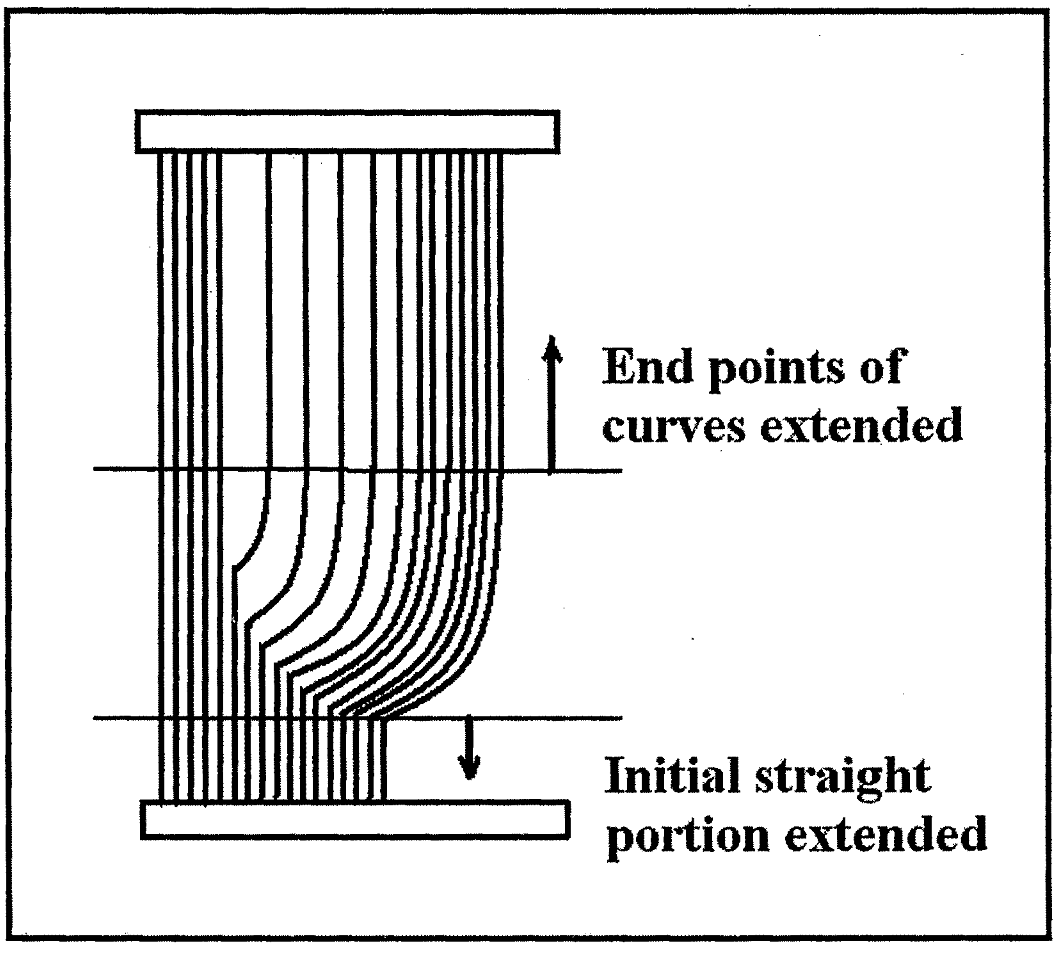

End points of
curves extended
Initial straight
portion extended

Figure 4.2

f = dent number for which curve is to be generated,

total number of dents to be designed= $\frac{wd}{2}$, i.e. 'f' ranges from 1 to $\frac{wd}{2}$ $(1 \leq f \leq \frac{wd}{2})$

Figure 4.3 shows form of shape of dents. Each dent has initial sloping portion followed by a line parallel to y axis. To generate shape of each dent three co-ordinates, i.e. (x_1, y_1), (x_2, y_2) and (x_3, y_3) should be found.

$$x_1 = \frac{f}{d}, \qquad y_1 = 0,$$

$$x_2 = \frac{f}{d\cos\{\tan^{-1}(\frac{2h}{w})\}}, \qquad y_2 = \frac{fl}{wd}$$

$$x_3 = \frac{f}{d\cos\{\tan^{-1}(\frac{2h}{w})\}}, \qquad y_3 = l + s$$

Here 's' is required length of dents to be extended to allow shed when reed is in its down most position. Similarly from point (x_1, y_1) reed dent should be extended by a line parallel to y axis to get line of beat up for ground portion without shape. This is illustrated in figure 4.4.

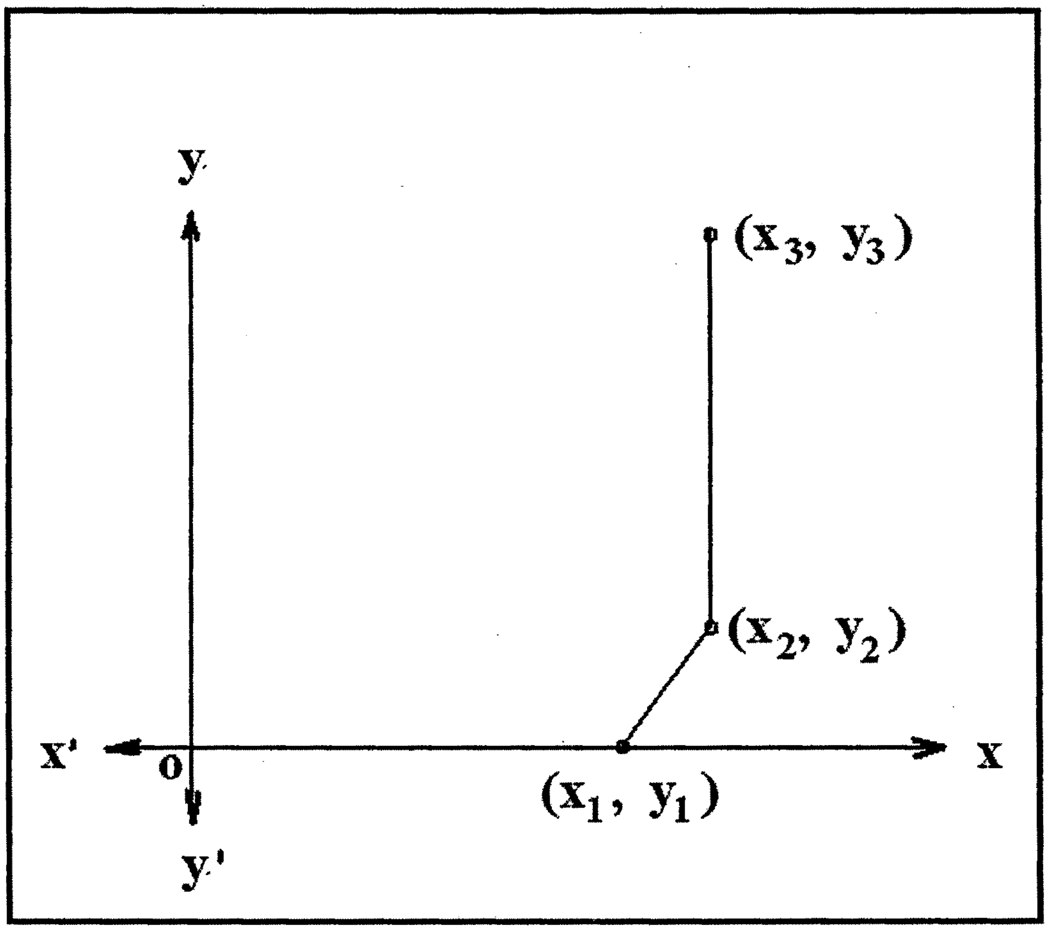


Figure 4.3

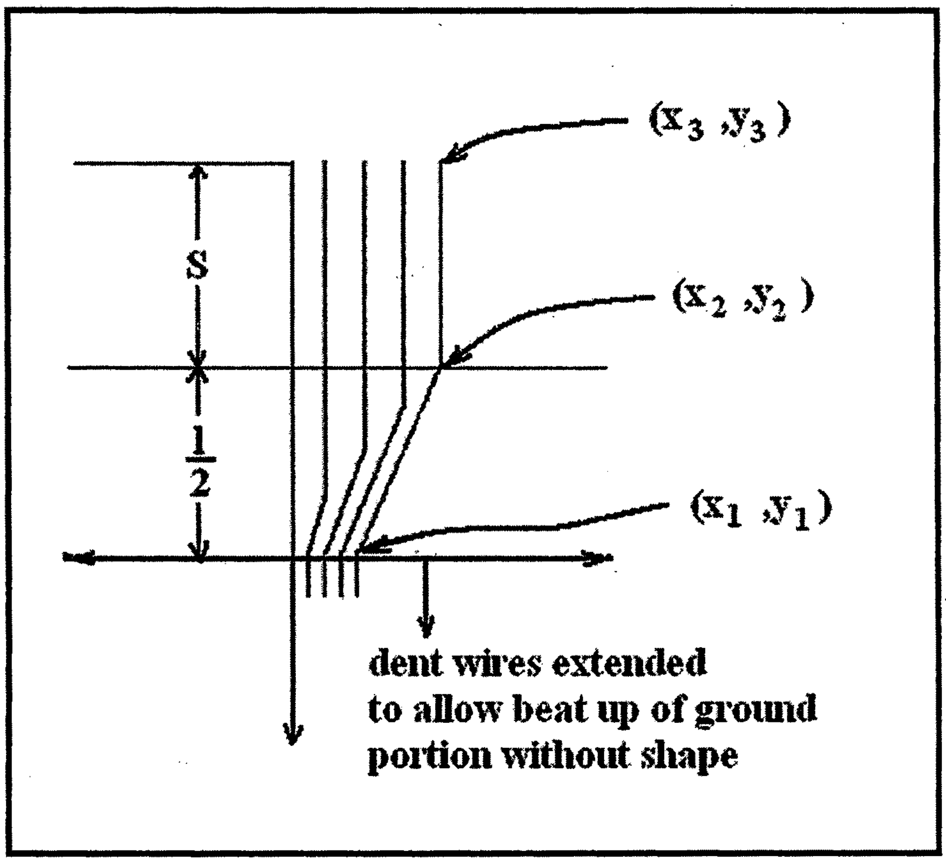

(x3 ,y3)
S
(x2 ,y2)
1
2
(x1 ,y1)
dent wires extended
to allow beat up of ground
portion without shape

Figure 4.4

v. As mentioned in 3.3.5.2.1 (Page 109) a tool is developed applying geometric transform that generates curves of shapes of reed dent wires for hemispherical and pyramidal shapes with MATLAB software.

vi. For generating skeleton grid view as well as curves of shapes of reed dent wires for hemispherical shapes four values are to be entered namely lower limit, upper limit, radius and number of threads. Lower limit and upper limit refers to distance between one end of the fabric to the other. Figure 4.5 shows skeleton grid view obtained with entered values of '-10' and '+10' for lower and upper limits respectively. Value of radius entered was 10. Therefore the skeleton grid view only would cover square portion covering entire shaped region. If value of radius entered is less than half the range between upper and lower limits, part of grid view would include part of portion without shaped region as shown in figure 4.6 where value of radius entered was 6. Number of threads refers to those present between the lower limit and upper limit. For out put shown in figure 4.5, value 21 was entered. Therefore there are total 21 grid lines. In reed there will be 10 dents as shown in figure 4.7.

vii. For generating skeleton grid view as well as curves of shapes of reed dent wires for pyramidal shapes, three values are to be entered namely lower limit, upper limit and number of threads. Values of lower limit and upper limit refer to distance between one end of the fabric to the other as it is in hemisphere. Number of threads refers to those present between the lower limit and upper limit. Figures 4.8 and 4.9 shows out put where values entered were lower limit = -12, upper limit = 12 and number of threads = 25.

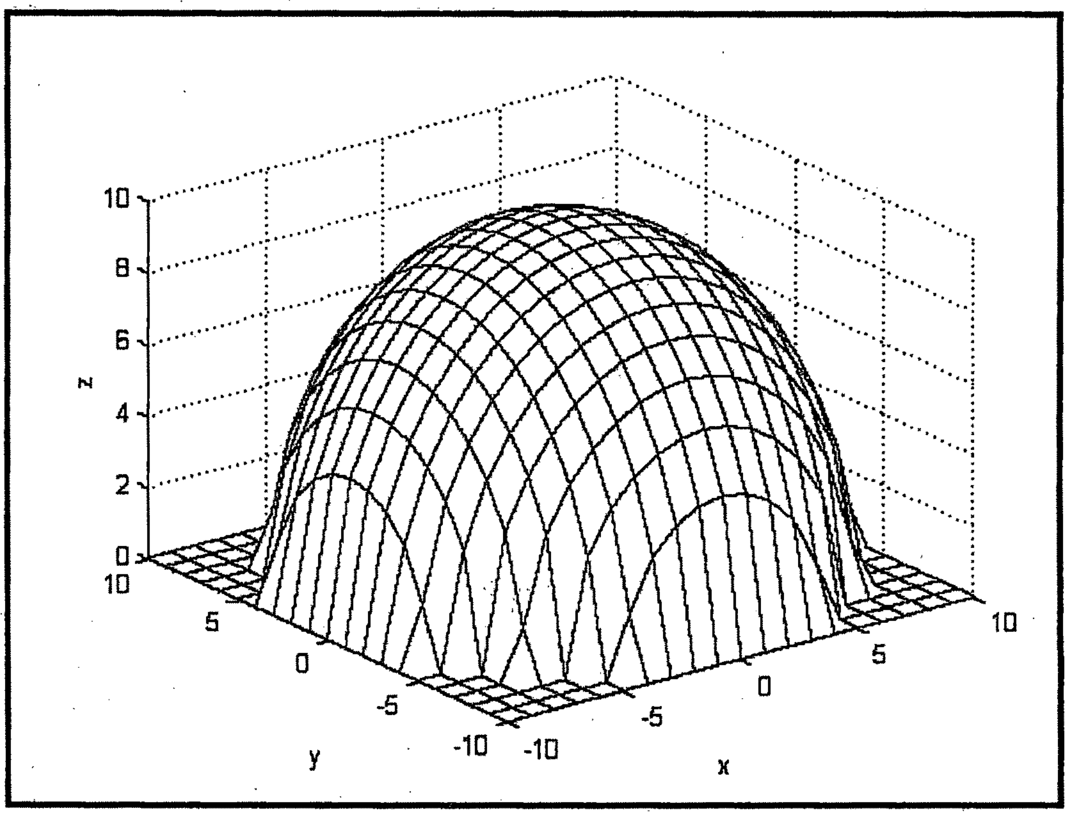


Figure 4.5

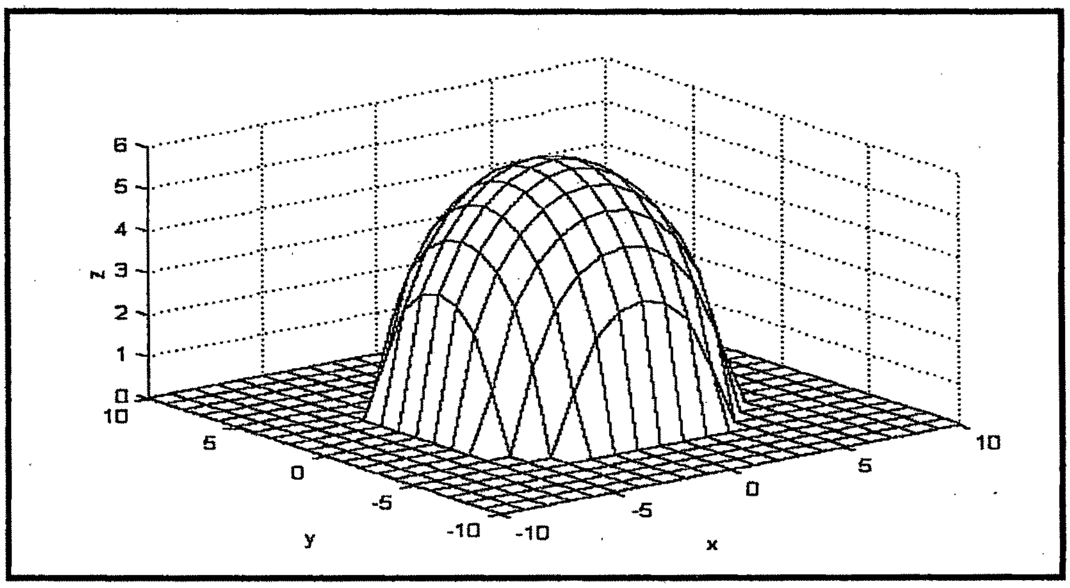


Figure 4.6

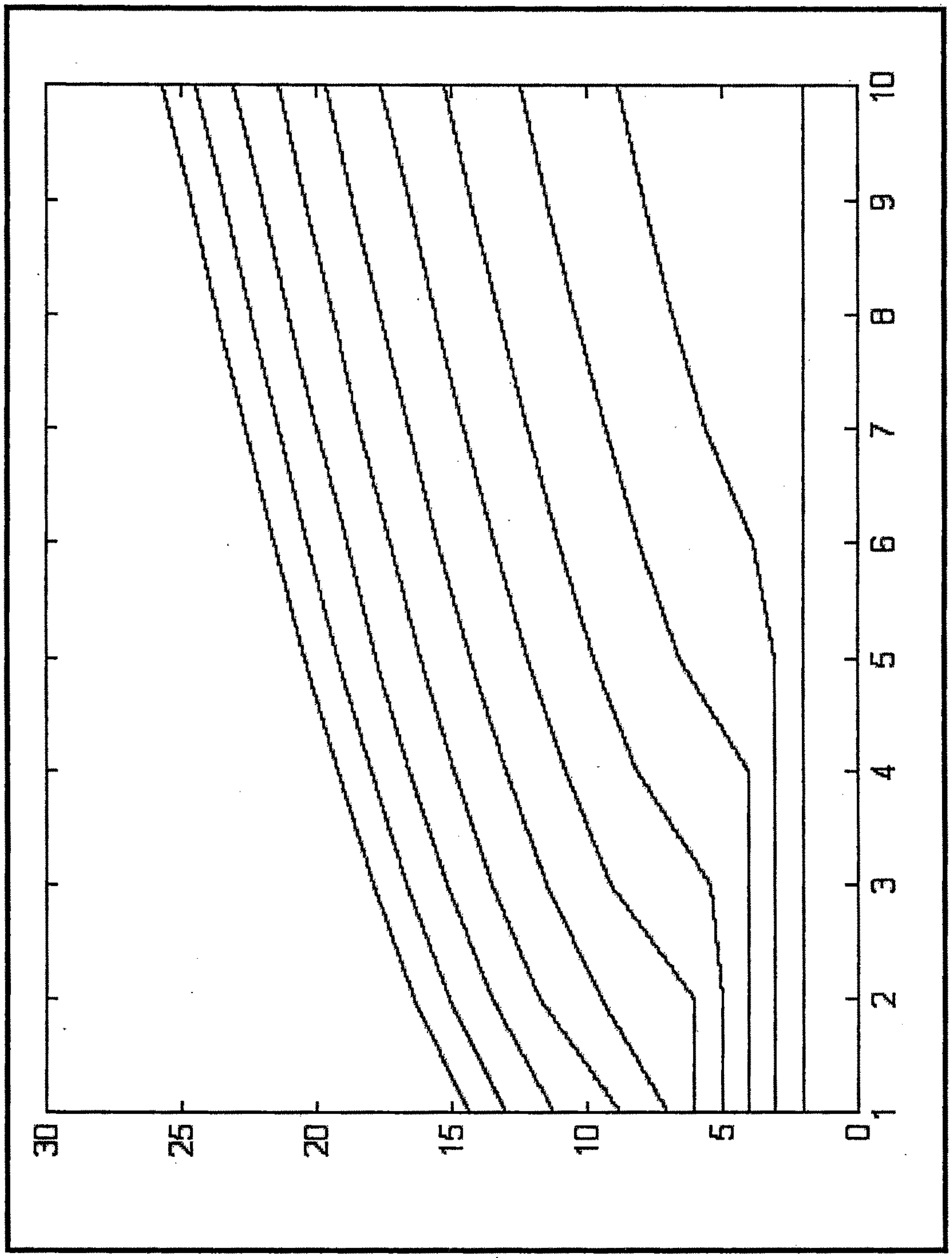


Figure 4.7

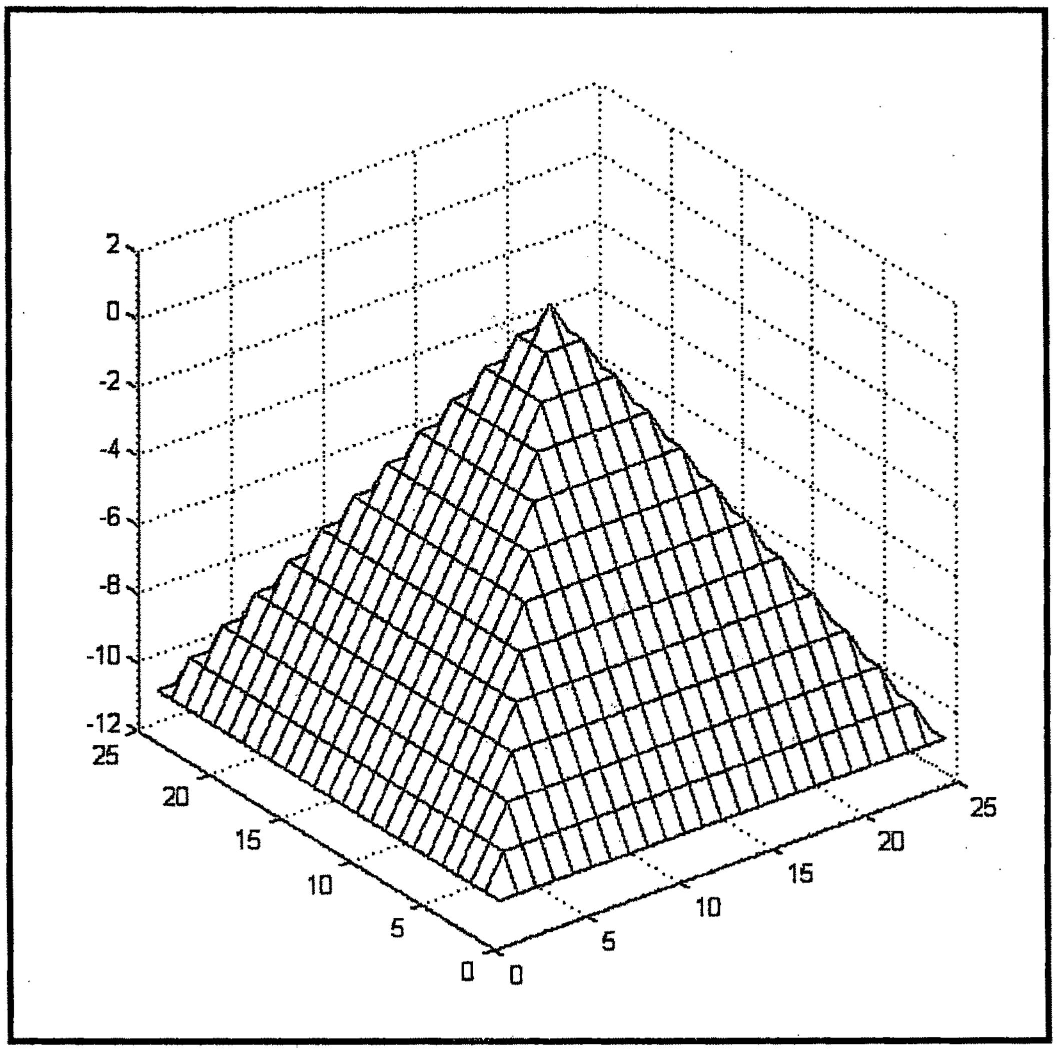


Figure 4.8

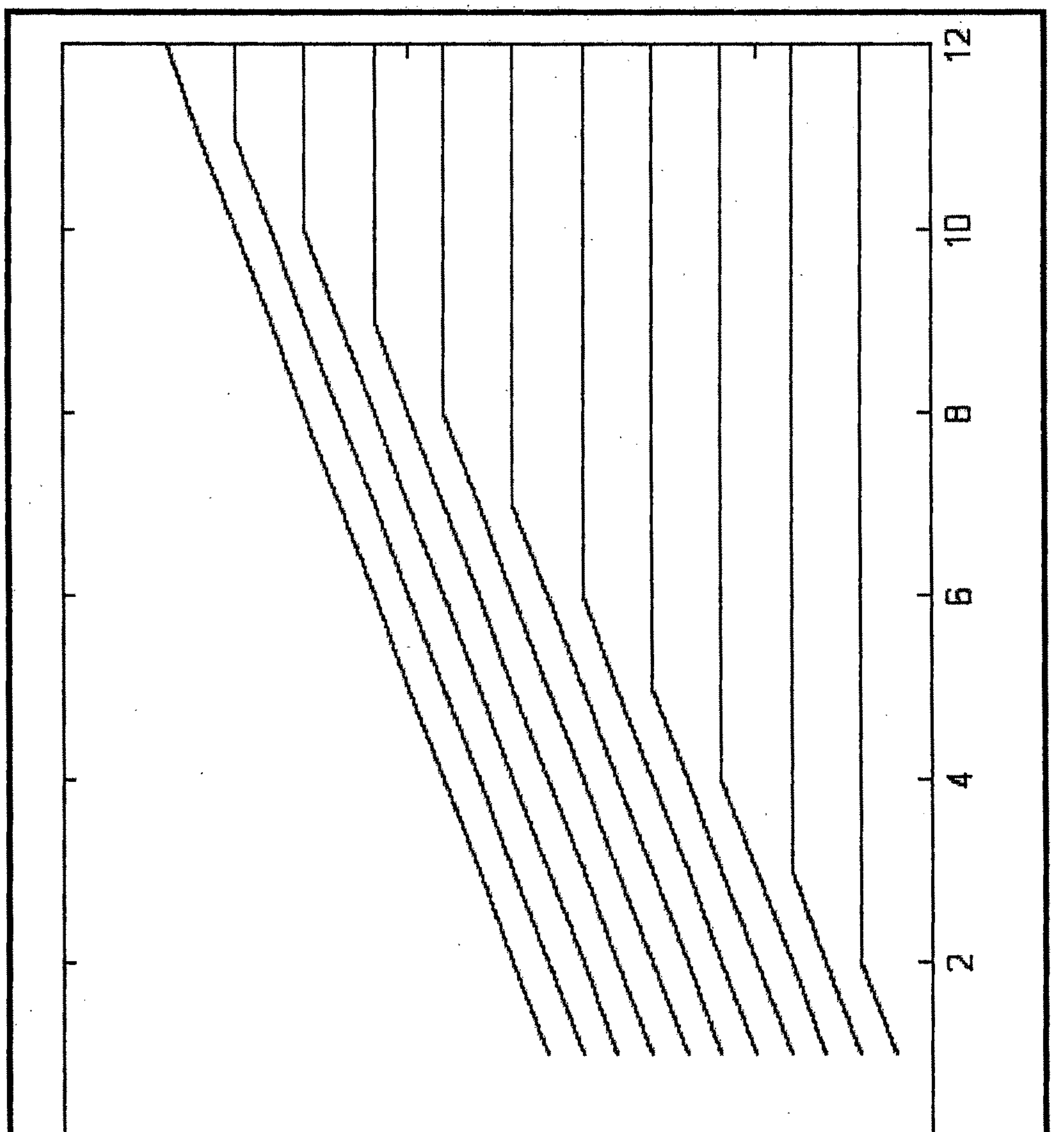


Figure 4.9

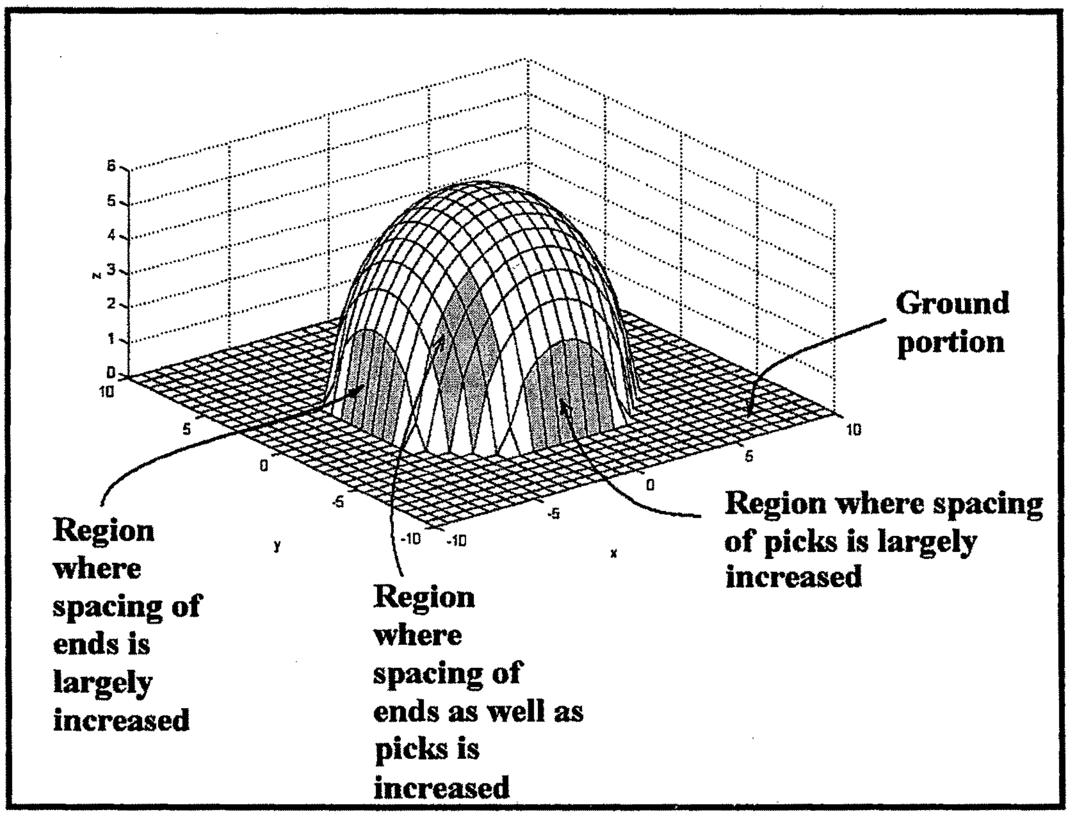
Out put obtained can be exported from MATLAB to other formats, e.g. BMP format. The figure size can be enlarged to required dimensions and print out can be obtained for fabricating reed. This tool is developed for pyramid whose length and width is same. There is no input of height. However, for pyramidal shape, shapes of dent wires for the reed can be obtained by enlarging out put by required amount.

viii. As described in 3.3.5.3 (page 111) pyramidal and hemispherical shapes were produced on handloom using reed with shaped dent wires. It became possible to weave these shapes. Following points were noteworthy for further work.

- Warp supply should be from a warp feeding creel with an arrangement to apply desired tension to ends and keeping this constant during weaving.
- The dimensions of shapes produced were smaller than those for which reed was designed. When weaving was carried out without weave assistance, i.e. using same weave all over, changes in spacing of ends and picks was not achieved as desired. Thread spacing is also influenced by crimp. The contraction, which is mainly caused by crimp, reduces actual dimensions of shape. Therefore shape dimensions taken for weaving should be larger than desired shape to an extent that will produce 3D shape of desired dimension after contraction. Crimp percentage depends upon factors like linear density, thread interlacements, tension etc. In a 3D shape thread density is non-uniform in shaped region. Therefore, it would be difficult to find those dimensions of shape which on contraction give exact required dimension. If any of the factors those

influence contraction largely vary from one piece to the other during weaving, exact dimensions will not be reproduced due to non-uniform contraction.

- In shaped region spacing of ends and picks vary largely. In some regions spacing can widen to a great extent as shown in figure 4.10. The fabric can become very open in these regions. Weaving process is required to be managed in such a way that such open regions are woven and retained. Manipulating weaves skillfully in such regions can cover the area and avoid openness. This would also help in generating and retaining shapes. This would necessitate jacquard shedding.
- Open spaces were covered well in pyramid that was woven with suitable weave employing jacquard shedding. Better shape uniformity was also observed.
- During weaving shaped region width of fabric at cloth fell changes from pick to pick. To keep warp and fabric under tension as well as maintaining fell at proper position, spring loaded hooks were anchored near closed end of fabric in region near cloth fell as shown in figure 4.11. These hooks were shifted, as fabric was woven pick after pick. Suitable mechanism would be necessary that would perform similar function during weaving on power loom.
- During weaving pyramidal shape in which weave assistance was obtained by selecting suitable weave with jacquard shedding, unequal length of fabric across width on successive picks is produced. For proper shape formation differential rate of take up across width of fabric on successive picks is necessary.



6
5
4
3
2
1
0
z
10
5
0
-5
-10
y
-10
-5
0
5
10
x
Ground portion
Region where spacing of ends is largely increased
Region where spacing of ends as well as picks is increased
Region where spacing of picks is largely increased

Figure 4.10

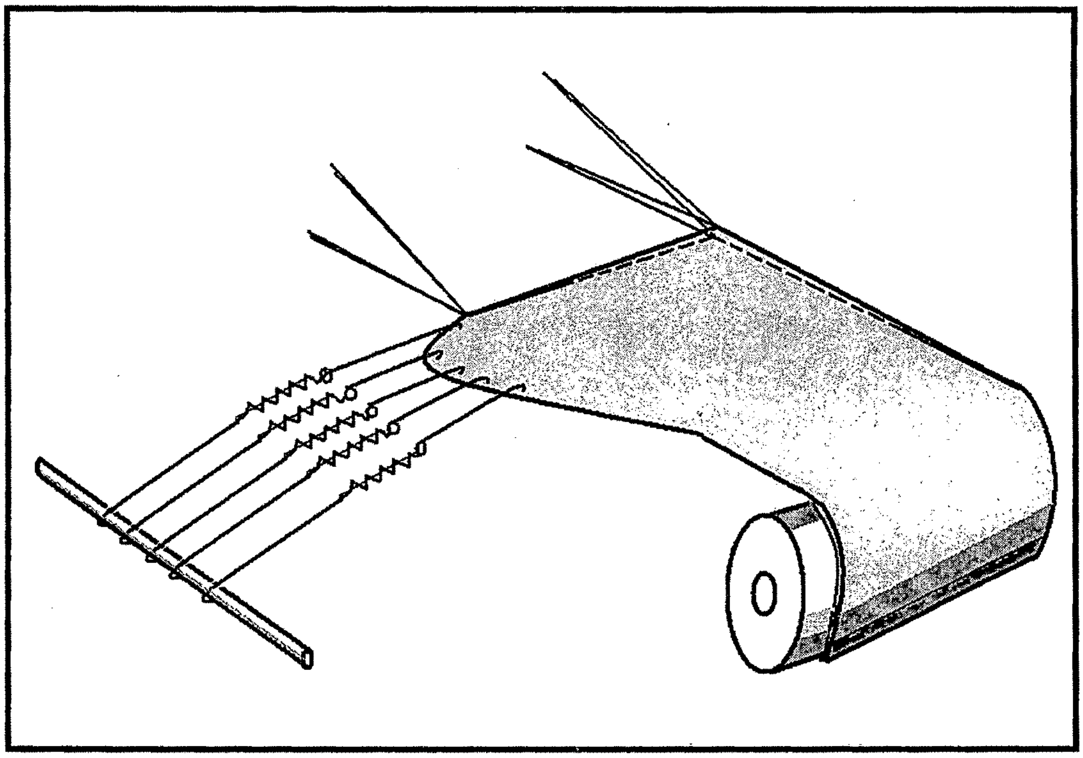


Figure 4.11

- Differential rate of take up should be such that it brings about change in spacing of picks depending upon shape profile. If this is not done and rate of take up kept is same, regions which are produced longer would tend to remain towards reed and those woven shorter would comparatively remain away from reed. As weaving was carried out without differential take up, irregularities occurred in shape formation.
- With greater angle between instantaneous direction of dent wire and that along reed height, difficulties are observed in shed formation. Therefore measures should be taken to keep this angle as low as possible.
- As path followed by ends as well as picks in shaped regions is different from one another, ideally there has to be an individual dent for each end and a take up motion that can take up each end at desired differential rate. Practically this is difficult as pitch of reed would become too fine and would give difficulty in reed fabrication. Actually a reed dent controls a small group of threads instead of an individual one. Practically it was observed that shape generated is not disturbed. However when jacquard shedding is employed, weave can be developed that can influence path of individual ends and picks.
- A mechanism is necessary that displaces reed vertically and give desired line of beat up depending upon shape profile.
- Finally it can be said that desired supply of ends at uniform tension, suitably designed reed and its position control, proper warp and fabric control, weave assistance and differential take up can produce desired shape.

- This method of producing 3D shapes is suitable for bilaterally symmetrical shapes only. The elements for shape formation for other shapes can be designed on the principle similar to that for pyramid and hemisphere.
- As 3D shape is woven in folded form, width of shape produced is about twice than that on loom.

4.4 Establishing set up for weaving 3D shape on power loom

After weaving 3D shapes on hand loom, subsequent stage was of establishing set up for weaving 3D shape on a power loom. Stage wise progress towards this is as follows.

4.4.1 Procurement of a power loom:

As described in 3.5.2.1 (page 128) a narrow loom with reed width of 20 inches was selected as larger dimension of 3D shape is obtained when it is unfolded out side loom. Narrower loom would require lesser ends, facilitate development of modifications as their dimensions would be smaller width wise.

4.4.2 Warp feeding creel:

As described in 3.5.2.2 (page 130), 800 capacity warp feeding creel was designed and fabricated. A pair of disc and washer type of tensioner is provided for each end for adjusting. Each end is suspended with a dead weight to act as a tension compensator.

4.4.3 Shuttle guidance through the shed:

As described in 3.5.2.3 (page 134), for guiding shuttle through shed without reed support, needle bar mechanism, as provided in lappet weaving was employed. This is required because it is difficult to produce reed with an absolute even face. Moreover reed is not fixed but displaces vertically during weaving of shape. This arrangement guided shuttle without any difficulty during picking.

4.4.4 Bracket for supporting reed:

As described in 3.5.2.4 (page 134), for initial trial of weaving 3D shape on power loom, a bracket was designed and fabricated for mounting and supporting reed. In this bracket, slides for supporting reed were made of wood. This arrangement worked satisfactorily for initial trial when reed was smaller and lighter.

After experience with initial trials, an improved single piece bracket was designed and developed as described in 3.5.4.1 (page 156). In this arrangement reed is fastened on an aluminium frame that is guided in slides. As this bracket was fabricated in one piece, alignment of two slides is always maintained which enables smooth and trouble free movement of reed.

4.4.5 Fabrication of reed with shaped dent wires:

In 3.5.2.5 (page 137) procedure developed for fabricating reed with shaped dent wires is described. For fabricating reed, reed manufacturers were consulted for fabricating reed with shaped dent wires. Even after interacting with them, explaining them specific features and requirements of the reed and supplying shapes of curves of reed wires, satisfactory reed was not fabricated. Therefore after trying several methodologies, suitable procedure could be developed for reed fabrication.

4.4.6 Mechanisms for reed displacement vertically:

To change spacing of ends during weaving, reed is required to be displaced vertically to change line of beat up. For initial trial a mechanical reed position control system was developed. Subsequently a programmable stepper motor drive was developed for reed position control.

4.4.6.1 Mechanical system for vertical reed position control:

- As described in 3.5.2.6 (page 140), a mechanical system was developed for displacing reed vertically. This mechanism was suitable for smaller reed dimensions and therefore smaller shapes as only 140 mm total displacement was possible. Reed displacement per step (for one teeth rotation of movement of ratchet) was larger. Therefore, instead of displacing reed every pick, it was displaced after interval of some picks to enable production of little bigger shape.

This arrangement worked satisfactorily for initial trial and confirmed that weaving becomes possible with reed displacing vertically.

4.4.6.2 Programmable stepper motor drive:

A described in 3.5.4.2 (Page 158) a programmable stepper motor drive was developed. This drive worked successfully. Main features of this drive are as follows.

- Basic driving element is a 200 steps, 60 kg-cm torque stepper motor.
- Every pick a pulse is generated by a proximity switch through an actuator mounted on crank shaft.
- On receiving pulse, stepper motor drive controller determines the rotation of stepper motor depending upon values fed in programme.
- Through programme, stepper motor stepper motor can be made to rotate in multiples of steps of $\frac{1}{200}$ rotation in any direction (clockwise/ anticlockwise) or can be kept stationary.
- Thus amount of rotation and its direction can be programmed per pick.
- There are in total five counters in the drive controller. Each counter is to be input with two values. One value decides direction of rotation of rotation of stepper motor and the other one the number of picks for which that rotation is to be given. Thus with five counters, five different mode of rotations of stepper motor for corresponding number of picks can be obtained.
- Stepper motor programming through a computer was developed as mentioned in 3.5.4.4.1 (page 173) as a subsequent development. This enabled storing of programmes run and retrieving them as and when desired.

Through a suitable mechanism the drive from stepper motor shaft should be transmitted to reed so that desired reed displacement can be obtained. Two mechanisms were designed and fabricated for this purpose, viz. -

i. Screw mechanism.

ii. Pulley and cord mechanism.

4.4.6.2.1 Screw mechanism:

As describe in 3.5.4.3.1 (page 161), a screw mechanism was developed to transmit drive from stepper motor to reed. Out come of this effort was as follows.

- This mechanism did not perform satisfactorily for the following reasons.
- Mounting of entire mechanism was on rocking shaft including stepper motor because reed moves to and fro with sley. Due to greater mass of mechanism, its angular position was getting disturbed. Due to this, misalignment was taking place between line of motion of screw and that of reed in its supporting bracket.
- Reed was also comparatively heavier (up to 5 kg) and bigger in dimension. There was only one point of transmission of drive from screw to reed was possible from bottom as screw mechanism was located at bottom. It was difficult to locate this point exactly in line with center of gravity of reed. Therefore some imbalance was created.
- Therefore, with misalignment of motions of screw and imbalance created due to transmission of drive from screw to reed only at one

point, reed was not moving freely. So torque requirement was exceeding the torque limit of stepper motor and so this development did not work. Severity of problem was acute with larger displacement required per pick.

Considerable time and effort was spent in design and development of screw mechanism but it did not work. So doubt arose whether torque of stepper motor was enough or not. However 60 kg-cm torque stepper motor can generate 60 kg force at a distance of 1cm from centre of its shaft, i.e. it can lift mass of 60 kg with a cord wound on a pulley of 1 cm radius on stepper motor shaft. The mass of reed does not exceed even 5 kg. Therefore attempt should be done to develop a simple mechanism that is mounted out side sley and that generate minimum friction. Keeping these things in mind, pulley and cord mechanism was developed.

4.4.6.2.2 Pulley and cord mechanism:

As described in 3.5.4.3.2 (page 163) a pulley and cord mechanism was developed. In this mechanism stepper motor and other elements of drive are mounted out side sley. Stepper motor rotates a pulley. One end of cord is fixed on the pulley and the other end is connected with reed at top. On rotation of pulley, the cord winds or unwinds that causes lifting / lowering of reed. The elements added on sley consist of extension on bracket supporting reed with small pulleys and cord. The mass added is negligible. This mechanism worked satisfactorily. Following points of this mechanism are noteworthy.

- A pinion of 24 teeth on stepper motor shaft drives a pinion of 90 teeth on pulley shaft. Therefore torque available on shaft of pulley is $[\frac{60\,x\,90}{24}]$, i.e. 225 kg-cm. Radius of pulley is 3.2 cm. Therefore, mass of $[\frac{225}{3.2}]$ kg, i.e. Approximately 70 kg can be lifted. Apart from weight of reed, other major forces to be considered are friction and inertia. As the mass of reed was at the most 5 kg and frictional force involved is minimised, no difficulty was observed in reed displacement even for greater reed movement per pick.

- When stepper motor is programmed for one step rotation, minimum possible reed movement is obtained, i.e. $\frac{\pi.24.64}{200.90}$, which equals approximately 0.202 mm. Thus reed movement can be adjusted in multiples of very fine steps of 0.202 mm. If required this can be changed by changing pinions.
- As this drive mechanism is mounted out side sley, motion of sley can disturb reed position. As stepper motor pulley is located at considerable distance from loom on right hand side of loom, practically there was no influence of sley movement on reed position.
- The cost of such mechanism would be low.

4.4.7 Shedding mechanism:

For initial trials dobby shedding was employed. Subsequently jacquard shedding was employed.

4.4.7.1 Dobby shedding:

As mentioned in 3.5.2.1 (page 128), a 16 jack double lift single cylinder climax type dobby was employed for shedding during initial trials. Dobby worked without any problem. How ever, only simple weaves could be employed as ends could not be controlled individually. Therefore weave assistance in generating and retaining shapes could not be obtained. However it proved very useful to confirm working of loom under different conditions of weaving like moving reed with shaped dent wires, changing width at cloth fell; warp supply from warp feeding creel etc. Double cloth was woven without any difficulty.

4.4.7.2 Jacquard shedding:

After encouraging results from initial trials, 800's capacity double lift double cylinder jacquard shedding was employed to control ends individually and employ weave that will assist in shape generation and retention, as mentioned in 3.5.4.5 (page 173). Due to quite unusual weaving conditions during weaving 3D shaped region, i.e. changing width at cloth fell that makes it difficult to decide count of comber board and also prevents ends from lying straight between mail eyes and reed dents, use of a larger sized reed that is displaced vertically and located towards rear side reed etc. presented many difficulties in setting up jacquard. After putting in considerable effort, ultimately jacquard shedding could be set up. Following points are noteworthy regarding this:

- Comber board with 72's count was selected.
- Comber board along with bracket that supports and carries it, was required to be shifted backwards due to greater dimension of reed in terms of height as well as its displacement vertically.
- Shifting comber board backwards, shifted heald eyes backwards, which necessitated greater lift for heald eyes.

- While increasing lift, knives were interfering with each other. This problem was overcome by making modifications as described in 3.5.4.5 (page 177).

4.4.8 Mechanism to control fabric, under situation of changing width at cloth fell during weaving of shaped region:

Changing width of fabric at cloth fell during weaving of shaped regions necessitated replacement of conventional temple by a different mechanism. This mechanism should allow changes in cloth width, at the same time keep fabric stretched and under control at cloth fell.

4.4.8.1 Fell control mechanism using combs:

As described in 3.5.2.7, a fell control mechanism employing two combs was developed initially. This mechanism allowed weaving during initial trials. A method was also evolved to fabricate combs.

4.4.8.2 Fell control using series of spiked rollers across full width:

As described in 3.5.5.5.1 (page 183), a fell control mechanism employing series of spiked rollers across full width was developed subsequently.

4.4.9 Conical roller for control of shuttle flight:

In this weaving left hand selvedge can not located closer to left hand shuttle box. Therefore shuttle is supported by needle bar and race board, without any aid by shed, as it leaves left hand shuttle box. This leads to increased chances of shuttle flight during weaving. To prevent this, a conical roller was mounted above race board nearer to left hand shuttle box, as described in 3.5.5.5.2 (page 183). This roller was found to be very helpful in controlling shuttle fight.

4.5 Results of weaving 3D shapes on power loom :

Initial trial of weaving pyramidal shape on power loom was taken with warp supply from warp feeding creel, mechanical reed position control, dobby shedding and fell control mechanism using combs.

The results were as follows:

- Warp threads were supplied uniformly from creel.
- Mechanical reed position control mechanism as describe in 3.5.2.6 could displace reed. Some times ratchet of the mechanism over ran while descending due to torque exerted by weight of the reed on cam shaft through follower and cam. How ever, the displacement was acceptable for trial.
- Shaped dent wires of the reed brought about changes in spacing of warp threads at reed. This confirmed that reed with shaped dent wires can be used on power loom too.
- As the distance between right hand selvedge to shuttle eye with shuttle in right hand shuttle box, was smaller than that when was in left hand box, loops of weft were formed at right hand selvedge. To avoid this, the right hand selvedge should be located in the middle of shuttle eye position in two boxes or should be towards right hand side or shift the location of shuttle eye.

- To prevent loop formation, two extra eyes were fixed in the middle of front wall of shuttle box on weft as described in 3.5.3. This increased weft tension which caused other problems. Therefore in subsequent work, it would be necessary to ensure locate right hand selvedge at suitable place.
- Fabric width was the narrowest while weaving ground portion and would increase while weaving shaped portion. Wide gap between entry point of right hand shuttle box and left and selvedge while weaving ground portion caused difficulty in controlling shuttle flight. This happened because on leaving left hand shuttle box, shuttle was guided by needle bar and race board only without any control by shed. In subsequent development, suitable means was to be sought to over come this problem.
- Fell control mechanism with combs was developed to control fabric at cloth fell as discussed in 3.5.2.7 (page 143). The function of the combs is to allow changes in spacing of ends brought about by reed and retain them. Any lack of control in this regard was found to cause problem in weaving.
- Consider case when fabric width has been increased by reed. Fell control mechanism has to allow this increase in width and keep the fabric stretched at cloth fell so that width of fabric at cloth fell remain equal to that of warp in reed. If fell control mechanism looses its control on fabric, warp tension drags the portion of fabric which has been widened by reed, towards reed. Therefore effective width of fabric at cloth fell reduces. This causes deflection of ends at left end of fabric around reed wires. These ends exert pressure on dents of reed located at left end. Due to this, the dent wires in this area tend to come closer to one another. At times they may touch one another. If the dent wires come very close to one another

or touch, the ends passing through these dents can not move freely which hinder shed formation. If clear shed is not formed on left hand side, shuttle starts flying.

- Deflection of ends around dent wires also causes all ends passing through a dent, line up vertically. This creates a thick band of ends towards left end which form a sort of '*bump*' for the shuttle. Therefore shuttle flight is caused.
- Dragging away of the portion of fabric which has been widened by reed, towards reed by warp tension also causes slackening of ends on the left hand side. Therefore when shuttle moves from left hand to right hand shuttle box, weft drags these ends towards centre of fabric. This causes further decrease in fabric width at cloth fell, causing further difficulties in picking. Therefore for trouble free weaving, width of fabric at cloth fell must be maintained exactly equal to that of warp in reed.
- For maintaining width of fabric at cloth equal to that in reed, a mechanism with two combs was developed as discussed in 3.5.2.7 (page 143). The comb nearer to reed is lifted when reed approaches towards front centre and is lowered suddenly by a spring force at front centre to '*lock*' the change in warp thread spacing brought about by reed. When this comb is lifted, the other comb is held down to retain fabric to same spacing of threads as that '*locked*' by comb nearer to reed. With higher weaving resistance, cloth fell position shifts backwards from front most position of reed. Shifting of cloth fell position backwards from front most position of reed does not allow '*locking*' of fabric width at cloth fell to width equal to that of warp in reed as comb can not penetrate on pick that is woven last. If this happens, proper control is not exercised at cloth fell because of which width at cloth fell become less than that of

warp in reed, and problems stated in previous point starts. Therefore, for proper control of fabric at cloth fell, fell should be located at front most position of reed. It was observed that when cloth fell was remaining backwards from front most position of reed, weaving became difficult due to lack of control on fabric at cloth fell. When finer wefts were taken replacing coarser ones and the cloth fell lied at front most position of reed, proper control was exercised on cloth fell and it became possible to continue weaving. In short it was observed that when cloth fell lies at front most position of reed, proper control can be exercised on cloth formation and weaving becomes possible.

- Weaving resistance is related to fabric cover. In 3D shape portion the spacing of ends and/or picks, gets widened depending upon shape profile. Therefore fabric tend to be open than it is in ground portion. To cover up the openness created in shaped region, one of the options is to increase binding points in the open region. For this reason, the fabric in ground portion should be with '*crowded*' ends and picks, with fewer interlacements. But keeping threads '*crowded*', means attempting for highest possible cover factor. This is contradicting requirement.
- While attempting to weave with high crowding of ends, ends could not cross one another and shed formation became impossible. For given linear density of ends and given pitch of reed, there is a limit beyond which ends per unit space can not be increased. As 3D shape is woven in folded form, maximum number of ends per unit space that can be taken in ground portion of single cloth is half of maximum that can be taken in double cloth. This also limits to '*crowding*' of ends that is desired.

- With given end density and weave, picks can be '*crowded*', till fell of the cloth tend to remain at front most position of reed to avoid problems in weaving, i.e. pick density can be increased till fell of the cloth would remain at front most position of reed. This limit of pick density can be increased by opting for a weaving machine for weaving heavier fabrics and keeping higher warp tension during weaving. With warp supply from beam higher warp tension can be managed. With warp threads fed from creel, managing very high warp tension becomes difficult. Moreover, very high warp tension necessitates higher force to change spacing of warp threads and control fabric at cloth fell.
- Thus, in subsequent stage of development suitable solution was to be sought to overcome the difficulties mentioned above.
- For initial trial dobby shedding was employed. Therefore there was no assistance of weave in generating and retaining shape. End spacing was changed by reed but pick spacing was not changed as there was neither assistance of weave nor provision of differential take up. Therefore proper 3D shape was not generated.
- During weaving shaped region fabric width at cloth fell was changing. No difficulty was observed in shedding, as heald wires could slide freely and change their spacing according to those brought about by reed. Difficulties would be expected when jacquard shedding was to be employed in subsequent stage.
- Instead of displacement to reed every pick, reed was displaced once in eight picks. No major visual disturbance was observed in sample.

In subsequent stage pyramidal shape was woven with improved set up consisting of an improved bracket for supporting and mounting of reed, programmable stepper motor drive with pulley and cord mechanism to transmit drive from stepper motor to reed, jacquard shedding employing weave that assists in shape generation and retention, fell control using spiked rollers across full width and conical roller for controlling shuttle flight.

The results were as follows.

- Programmable stepper motor drive with pulley and cord mechanism to transmit drive from stepper motor to reed displaced reed as required.
- Reed brought about change in spacing of ends as per shapes of dent wires.
- When reed changes spacing of ends, spacing of individual heald wires carrying lingo at bottom is also changed. Force for this is given by dent wires through wires. This would influence tension of individual ends. However proper shed formation occurred provided fell control mechanism managed to maintain width of fabric at cloth fell equal to that of warp in reed at all stages of weaving.
- As jacquard shedding was employed using weave that would assist shape formation, weave assisted in changing spacing of ends and picks.
- Due to assistance of weave in changing spacing of picks, differential length of fabric was woven across width, on successive picks.
- For proper weaving take up motion that can give differential take up rate across width on successive picks is necessary. In normal

take up a cylindrical take up roll is provided that takes up entire fabric at same on successive picks. For generating 3D shape, take up motion can be imagined to be composed of take up roller divided in several segments. Ideally there has to be a segment for each warp thread. Preferably these segments should be located at cloth fell. Each segment should have its individual drive. Amount of rotation of a segment on a particular pick will decide rate of take up of its end for that pick or will decide gap created between those picks at that end. This is determined by shape profile. This requirement has been understood clearly in principle but it has not been possible to develop such mechanism.

- Due to constant rate of take up, areas where fabric produced is longer, tend to shift towards reed. Therefore cloth fell does not remain in straight line. When some portion of cloth fell shifts very close to reed difficulties arise in picking. Moreover, there is non-uniform beat up of weft across cloth fell.
- However, weaving was carried out for the entire shaped region manipulating fabric at cloth fell manually. But this could not maintain uniform desired conditions during weaving.
- Ultimately it can be said that almost all conditions necessary for weaving a three dimensional shape, as identified through weaving on handloom, were met with on power loom except differential take up. If this could be developed desired 3D shape could be produced.