Geometrical Analysis of Single Lift Single Cylinder Mechanical Jacquard Shedding Mechanism for Ethiopian Hand-Loom Products

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Abstract
Ethiopia with its diverse cultural backgrounds of its people and varieties of natural resource has a rich heritage of crafts skills. As part of the handicraft heritage, Ethiopia has diverse traditional hand-loom products and handicraft is considered to be one of the most important and widely spread occupations next to agriculture.To producecomplex pattern hand-loom products without the use of extra drawstring mechanism, the use of a draw boywas relevant because the design operated by hand for each line and certain threads were pulled by experienced weaver to get finished pattern. This process is slow and tedioustherefore single lift single cylinder mechanical jacquard shedding mechanism is one of alternative solution. Since it is designed to control each warp ends independently and to produce maximum variety of warp shed for utilizing and producing diversifiedhand-loom productswith the minimum amount of mechanism mounting and space. However, it forms a bottom-closed shed which highly strained the lifted warp ends and causes end breakage. Together with much wasted movement, it requires more time to form shed and it can drastically limit the speed of the machine. The goal of this study works describe the geometrical analysis of single lift single cylinder mechanical jacquard shedding mechanism in order to formulate a simplified mathematical model and correlate warp strain with the required shed height, shed angle, head lever rotary angle and all angles in cylinder changing mechanism. Thus, it exemplified the warp strain for any change in geometry of single lift single cylinder mechanical jacquard shedding mechanism. There by the geometrical analysis were started from analysing the warp strain for bottom-closed shed and were tried to correlate warp strain with the required shed height through the actual boat shuttle size, and shed angle, and also by relating its calculated result directly with the lifting and cylinder changing mechanism as well.
Keywords: Warp Strain; Shed Geometry; Single Lift; Single Cylinder; Jacquard Mechanism

I. Introduction

As part of the handicraft heritage, Ethiopia has diverse traditional hand-loom products. This sub sector provides large-scale employment and is an important source of livelihood for numerous people in urban and rural areas. Based on the data collected in Year 2002 by the Central Statistical Authority (CSA) on cottages and handicrafts, it was revealed that there were a total of 211,842 hand-loom weaving textiles enterprises in the country in various forms of ownership though benefits accrued from this sub-sector was much below than expected [1, 2]. It is against the above background and the desire to enhance the economic growth through the export of homemade products that the development and promotion of Ethiopian hand-loom products is given due attention. This is also a deliberate effort to stimulate the growth and potentials of this sub-sector. The growth of this sub-sector necessarily requires the creation of demand of hand-loom products [1]. One of the means to achieve this goal is through seeking the export market by making the product more versatile in design and increasing the production capacity as well with the required quality. In order to sustain the hand-loom sector, it is essential to put in continuous efforts to upgrade the hand-looms and to improve the productivity and reduce the fatigue so that the weaver's earnings are improved. Scientific advancement and technology are not only an integral part of industry but also major determinants of competitiveness. For a meaningful intervention for technology change, it is important to understand the prevailing level of technology [2, 3]. Vital areas concerning improvements and innovations in process and skill level which can bring about major changes in the way things are done. It is sometimes forgotten that the hand-loom sector thrives totally on the skill of the weaver [4]. It is also forgotten that it is the manual labor involved in the process of hand weaving. Any change that requires extra labor or develops quick fatigue to the weaver will be rejected. However, positive interventions in these areas would result in substantial savings in human effort, time, energy and other valuable resources [3, 5]. Weaving was mostly done with hand-looms for diverse traditional and cultural fabric in Ethiopia. So that weavers had to undergo a complex process of maintaining designs in the textile. Some weavers used draw looms. Draw looms had extra drawstrings on a harness mechanism which was attached above and to one side of the loom. The weaver had to employ a draw boy or girl usually drawer is a boy to pull or draw the mechanism when required. Immensely complicated patterns could be produced on draw looms because the extra drawstrings multiplied the weft combinations [5]. It was the time of the Industrial Revolution in Europe, where everyday entrepreneurs were coming up with new inventions. Joseph Marie Jacquard, a weaver and entrepreneur from France, realized that weaving tapestry was a delicate and repetitive process. So, he designed an improved loom, now known across the world as the jacquard loom. The functioning of the loom was governed by a series of punch cards and produced complex patterns without the use of extra drawstring mechanism. So that hand-loom weavers would make their own designs and punch the cards themselves [5]. The jacquard machine is designed to control and operate each warp ends independently to produce maximum variety of warp sheds for ornamenting purpose with the minimum amount of mechanisms, mountings and space [5]. Jacquard shedding motion is used in weaving designs that are beyond the scope of dobby shedding motion i.e. designs which consists of more than 24 different order of interlacing [6, 7]. The principal differences between so called plain, harnesses draw boy, dobby, and jacquard looms lie in the shed formation mechanism [8, 9]. Shed formation is the central technology of weaving. No other aspect of the loom has received as much attention, nor been elaborated into as many complex variations. Jacquard machine may be divided into three main parts; one is jacquard head (engine) which consists of knives, hook, needle, spring, and cylinder and pattern paper. The second is a harness which consists of neck cord, harness cord, mail and lingo. Each warp end passes through a single harness cord, consisting of a central eye for the warp and upper and lower eyes for attachment to the mechanism [9]. And the third is a mechanism which links the jacquard head (engine) to the weaving machine. A mechanism consists of levers that connect the main shaft to the knives. It is the connection which controls the up and down movements of the knives. The knives in turn move up and down hooks to form the shed according to the shed design. Thus, shedding mechanism does its work by raising or lowering the harness cord, hence the warps. It also characterized by three principal motions as distinctive features of selection, lifting and drives mechanism that links the jacquard head (engine) to the weaving machine [7]. Generally, a single lift single cylinder mechanical jacquard shedding mechanism is mostly used for hand-looms [10] and the shed is formed by raising the hooks through the knives that makes the bottom shed is stationary. Hence, it can form a bottom-closed shed. There is therefore much wasted movement, together with a tendency for the whole harness to swing. The cylinder must reciprocate and turn and also the griffe must rise and fall every pick [6]. This requires more time to form the shed. This consideration drastically limits the speed at which the loom can be run. Additionally, the lifted warp ends are highly strained and this may cause end breakage.

A. Principle of Single Lift Single Cylinder Jacquard

In single lift single cylinder mechanical jacquard shedding mechanism, the design is transferred from squared paper design to pattern cards in the form of holes and blanks. A hole indicates a lift of an end and a blank indicates a fall of an end.

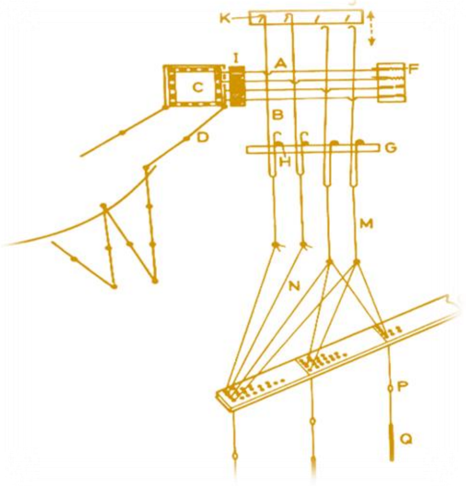


Fig1. Principle of Jacquard Shedding[7]

One card controls the selection of all ends in the cloth for one pick [7]. In the diagram, each horizontal needle **'A'** is connected to a vertical hook **'B'** by forming a loop and is supported by needle board **'I'**, through which it projects slightly. The rear end of each needle, which is formed in to a narrow loop is pressed by a spiral spring **'F'** to ensure the return of the needle to the original position after each selection. The hooks are prevented from turning sideways by doubling up their lower ends and passing them through narrow slits in grate **'G'** with the bent ends resting on spindles **'H'** when the hooks are in the low position. The number of needles in each short row varies from 4 up to 16 and the number of short rows is multiplied to give the required size of machine [7]. It is a general rule to connect the needles and hooks in the order shown in the ***Figure 8***, the top needle being connected to the hook nearest too, and the bottom needle to the hook farthest from the cylinder **'C'**. The same number of inclined lifting knives **'K'** is carried in iron frame or griffe **'J'** as there are hooks **'B'** in a short row. A card cylinder **'C'**, over which the pattern card **'D'** passes, contains on each surface a hole opposite to the end of each needle. Each face of the cylinder is provided with two pegs which act as the locating points to ensure proper registration of the card against the cylinder perforations[6]. The number of cards **'D'**, which is equal to the number of picks in the complete one repeat of a design are laced together at the sides and in the middle, and then the last card is joined to the first so that an endless chain is formed. The pitch of the needles and holes in the card cylinder and cards is exactly the same [10]. The harness consists of neck cords **'M'** that are suspended from the hooks **'B'**; harness cords **'N'**, which are connected to the neck cords and passed separately through holes in a comber board **'O'**; mails **'P'**; and lingoes or weights **'Q'**. The number of harness cords, mails, and lingoes, connected to each neck cord **'M'**, varies according to the tie and sett of the harness. By means of lingoes **'Q'**, the warp threads, cords and hooks are returned to their original position after they have been raised [6, 10].

II. Materials and Methods

A. Materials

Equipment and material: All equipment and material have been used for this study of works are listed as follows: card lacing, card puncher, caliper, jute and 20 Ne cotton yarn, meter, ruler, setsquare and compass.

Software: AutoCAD, GEOGEBRA and Mech Analyzer mechanism analysis software were utilized for studying the motion of each link during single lift single cylinder jacquard shed formation mechanism.

Machine components: Different type of component has been studied, and each component has its own role and setting relative to the other for precise shed formation. In this study of work components were used as follows: head lever, knives, hooks, needles, cylinder, neck cord, harness cord, mail and lingo.

B. Methods

There are many hand-loom enterprises in Addis Ababa and around in various form. However, the data were collected and organized for ten hand-loom enterprises which had jacquard hand-looms from Ethiopian textile industry development institute (ETIDI) because the institute was tried to collect data every year throughout Ethiopia. And assessments were also done for five randomly selected hand-loom enterprises out of ten hand-loom enterprises for confirmation and reliability of the collected data. Hence, the data collection was incorporated to find out the major parameter of the study called geometrical analysis demand determination.

In order to determine the demand, the basic parameter were collected selectively and used as a reference for the geometrical analysis of single lift single cylinder mechanical jacquard shedding mechanism as shown in ***Table 1***. However, the collected demand data were based on the current hand-loom design. So that it is not satisfactory at the later age when it is more familiar to varies type of design. To solve this limitation, demand projections were made for future use. Furthermore, demand corrections were also done for the data having different value, hence only one single value were obtained for each parameter.

Table 1: Specification of Components

No.	Components	Specification	Unit
1	**Length of Griffe Connecting Link**	**250**	**mm**
2	**Length of Cylinder Connecting Link**	**265**	**mm**
3	**Length of Swing Frame**	**210**	**mm**
4	**Initial Warp Length**	**1370**	**mm**
5	**Length of Head Lever**	**264**	**mm**
6	**Cylinder Lifting Height**	**10**	**mm**
7	**Cylinder Forward Movement**	**35**	**mm**

III. Calculation and Discussion

A. Warp Strain

When the harness are on the warp line (harness are leveled), the path taken by the warp is the shortest. However, as the harness move away from the warp line, the warp takes a longer path [11]. Thus, warp yarns are extended which has to be compensated either by the extensibility of the warp or by the regulation of the yarn delivery system.Hence, length of front shed *'L_1'*, length of back shed *'L_2'* and shed height *'H'* are the main shed parameters as shown in ***Figure 2***. If the length of the back shed is increases, then yarn extension is reduced and this is preferred for weaving delicate yarns like silk. However, shorter back shed creates clearer shed and it is preferred for weaving coarser and hairy yarns. It is important to understand the factors which influence the degree of yarn extension during the shed formation [11, 12]. A simplified mathematical model has been presented to relate the warp strain with the shed parameters. So that let us *represent warp yarn elongation in the front and back shed by 'E₁' and 'E₂'* respectively, and consider *'H'* as the shed height in ***Figure 3*** for a bottom-closed shed type.

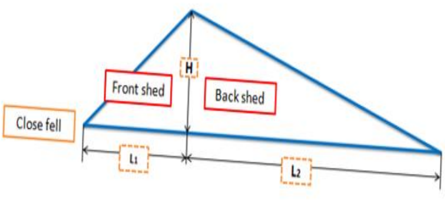


Fig 2. Geometry of shed

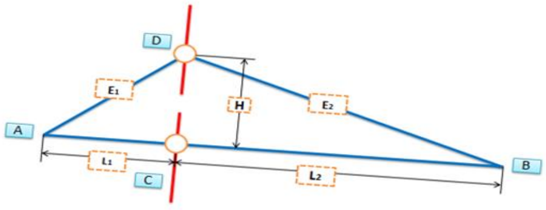


Fig 3. Warp Strain during Shedding

From a triangle **'ACD'** of ***Figure 3***, *warp yarn elongation in the front shed can be stated as:*

$$\boldsymbol{E_1 = AD - AC}[1]$$

Warp yarn elongation in the front shed can be written as follows by using Pythagoras theorem on a triangle **'ACD'** of ***Figure 3***.

$$\boldsymbol{E_1} = \sqrt{(\boldsymbol{L_1^2 + H^2})} - \boldsymbol{L_1}[2]$$

And the equation rewrite as:

$$\boldsymbol{E_1 = L_1\left[1 + \left(\frac{H}{L_1}\right)^2\right]^{\frac{1}{2}} - L_1}[3]$$

Using a binomial expansion, the equation also rewrite as:

$$\boldsymbol{E_1 = L_1\left[1 + \frac{1}{2}\left(\frac{H}{L_1}\right)^2 + \frac{\frac{1}{2}\left(\frac{1}{2}-1\right)}{2}\left(\frac{H}{L_1}\right)^4 + \cdots\right] - L_1}[4]$$

And the equation seems as follows after neglecting the higher power of H/L_1 which is less than one.

$$\boldsymbol{E_1 = \frac{H^2}{2L_1}}[5]$$

Where the front and back shed length ratio is called shed symmetry parameter [11], and it *represented by 'i'*. Therefore, the shed symmetry parameter *'i' is equal to* L_1/L_2.And the initial warp length **'L'** can be calculated as:

$$\boldsymbol{L = L_1 + L_2}[6]$$

Where, the length of back shed *'L₂'* is equal to L_1/i andthe value of initial warp length **'L'** are equal to **'AB'** as shown in ***Figure 3***.

$$\boldsymbol{L = AB = L_1 + \frac{L_1}{i}}[7]$$

And the equation also rewrite as:

$$\boldsymbol{L = AB = L_1\left(\frac{1+i}{i}\right)}[8]$$

The total elongation or change in length of warp **'E'** can be calculated as:

$$\boldsymbol{E = E_1 + E_2}[9]$$

When the value of *'E_1'* and *'E_2'*are substituted by equation (5), the equation seems as:

$$\boldsymbol{E = \frac{H^2}{2L_1} + \frac{H^2}{2L_2}}[10]$$

The equation also rewrites by taking a common variable on the equation and using L_1/i as a substitute for length of back shed *'L_2'* as:

$$\boldsymbol{E = \frac{H^2}{2L_1}(1 + i)}[11]$$

When a system of force or load acts on warp yarns during shed formation, the warp yarn undergoes some deformation. Hence, this deformation per unit length is known as unit strain [13] or simply called warp strain. Warp strain *represented by a Greek symbol epsilon* **'ϵ'** since it is a unit strain and itcan be calculated as:

$$\boldsymbol{\epsilon = \frac{E}{L}}[12]$$

Once substituting the value of total elongation *'E'* by equation (11), the equation rewrite as:

$$\boldsymbol{\epsilon = \frac{1}{L} * \frac{H^2}{2L_1}(1 + i)}[13]$$

Finally, the equation rewrite in a simplified form after substituting the length of front shed *'L_1'*from equation (8) as:

$$\boldsymbol{\epsilon = \frac{H^2}{2L^2}\left[\frac{(1+i)^2}{i}\right]}[14]$$

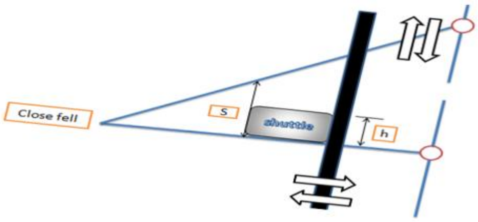
From the above equation the following things can be inferred. Warp strain increases with the increase in shed height and warp strain reduces with the increase in shed length and also warp strain reduces as the shed becomes symmetrical.

B. Bending Factor

Bending Factor is defined as the ratio of depth of shed in front of shuttle *'S'* and the actual height of the shuttle *'h'* shown in ***Figure 4*** and it represented by **'B.F'**. If there is no any abrasion between warp sheet and shuttle, the bending factor will be higher than one. Conversely, if it is much lower than one, then severe abrasion will take place between warp sheet and shuttle. This may lead to high warp breakage rate and even the trapping of shuttle within the shed [14].

$$\boldsymbol{B.F = \frac{S}{h}}[15]$$

The bending factor changes continuously as it is influenced by the following two factors which are movement of the harness and movement of the sley. The bending factor will reduce as the top shed line will move in the downward direction causing reduction in the value of **'S'** and vice versa. Besides, as the reed moves towards the cloth fell, the depth of shed in front of shuttle **'S'** will reduce. Thus, severe abrasion between the warp sheet and shuttle is quite obvious while the bending factor is low or reduces as shown in ***Figure 5***.



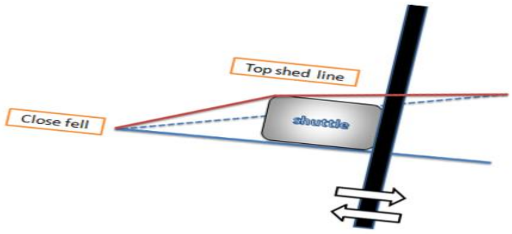


Fig4: Bending Factor **Fig 5: Situation with Low Bending Factor**

C. Shed Geometry

Shed Geometry requires a great consideration and precision. It is desirable to have a small shed height in order to reduce the lifting height of harness and stress on warp yarns [15]. And it is also determined by the size of weft insertion media and by means of beat up motion, but it mostly determined by the size of weft insertion device [6, 16]. Because the loom beating mechanism is takes place after picking weft yarn through warp shed by using reed with the help of one hand and it indicates that the manual beat up motion controlling mechanism. While the flying shuttle travel between the warp threads by the pulling effect of one hand on the picker through the strings and handle which attached in the loom frame to provide a catapult effect for shuttle across the warp threads shed on the sill of the frame [17]. So that the actual shuttle width **'A'**, actual shuttle height **'h'**, shed depth at reed **'D'**, shed depth in front of shuttle **'S'**, front shed length **'L_1'** and shed height **'H'** are shown in ***Figure 6***.

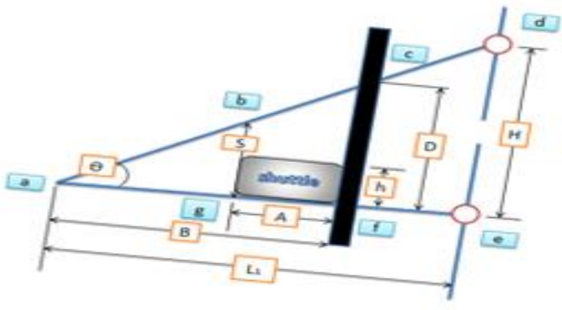


Fig 6: Shed Geometry

The shed angles should not exceed 25^0 with very poor warps because it would require excessive lift of the fastest harness from the beat up line [6, 16]. In order to prevent high warp yarn breakage rate and shuttle trapping within the shed and also excessive abrasion between the warp sheets and shuttle, the bending factor should not be lower than one as explained in the above and it assumed as 1.2 for the following calculation. The actual size of traditional boat shuttle which used for production of different Ethiopian hand-loom products are 285.75 mm in length, 41.275 mmin width and 31.75 mm in height [12, 18]. Hence, the shed size can be expressed in terms of the front shed angle and it also expressed in terms of warp strain with a simplified mathematical model presented as follows. Since the value of shuttle height **'h'** andbending factor **'B.F'** are given as 31.75 mm and1.2 respectively, the shed depth at the front of shuttle can be calculated as:

$$\boldsymbol{S = B.F * h} \quad [16]$$

From a triangle **'abg'** of shed geometry in ***Figure 6***, the front shed angle **'θ'** can be stated as:

$$\boldsymbol{\tan\theta = \frac{S}{B-A}} \quad [17]$$

When the value of shed depth in front of shuttle **'S'**, shuttle width **'A'** and shed angle **'θ'** are given as 38.1 mm, 41.275 mm and 25^0 respectively, the value of front shed length up to reed **'B'** can be calculated as:

$$\boldsymbol{B = \frac{S}{\tan\theta} + A} \quad [18]$$

Similarly from a triangle **'acf'** of shed geometry in ***Figure 6***, the front shed angle **'θ'** can be restated as:

$$\boldsymbol{\tan\theta = \frac{D}{B}} \quad [19]$$

When the value of front shed length up to reed **'B'** and shed angle **'θ'**are given as 123.035 mm and 25^0 respectively, the value of shed depth at reed **'D'** can be calculated as:

$$\boldsymbol{D = B\tan\theta} \quad [20]$$

As stated on the strain equation (14) above, the warp strain can also express in terms of shed height as follows:

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$$\boldsymbol{H = \frac{L}{(1+i)}\sqrt{2\,\epsilon\ i}} \quad [21]$$

And from a triangle **'ade'** of shed geometry in ***Figure 6***, the value of front shed angle **'θ'**can be calculated as:

$$\boldsymbol{\tan\theta = \frac{H}{L_1}} \quad [22]$$

Where the value of shed height **'H'** is equal to $L_1 tan\ \theta$ and the value of front shed length **'L₁'** are equal to $(L\ i)/(1+i)$ using equation (22) and (8) respectively and the equation write as:

$$\boldsymbol{H = \left(\frac{L\,i}{1+i}\right)\ \tan\theta} \quad [23]$$

The shed angle can be related with the warp yarn strain by equating the equation (21) and (23) simply as follows:

$$\boldsymbol{\left(\frac{L\,i}{1+i}\right)\tan\theta = \frac{L}{(1+i)}\sqrt{2\ \epsilon\ i}} \quad [24]$$

Andthe equation simplified as:

$$\boldsymbol{i\tan\theta = \sqrt{2\ \epsilon\ i}} \quad [25]$$

Finally, the equation also rewrite in a simplified form as:

$$\boldsymbol{2\,\epsilon = i\tan^2\theta} \quad [26]$$

From the above equation the following things can be significant. Warp strain increases with the increase in shed angle and shed angle reduces with the increase in shed symmetry parameter. And warp strain also reduces as the shed becomes symmetrical. In order to find out the value of warp yarn strain, breaking elongation in percentile for good, average and poor carded cotton yarn would be 6.0, 5.5 and 5.0 respectively for 20 Ne yarn count, and 5.8, 5.5 and 5.0 respectivelyfor 40 Ne yarn count as-per SITRA norms for spinning mills [19]. However, the warp yarn has undergone sizing for sufficient yarn strength during shed formation. Hence,the loss in elongation at break and gain in strength would be 15% and 25% respectively for sized yarn count up to 40 Neas-per SITRA norms. By considering carded cotton yarn with average property of 20 Ne, the breaking elongation of un-sized yarn is 5.5% and loss in elongation at break of sized yarn is 15%. Thus, the breaking elongation of sized yarn is 4.675% and its strain value is 0.04675 for 20 Ne carded cotton yarn count with average property. And the front shed angle is 25^0 and the initial warp length is taken as 1370 mm from the collected data.

$$\boldsymbol{i = \frac{2\ \epsilon}{\tan^2\theta} = 2\ \ \epsilon\cot^2\theta} \quad [27]$$

According to the above assumption, the shed symmetry parameters **'i'** determined as 0.43 and the value of **'L₁'** and **'L₂'** can also determine using $i = L_1/L_2$ and $L = L_1 + L_2$ equations as 411.958 mm and 958.042 mm respectively. Furthermore, the shed height **'H'** can be calculated using the value of front shed length **'L₁'**and front shed angle **'θ'** which is six times the actual shuttle height **'h'** through:

$$\boldsymbol{H = L_1\tan\theta} \quad [28]$$

So that the shed height should be similar with the required lifting height of warp yarns by head lever in order to pass the boat shuttle through the shed without fail.

D. Head Lever Geometry

Size of shed is very critical in which the yarns are converted into the fabric. It should allow a secured weft insertion. The requirements of shed opening are determined by the means of weft insertion and beat up motion [6, 16]. It is desirable to have a small shed opening in order to reduce the lifting height of head lever and therefore to reduce the stress on the warp yarns [15]. However, the magnitude of shed opening is mostly determined by the size of weft insertion device as mentioned in the above. During the passage of the shuttle, the value of front shed length up to reed **'B'** and shed depth at reed **'D'** are both varies because of the motion of the reed, and the value of shed depth at reed **'D'** will also vary owing to the movement of head lever unless the passage of the shuttle coincides with the period of dwell as shown in ***Figure 6***.

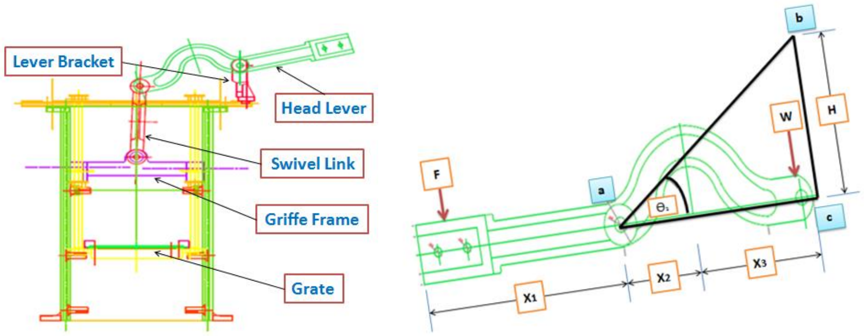


Fig 7: Head Lever Mechanism **Fig 8:** Head Lever Geometry

The head lever is used to lift the griffe frame with its own full setup to form the required warp shed with the minimum amount of applied force which results substantial saving in weaver effort, time, energy and other valuable resources as shown in ***Figure 7*** and ***8***. And the head lever is connected with the griffe frame through swivel link in one side and connected with the loom pedal through connecting cord in the other sides, and it also supported with the lever bracket in between. Due to this, the head lever is subjected to a bending load which caused by the applied load, suspended weight on two ends and the reaction force at fulcrum point. Thus, the head lever is used to control the up and down movement of harness in one side when the loom pedal is actuated or pressed by leg in the other side. From a triangle **'abc'** of head lever geometry in ***Figure 8***, the value of head lever rotary angle **'θ_1'** can be calculated as:

$$\boldsymbol{tan\ \theta_1} = \frac{\boldsymbol{H}}{\boldsymbol{X_2+X_3}} [29]$$

When the value of shed height **'H'** can be expressed either $H = L_1/i\ \sqrt{2\ \epsilon\ i}$ or $H = L_1\ tan\,\theta$ as stated on equation (21) and (28) respectively by substituting the initial warp length **'L'** in equation (21) with the front shed length **'L_1'**, the final simplified relation between shed angle and head lever rotary angle can be stated as follows: $\boldsymbol{tan\ \theta_1} = \frac{\boldsymbol{L_1\ tan\ \theta}}{\boldsymbol{X_2+X_3}}$**[30]**

(Or)

$$\boldsymbol{tan\ \theta_1} = \frac{\boldsymbol{L_1\sqrt{2\ \epsilon\ i}}}{\boldsymbol{i\ (X_2+X_3)}} [31]$$

From the above two equation the following things can be important. Warp strain increases with the increase in head lever rotary angle and head lever rotary angle reduces with the increase in shed symmetry parameter and length of head lever and also warp strain reduces as the front shed length increase. So that head lever rotary angle **'θ_1'** can be determined using equation (29) by substituting the value of shed height **'H'** and length of head lever **'X_2+X_3'** as 192.099 mm and 264 mm respectively from the collected data given above. And it is equal to 1.44 times higher than the front shed angle which would have a great and valuable contribution in minimization of weaver working load or applied load.

$$\sum m = 0, at\ fulcrum\ point\ of\ head\ lever$$

And by finding moment in the middle of the head lever called fulcrum point, the value of **'X_1'** can be determined as:

$$\boldsymbol{-F\ X_1 + W\ \ (X_2 + X_3) = 0} [32]$$

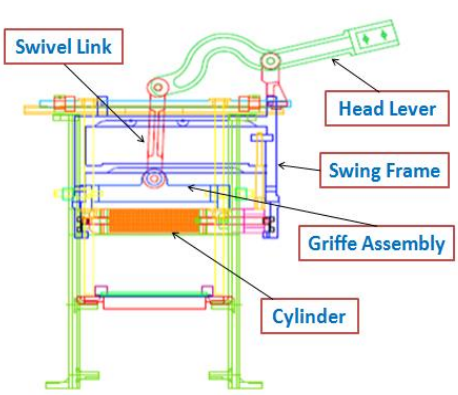
The required force which applied by weaver is recommended to be small as possible. The total weight **'W'** should consider the weight of griffe frame, griffe knife, hook, harness and lingo based on the density of selected material which multiplied by gravity to determine total weight in Newton rather than mass in Kilogram. Consider 15 Kg of total mass that makes the total weight **'W'** 150 Nand also 100 N for the load **'F'** which applied by weaver.

$$\boldsymbol{X_1} = \frac{\boldsymbol{W\ \ (X_2+X_3)}}{\boldsymbol{F}} [33]$$

Considering various undetermined parameters like frictional force and other, the value of **'X_1'** is 388.476 mm but it enhanced and preferable to be 390 mm depends on mechanical design point of view [20] for a suitable geometrical design.

E. Cylinder Geometry

Suitable connections from the loom provide the rising and falling movement to the knives, and the in and out movement to the card cylinder ensuring correct synchronization of the jacquard action with the loom cycle. The cylinder is turned one quarter of a revolution as it moves back thus presenting a new card of next pick for selection each time it moves in to press against the needles [6]. Each hook controls as many warp threads as there are harness cords connected to the corresponding neck cord. Warp threads are moved from the bottom of the shed to the top and back to bottom again, or twice the depth of the shed at every pick. The cylinder changing mechanism is used to change the punched card after inserting weft thread through the shed and it consists of griffe connecting link, cylinder connecting link and frame connecting link [7]. When the punched card is pressed against the needles by cylinder, the needles in front of holes are not pressed and hence do not displace hooks whereas the knife (griffe) needles in front of blank space are pressed back which in turn press back the hooks and take them out of griffe knives [7]. When the griffe assembly moves up, all hooks, which are not pressed, are taken up whereas the hooks pressed back are not lifted as shown in ***Figure 9*** and***10***.



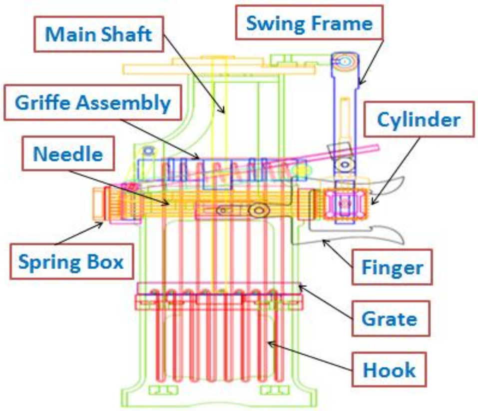
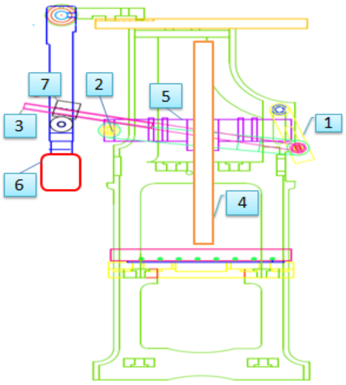


Fig 9: Suitable Cylinder Connection **Fig 10:** Cylinder Changing Mechanism

The lifted hooks lift corresponding heald eye through neck cord and harness and thus takes up that warp thread to form a shed. When the hook goes down through the downward movement of griffe, harness, mail and lingo with their own weight, and the warp thread brings down to close open shed at the bottom [7]. Each number that indicated in ***Figure 11*** are represented the frame to griffe connecting link, griffe connecting link, griffe to cylinder connecting link, griffe main shaft, griffe assembly, cylinder and swing frame in respective order. In both ***Figure 12*** and ***13***, the solid line represents different link which can form geometry and mechanism at rest position. And the dash line also represents similar link listed on the solid line after deflection of definite angle.



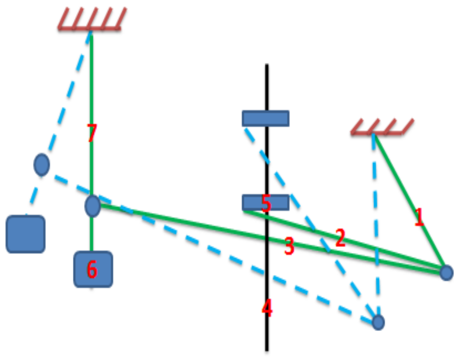


Fig 11: Overall Link Mechanism **Fig 12:** Line Representation of Link

It is also possible to represent the entire mechanism with respect to X and Y-axis based on one fixed reference point on X and Y-plane.

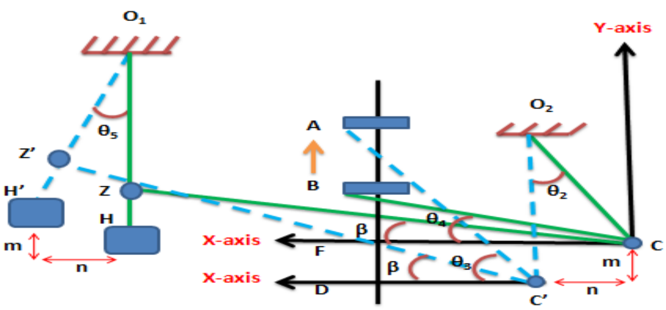


Fig 13: Link Representation in X and Y-axis

Where frame to griffe connecting link **'O_2C'**, griffe connecting link **'CB'**, griffe to cylinder connecting link **'CZ'**, swing frame **'O_1H'**, cylinder **'H'**, griffe lifting height **'AB'** which is equal to the required lifting height by head lever for shed formation are shown in ***Figure 13***. The value of **'β'** is assumed to be 10^0 from X-axis by taking a fixed reference point from X or Y-axis and also the value of lifting height is 192.099 mm as already know from the above calculation. The cylinder lifting height **'m'** can be calculated from a link representation in X and Y-axis of ***Figure 13*** as:

$$m = O_2C\,(1 - \cos\theta_2)[34]$$

And the cylinder forward movement **'n'** can also determine from a link representation in X and Y-axis of ***Figure 13*** as:

$$n = O_2C\,\sin\theta_2[35]$$

It was collected that the cylinder is changing after it moves 35 mm in X-axis and 10 mm in Y- axis so that the value of **'m'** is equal to 10 mm and **'n'** is equal to 35 mm. However, the value of **'θ_2'** is not known yet. Hence, it is better to take a ratio of cylinder lifting height**'m'** and cylinder forward movement**'n'** in order to determine the value of **'θ_2'** as:

$$\frac{m}{n} = \frac{O_2C\,(1-\cos\theta_2)}{O_2C\,\sin\theta_2}[36]$$

(Or)

$$\frac{m}{n} = \frac{1-\cos\theta_2}{\sin\theta_2}[37]$$

As stated above, a simplified mathematical model presented below to determine the value of **'θ_2'**.

$$m\sin\theta_2 = n\,(1 - \cos\theta_2)[38]$$

The optimal value of **'θ_2'** determineswhenthe value of both function f (x) and g (x) are zero as shown in ***Figure 14*** belowusing the above two mentioned consecutive equations (37) and (38). Thus, the optimal value of **'θ_2'** is at 0.56 radian in X-axis after rearranging both equations and substituting the value of **'m'** and **'n'**. Thereby the graph was constructed for both function f (x) and g (x) from -0.5 up to one. However, the graph extends up to 90^0 and the result is obtained at 31.9^0 which indicate the intersection point of two functions at point **B.**

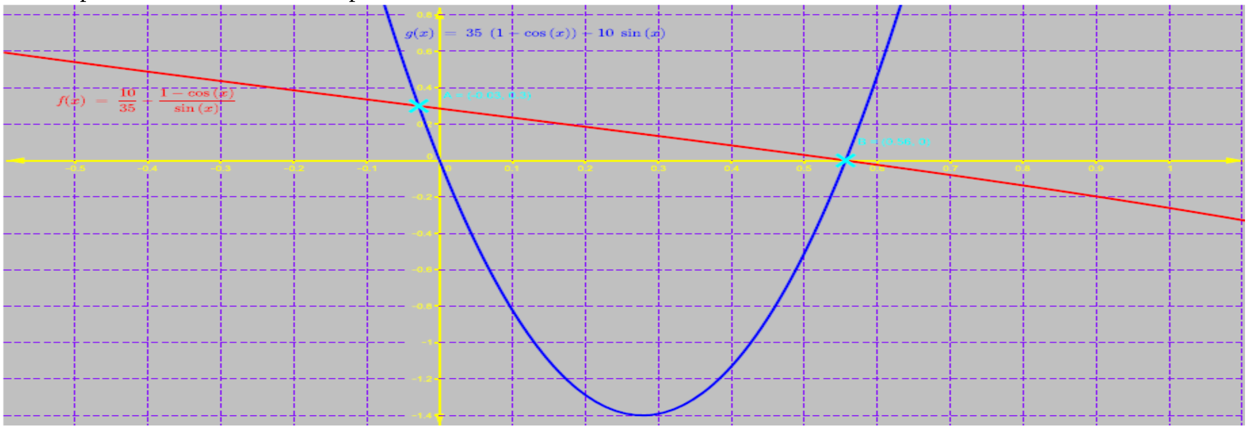


Fig 14: Graph for Optimal Value of **'θ_2'**

The frame to griffe connecting link **'O_2C'** can be calculated using equation (34) by substituting the value of **'θ_2'** as 31.9^0 and **'m'** as 10 mm in the following.

$$O_2C = \frac{m}{1-\cos\theta_2}[39]$$

Depends on mechanical design [13] point of view, a preferable number could be 68 mm for frame to griffe connecting link **'O_2C'** however 66.213 mm is the calculated result for it. From the line representation of overall mechanism formed by link in X and Y-axis shown in ***Figure 13***, the value of **'AD'** can be expressed as:

$$AD = AB + BF + FD[40]$$

Where, the value of griffe lifting height **'AB'** is equal to the required shed height **'H'**, and **'BF'** is equal to $BC\sin\theta_4$ from a triangle **'CBF'**, and the value of **'FD'** is also equal to the cylinder lifting height **'m'** as shown in ***Figure 13***.

$$AD = H + m + BC\sin\theta_4[41]$$

Similarly, from a line representation of overall mechanism formed by link in X and Y-axis shown in ***Figure 13***, the value of **'AD'** can also express using triangle **'ACD'** as:

$$AD = AC'\sin\theta_3[42]$$

The value of **'θ_3'** and **'θ_4'** can be expressed in terms of shed height with a simplified mathematical model presented below by equating the equation (41) and (42).

$$H + m + BC\sin\theta_4 = AC'\sin\theta_3[43]$$

Or

$$AC'\sin\theta_3 - BC\sin\theta_4 = m + H\,[44]$$

Where the value of AC′ is equal to BC and the equation rewrite as:

$$\boldsymbol{sin\theta_3 - sin\theta_4} = \frac{\boldsymbol{m+H}}{\boldsymbol{BC}} [45]$$

Once substituting the value of **'m'** and **'H'** from equation (28) and (38) respectively to the equation (45) on the above, the value of **'θ₂'**, **'θ₃'**and **'θ₄'** can be related with the front shed angle **'θ'** and expressed as follows:

$$\boldsymbol{tan\,\theta} = \frac{\boldsymbol{BC\ sin\theta_2\ (sin\theta_3 - sin\theta_4) - n\ (1 - cos\theta_2)}}{\boldsymbol{L_1 sin\theta_2}} [46]$$

Or

$$\boldsymbol{tan\,\theta} = \frac{\boldsymbol{BC\ (sin\theta_3 - sin\theta_4) - O_2C\ (1 - cos\theta_2)}}{\boldsymbol{L_1}} [47]$$

Using either of one equation in the above, the value of **'θ₂'**, **'θ₃'** and **'θ₄'** can also relate with warp strain **'ϵ'** using $i\ tan\,\theta = \sqrt{2\ \epsilon\ i}$ mentioned on the above equation (25) as follows:

$$\frac{\boldsymbol{\sqrt{2\ \epsilon\ i}}}{\boldsymbol{i}} = \frac{\boldsymbol{BC\ (sin\theta_3 - sin\theta_4) - O_2C\ (1 - cos\theta_2)}}{\boldsymbol{L_1}} [48]$$

Or

$$\frac{\boldsymbol{\sqrt{2\ \epsilon\ i}}}{\boldsymbol{i}} = \frac{\boldsymbol{BC\ sin\theta_2\ (sin\theta_3 - sin\theta_4) - n\ (1 - cos\theta_2)}}{\boldsymbol{L_1 sin\theta_2}} [49]$$

Furthermore, the value of **'θ₃'** and **'θ₄'** can be determined using the value of cylinder lifting height **'m'** as 10 mm, shed height **'H'** as 192.099 mm and a griffe connecting link **'BC'** as 250 mm through equation (45) as:

$$\boldsymbol{sin\theta_3 - sin\theta_4 = 0.81} [50]$$

When the value of $sin\theta_3 - sin\theta_4$ is knownas 0.81 and the value of cylinder lifting height **'m'** are equal to$O_2C\ (1 - cos\ \theta_2)$ as stated on equation (34), the equation which stated on equation (48) seems as follows:

$$\frac{\boldsymbol{\sqrt{2\ \epsilon\ i}}}{\boldsymbol{i}} = \frac{\boldsymbol{0.81\ BC - m}}{\boldsymbol{L_1}} [51]$$

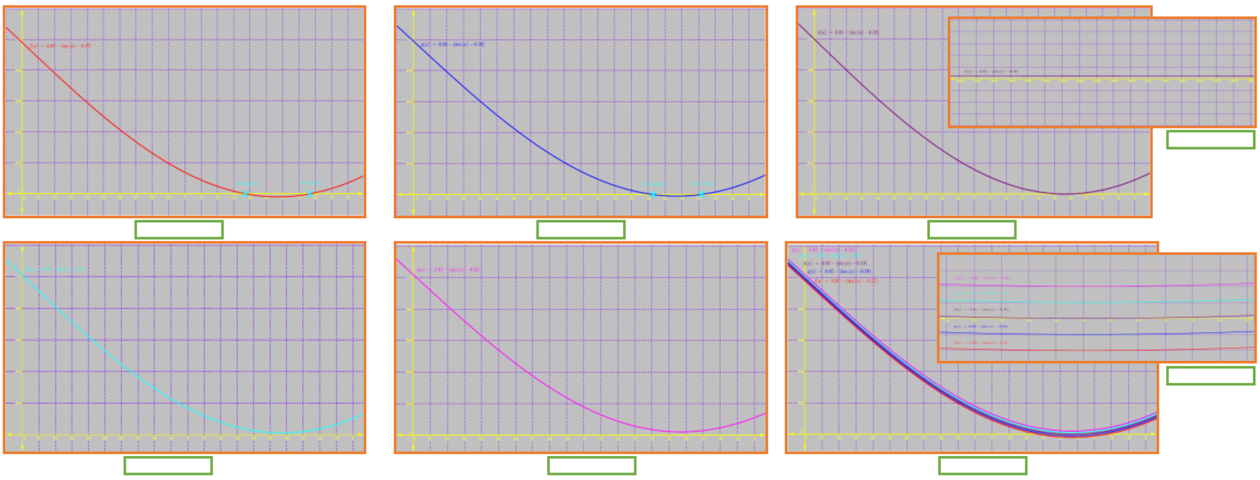
As stated above, a simplified mathematical model presented below as:

$$\boldsymbol{2\ \epsilon\ L_1^{\,2} = i\ (0.81\ BC - m)^2} [52]$$

From the above equation the following things can be noteworthy. Warp strain increases with the increase in griffe connecting link **'BC'** and cylinder lifting height **'m'** and also the shed symmetry parameter *'i'*. In contrary, warp strain reduces as the front shed length *'L₁'* increases or as the shed becomes symmetrical.

$$\boldsymbol{\epsilon} = \frac{\boldsymbol{i\ (0.81BC - m)^2}}{\boldsymbol{2\ L_1^{\,2}}} [53]$$

However, the value of **'θ₃'** and **'θ₄'** are not determined yet. Using GeoGebra, the optimal value of both **'θ₃'** and **'θ₄'** are obtained for different value which stated below in the figures to satisfy the above-mentioned equation (50).The optimal values for **'θ₄'** should be higher than 10^0 because the value of fixed reference is assumed to be 10^0 from the X-axis. And the optimal value for **'θ₃'** shouldalso lower than 90^0. In all graphs given below, the optimal value of **'θ₃'** where find in between zero and two on X-axis and zero and one on Y-axis. Thereby the X-axis expressed in terms of a radian and Y-axis represents as a function of f (x),



g (x), h (x), p (x) and/or q (x). Bring this in mind and select the optimal value, hence the selected optimal value for **'θ₃'** and **'θ₄'** are 82^0 and 10.5^0 respectively as indicated in ***Figure 15(b)*** given below in order to optimize the actual height of the machine for appropriate maintenance and operation as well. When the value of **'θ₄'** is 10^0, the graph shows that the optimal value at two different points of A and B for the value of **'θ₃'** in ***Figure 15(a)*** given below. But the value of **'θ₃'** has to be excluded 10^0 because of considering 10^0 as a fixed reference angle from X-axis. Therefore, any angle which has a smaller angle than 10^0 wouldn't incorporate to the graph.

Fig 15: Graph for Optimal Value of 'θ_3'

Similarly, the graph shows that the optimal value at two different points when the value of **'θ_4'** is 10.5^0 in ***Figure 15(b)*** given above. Since the value of **'θ_4'** are higher than 10^0, the optimal value of **'θ_3'** were achieved at C (1.43, 0) and D (1.72, 0) points that meant at 1.43 radian or 82^0 and 1.72 radian or 100^0. Even if the optimal value was obtained at two different points, it is better to take or select a smaller angle as optimal in order to optimize the actual height of the machine for appropriate maintenance and operation as well. In ***Figure 15(c), (e)*** and ***(f)***, the graph didn't show the optimal value for **'θ_3'** when the value of **'θ_4'** is 11^0, 11.5^0 or 12^0 respectively. Even if, it is clear to understand in ***Figure 15(e)*** and ***(f)*** or when the value of **'θ_4'** is11.5^0 and12^0, but it is difficult to recognize in ***Figure 15(c)*** when the value of **'θ_4'** is 11^0 because the graph seems that a close asymptotic line on X-axis for certain interval. Thus, it is better to zoom and figure out whether it is asymptotic or intersecting in ***Figure 15(d)*** shown above. ***Figure 15(g)*** and ***(h)*** shows that all results in one graph to visualize and differentiate the difference between each graph and function. As a result, zoom out each graph were contributed to the clarity of the results in respective order of the given function. From a line representation of overall mechanism formed by link in X and Y-axis for cylinder changing shown in ***Figure 13***, the value of swing frame link '$\mathbf{O_1H'}$'can be expressed as:

$$\boldsymbol{O_1H' = O_1Z' + Z'H'}[54]$$

Where the value of $O_1Z = O_1Z'$, $O_1H' = O_1H, Z'H' = ZH, ZH = CZ\ sin\beta$and length of griffe to cylinder connecting link **'CZ'** as 265 mm and length of swing frame '$\mathbf{O_1Z'}$' as 210 mm are taken from collected data given above in ***Table 1*** and rewrite as follows:

$$\boldsymbol{O_1H = O_1Z + CZ\ sin\beta}[55]$$

Moreover, the value of swing frame link **'O_1H'** is determined as 256.02 mm and the optimal value of **'θ_5'** is obtained from ***Figure 13*** as follows:

$$\boldsymbol{sin\,\theta_5 = \frac{n}{O_1H}}[56]$$

An approximate optimal value for **'θ_5'** is 8^0 however 7.86^0 is the calculated value for it. By substituting the value of **'n'** from equation (56) to the equation (46), the value of **'θ_2'**, **'θ_3'**, **'θ_4'** and **'θ_5'** can be related with the shed angle **'θ'** and expressed as:

$$\boldsymbol{tan\,\theta = \frac{BC\ sin\theta_2\ (sin\theta_3 - sin\theta_4) - O_1H\ sin\,\theta_5(1 - cos\theta_2\,)}{L_1 sin\theta_2}}[57]$$

IV. Conclusion

Generally, the present work is devoted to analyzed the geometry of single lift single cylinder mechanical jacquard shedding mechanism for complicated and diversified design patterns, and from the completed tasks the following conclusions are drawn; The motion forms the shed by dividing the warp end into two sheets, thus providing a path for the weft. This is done by raising and/or lowering frames. Shed geometry and shed characteristics require a great consideration and precision because it is the zone in which the yarns are converted into the fabric.It is desirable to have a small shed opening in order to reduce the lift of the harnesses and therefore to reduce the stress on the warp, however, the magnitude of shed opening is mostly determined by the size of the weft insertion medium. In addition, all analysis of geometrical results have a great contribution for proper and accurate operation of single lift single cylinder mechanical jacquard shedding mechanism and also synchronization of the three main primary motions to perform one motion to another in precise order and time. Those analyzed length and angle measurements are also important to repair, maintain and install the mechanism easily and it is also important to save time and energy of the weaver during operation.

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