Modeling of cloth-fell movement on an air jet loom

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Abstract - Weaving is the most versatile means of fabric formation. During the weaving process, it is essential to maintain a stationary cloth fell to ensure fabric quality despite cyclic variation in warp tension due to shedding, beat-up, take-up and let-off actions. Though many attempts have been made by researchers to model cloth-fell movement, these attempts were made under assumptions that may not be realistic due to the complex tension profile of the warp and hence could not provide high accuracy. A mathematical model explaining the relationship between the initial warp tension and the cloth-fell movement with a high level of accuracy has been developed by considering material properties such as elastic moduli, shed parameters, shed geometry, loom parameters and slay-mechanism parameters. The model has been validated using experimental results obtained with an accuracy of ± 0.15 mm that statistically demonstrated that no difference exists between the experimental and theoretical results at a 95% confidence level. The model developed can help even an inexperienced loom operator set the initial warp tension to acceptably control cloth-fell movement, which determines the quality of the woven fabric; hence, these findings have significant industrial implications..

Keywords - Air jet loom, Cloth-fell movement, Mathematical modeling, Shed geometry, Slay movement, Warp and fabric tension

1. Introduction

Weaving is considered the most versatile means of fabric formation. In the weaving process, weft yarn travels back and forth across the warp sheet in the loom. Weaving involves three primary actions (shedding, picking and beating up) and two secondary actions (take-up and let-off). To form a weave structure, all warp threads are temporarily separated into upper and lower warp sheets, enabling the weft to be interlaced into the warp and the shed to be formed, which is referred to as shedding. Passing the weft through the shed is called picking. After the insertion of each pick, the pick of the weft itself has to be pushed towards the cloth by a reed to a point adjacent to the previous pick, known as the fell, where cloth is formed; this is referred to as beating up. As weaving proceeds, the process of take-up causes the woven cloth to move forward so that the fell is maintained at the same position. The process of let-off feeds the warp yarns from a beam at the back of the loom to replace the warp woven into the cloth.

Looms mechanically coordinate primary and secondary weaving actions and the weft insertion process through the rotation of a crank shaft. Looms are usually powered by a motor fitted to rotate the crank shaft, although handlooms are driven by human power via a treadle system. However, irrespective of the type of loom, warp tension dynamically varies within a single weave cycle due to the aforesaid primary and secondary motions. Thus, cyclic variation in warp tension during weaving process has a significant influence on the end properties of the cloth. Though the main function of the let-off system is to maintain the correct warp tension as initially set, it is evident that preset warp tension undergoes sudden peaks—especially during shedding and beat-up motions, as they have considerable tension loads [1]. Fig. 1 depicts the typical tension variation in cloth and warp yarns.

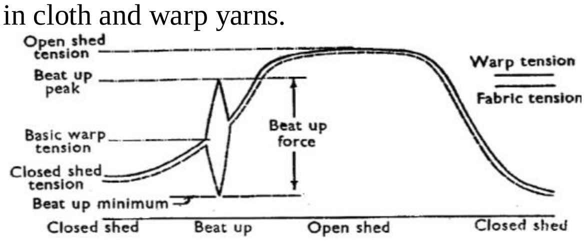

Fig. 1: Typical warp tension cycle [1]

Except during beat-up, the profile of typical cyclic tension trace is shaped by the shedding motion, which lasts for the longest period of the cycle, reaches a plateau at the open-shed position and has its minimum at the closed-shed position. Thus, the entire tension cycle can be characterized by five tension values: open-shed tension, closed-shed tension, basic warp tension, beat-up peak, beat-up minimum; the difference between the last two is equal to the applied beat-up force as per the excess tension theory.

High basic warp tension causes an extension of woven fabric, which causes the fabric fell to move towards the back rest and leads to an increase in weft density and weaving resistance. Moreover, an increase in weaving resistance causes a reduction in weft density. Therefore, there is a tradeoff between warp tension and fabric properties that determines the structure of the fabric being woven. Such effects cause an alternation between pick spacing and pick density in the fabric being woven, which is viewed as a flaw in fabric formation. Ch'enjui-lung [7] deduced equations for warp and cloth tensions during beat-up by taking displacement into account, and Huang Gu [25] attempted to reduce warp tension fluctuation and its consequences. Some researchers studied the performance of a fabric and its properties in relation to the yarn properties and weft density [20], while others concentrated on loom settings, such as warp tension [19, 23], weaving speed [22] and weaving conditions [21, 24].

There is a relationship between the let-off motion and the warp tension. When a loom is gaited up and weaving begins, the warp tension attains the value for which the let-off motion is set after weaving a certain amount of fabric [2]. This value is maintained as long as the loom runs satisfactorily, but when the loom stops, the warp tension may deviate greatly from the normal value because of relaxation or unsatisfactory letting back [3].

The magnitudes of stretch and strain on the warp are determined by the amounts of lift and the positions of the heald shafts. The amount of lift applied to heald shafts in order to create a clear shed depends on their positions. The farther a heald shaft is from the cloth fell, the greater its lift is, and the higher the tension of the warp yarns controlled by it should be [4]. This should be taken into consideration when analyzing warp tension during shed formation. Bakulin [5] observed a 25–30% lower warp tension at the front heald shaft than for the yarns at the back heald shaft, particularly for negative let-off motion; by contrast, with positive let-off motion, the tension was found to be lower for the warp yarns at the rear heald shafts [6]. This is possibly because when the rear heald shafts are lowered, the back rest is more depressed under the resultant higher warp tensions and, in turn, registers lower values of tension. The importance of this let-off motion in determining the subsequent warp tension is evident in the examples mentioned above. Fig. 2 shows the geometry of a shed with two heald shafts.

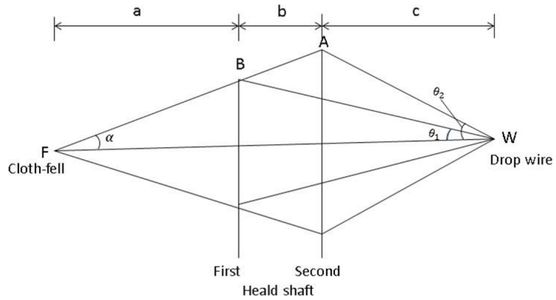

Fig. 2: Geometry of a shed and the stretch of warp yarns due to shed formation

The effect of the horizontal distance b between the heald shafts is negligible compared with the change in θ; therefore, the stretch of the 2nd heald shaft is higher during shed formation. An unnecessary increase in warp tension can be overcome by increasing the free length of the warp, within economical limits; this factor has been taken into consideration in modern shuttle-less looms. Despite the sophistication of modern looms, warp tension is still a major parameter in the weaving process [9, 10]. Many researchers have attempted to develop analytical models to describe the cyclic warp tension variation during weaving [13-15] or to optimize loom settings [11,16]. However, their endeavours were not very successful because sufficient accuracy could not be achieved, due to unrealistic assumptions, lack of consideration of the significance of cloth-fell movement during weaving or simplification of the cloth-fell movement in the model [12,18]. Hence, a meta-heuristic attempt at the modeling, simulation and optimization of warp tension in the weaving process was made by Gloy et al. [8].

Strength of fabric is the most important factor of a woven fabric and measured by tensile strength, bursting strength and tearing strength. The pick density is a decisive factor for tensile strength in warp direction [26] while warp and weft densities are for tensile strength as well as energy absorption properties measured by bursting and tearing strengths in protective clothing [27]. An empirical relationships of pick density to weave float, warp tension and weft count were derived and also found that no effect of weft type on warp tension in Jacquard weaving [29]. Tension profile of warp yarns and fabric are deterministic in fabric strength further to weavability, fabric quality and its GSM, and noise level of loom. The effect of warp tension variation on the quality of greige and dyed woven fabrics was investigated by Uzma Syed et. al and found that dynamic tension variations are more frequently occurred in textile manufacturing process [30]. During weaving, yarns are moving from weavers beam to the fabric roll under the influence of forces such as warp tension and fabric tension. The increased initial warp tension causes fabric deformation. The over extension gives permanent change in internal structure, and the decreased warp tension makes fabric holes [30].

The mechanical properties such as fabric surface properties depend on the loom setting parameters [31]. The tighter the fabric weave, the higher the initial warp yarns tension, and thus lower the value of warp yarn projections [32]. Through experimental and analytic methods, a co-relational study of 4 weaving factors namely initial warp tension, weft thickness, weft density and shedding height have been studied with a dynamic model of beat up process [33].

However, mathematical models based on the fundamental mechanics of woven fabrics often fail to yield satisfactory results as it is hardly possible to combine all the complexities in the model [28]. Most of researchers focused their attempts to investigate the influence of warp tension during weaving. However, a significant attention has not been paid to dynamic tension variation caused by the position and the movement of the fabric fell due to warp tension and fabric tension. A good set of loom factors could be reached through trial and error method in setting up a loom. This causes a considerable waste of raw materials, energy, production time and the efficiency of the weaver. Still optimal set of parameters could not be realized and fine tuning of fabric quality throughout the process of weaving, weaving efficiency and the noise level hazards still remains unaddressed.
The aims of this study are to investigate the behaviour of the fabric fell during shed formation and to develop a mathematical model to explain the relationship between the initial warp tension and the resultant range of cloth-fell movement with a high level of accuracy. Currently, the experience and ability of loom operators is used to decide and set the basic warp tension values. However, the scope of the study is limited to a plain weave woven using an air jet loom composed of negatively controlled tappets with four heald shafts. Finally, a weaver may be able to set the initial warp tension for a particular weave in a way that optimizes warp tension variation during weaving.

2. Mathematical Model

A Relationship for the Instantaneous displacement of cloth

During weaving, both the warp yarns and the cloth remain under tension and are subjected to cyclic variation in tension. The elastic properties of cloth create cyclic variation in tension, and the free length of the fabric is responsible for this flexible system. In the warp tension cycle, woven fabric and warp yarns reach equilibrium when interlaced with weft yarn; such an instance is depicted in Fig. 3, where l_W and l_C represent the free lengths of the warp and fabric, respectively; F is the cloth fell; C is the contact point of the fabric take-up roller; and W is the contact point of the warp beam.

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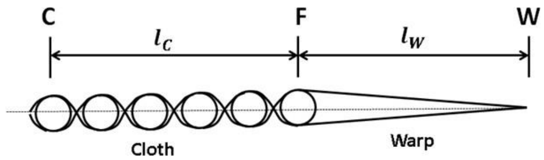

Fig. 3: Equilibrium state of woven fabric and warp yarns

Suppose the cloth tension drops below the basic warp tension or the cloth tension just before beat-up T_0 (Initial tension) drops to a new fabric tension T_C And the warp tension increases from T_0 to a new Instantaneous warp tension T_W During any instance of beat-up, such as

$$T_c = T_0 - \Delta T_c \qquad (1)$$

where $T_c = E_c Z/l_c$, Z is the instantaneous displacement of the of cloth from its basic position and E_c is the elastic modulus of the cloth. Similarly,

$$T_w = T_0 + \Delta T_w \qquad (2)$$

where $T_W = E_W Z/l_W$ and E_W is the elastic modulus of the warp.

The instantaneous weaving resistance *R* under the non- bumping condition is equal to the beat-up force exerted by the reed on the fell at any instance during beating up and is given by

$$R = T_w - T_c \qquad (3)$$

R can be written as

$$R = Z\left(\frac{E_w}{l_w} + \frac{E_c}{l_c}\right) \qquad (4)$$

Therefore, the instantaneous displacement of the cloth fell from its initial position Z can be expressed as

$$Z = \frac{T_w - T_c}{(\frac{E_w}{l_w} + \frac{E_c}{l_c})} \qquad (5)$$

Under a bumping condition, fabric is relaxed and Z is given by $$Z = \frac{T_w - T_c - T_0}{(\frac{E_w}{l_w})} \qquad (6)$$

It is usually observed that the fabric relaxes more than the warp yarns, making the cloth fell drift away from the weaver when the loom stops [17].

B. Mathematical model for total cloth fell movement

Cloth-fell movement can expect cyclic variation under some predefined conditions. Thus, it is convenient to explain cloth-fell behaviour by defining four main stages during a weaving cycle. Cloth-fell movement is proportional to the resultant stress applied to the fabric and the warp sheet. The cloth fell is represented by a point that oscillates along the horizontal plane that bridges the fabric and the warp.

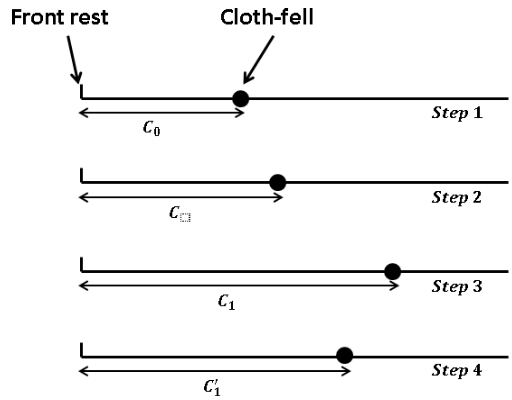

Fig. 4: Four main stages of cloth-fell movement

At stage 1, the reed brings the cloth fell to its most forward position after inserting a new pick. At this instance, the cloth fell is held by the dents of the reed such that the fabric is under its lowest tension and the warp sheet is at its highest tension. When the reed moves back, the pressure exerted on the cloth fell is released, and the cloth-fell line moves back to bring the fabric-warp system to a low potential energy, as at stage 2. When the shed is formed, excessive stretch is exerted on the fabric up to the heald eyes, making the cloth fell move towards the back rest as depicted in stage 3 of Fig. 4. This movement is proportional to the amount of shedding. During shedding, higher stress is applied to the warp sheet, and a considerable amount of strain occurs. Therefore, in certain power looms, an oscillatory movement of the back rest, which relaxes the fabric, takes place by moving forward when the heald frames are lifted and lowered. Due to this relaxation of the warp sheet, the position of the cloth fell moves towards the front rest as given in stage 4 in Fig. 4. From stage 2 to stage 4, the forces acting on the cloth fell are balanced by the external forces exerted by the fabric and the warp sheet. However, when the cloth fell is under the control of the reed, three forces—namely, the forces exerted by the reed (towards the front rest), by the fabric (towards the front rest) and by the warp (towards the back rest)—acting on the cloth fell.

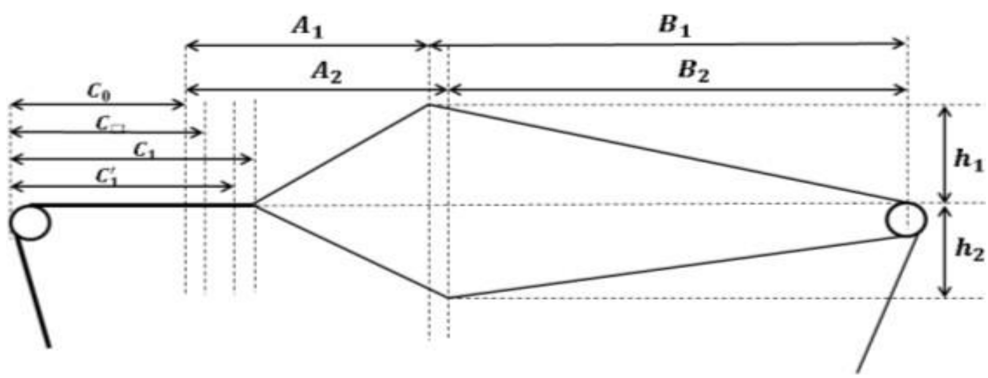

Fig. 5: Shed geometry and cloth-fell position

Fig. 5 shows the shed geometry and the position of the cloth fell as described in four main stages. Here, C_0, C, C_1 *and* C_1' Represent the extreme front position of the cloth fell and the cloth-fell positions after reaction of the reed (after beat-up), after warp shedding and after movement of the back rest, respectively. h_1 and h_2 denote the heights of the top and bottom sheds, respectively. A_i is the distance from the

Extreme front position of the cloth fell to the i[th] heald frame, and B_i is the distance from the back rest to the i[th] heald frame. Considering the geometry of the shed, its material parameters and the forces acting on the fabric, the displacement of cloth-fell movement due to beat-up $C - C_0$ of the crank-type slay mechanism can be expressed as

$$(C - C_0 = \lambda_b = \left(\frac{L_{sf}}{L_{ss}}\right)\left[R(1 - cos\alpha_B) + \frac{R^2}{2l} sin^2\alpha_B\right] \quad (7)$$

where αB is the angle of the beat-up zone, λb is the length of the beat-up zone, R is the radius of the crank arm, l is the length of the connecting rod, L_{sf} is the distance between the slay sword shaft and the cloth-fell, and L_{SS} is the distance from the slay sword shaft to the slay sword finger.

(C_1-C) represents the cloth-fell movement due to the shedding action. The position of the cloth fell is determined by the resultant stresses applied to the fabric and the warp sheet. Considering the geometry of the fabric and warp sheet, the cloth-fell movement due to shedding (C_1-C) can be expressed as

$$\begin{aligned}(C_1 - C)E_c + T_0 &= [\left\{\sqrt{A_1 - (C_1 - C)^2 + h_1^2} + \sqrt{B_1^2 + h_1^2} + (C_1 - C)\right\}E_w \\ &+ \frac{T_0}{N_A}N_U]\frac{[A_1 - (C_1 - C)]}{\sqrt{A_2 - (C_1 - C)^2 + h_1^2}}\ [\left\{\sqrt{A_2 - (C_1 - C)^2 + h_2^2} + \sqrt{B_2^2 + h_2^2} \right. \\ &\left. + (C_1 - C)\right\}E_w\ \frac{[A_1 - (C_1 - C)]}{\sqrt{A_2 - (C_1 - C)^2 + h_2^2}} \quad (8)\end{aligned}$$

where N_A, N_u and N_L are the total number of warps, the number of warps in the upper shed and the number of warps in the lower shed, respectively, and l is the length between the back rest and the cloth fell. Other notations are as illustrated in Fig. 5.
(C_1-C_1') is the movement of the cloth fell due to the forward movement of the back rest, and it can be expressed as $C_1 - C_1' = M\left(1 - \frac{1}{1+\frac{E_C - E}{E - E_W}}\right) \quad (9)$

Where M is the horizontal movement of a point on the warp sheet due to back-rest movement and E is the equivalent elastic modulus of the warp and fabric and mathematically generated from the following formula:

$$E = \frac{E_c E_W}{E_c + E_W} \quad (10)$$

Hence, total cloth-fell movement D is given by the following expression:

$$D = (C - C_0) + (C_1 - C) - (C_1 - C_1') \quad (11)$$

3. Methodology

A. Experimental setup

The experiment was performed under laboratory conditions using an air jet loom (Tsudakoma, model ZA 203) and poly/cotton warp and weft yarns with a Tex count of 16. During weaving, the initial warp yarn tension T_0 was set to 30 cN, and all tension readings were obtained with a yarn tension meter having the following specifications:

Make: ZIVY
Model: EL-TEN
Accuracy: 0.1 cN
Range: 0-400 cN

Using a Vernier caliper (for measurements less than 16 cm) or a measuring tape, the parameters related to the geometry of shedding were measured and are tabulated in Table 1. For a given loom, the parameters given in Table 1 have constant values. The values of h_1 and h_2 were measured when the shed was at a fully open or closed condition.

Shedding parameter	Value (in mm)
A_1	119.0
A_2	159.0
B_1	1023
B_2	983
h_1	42.0
h_2	45.0
L	1142

Table 1: Shed parameters

The width of the fabric woven was 140 cm, with a total of 3360 warp ends and a warp density of 24 ends/cm. Since the weave was plain, the warp ends are distributed equally between the upper and lower warp sheets; hence, $N_u = N_L = 1680$. The machine was operated at 525 rpm during the experiment.
The machine parameters related to equation (7) are given in Table 2.

Machine parameter	Value (in mm)
R	38
l	117
L_{sf}	228
L_{ss}	228
α_B	21^0

Table 2: Machine parameters

A high-definition (HD) video camera was used to record the fabric-fell movement during weaving. The specifications of the camera used are summarized as follows.

Name : SONY A6300

Sensor : 24.2 MP APS-C Exmor CMOS Recording frame rate : XAVC-S (100 Mbps)
Frame size : 1920 x 1080 pixels
Frame rate : 120 frames/second

The experimental setup for measuring the dynamic cloth-fell movement during weaving at a speed of 525 picks/min is given in Fig. 6. When the loom operates at 525 picks/min, approximately 9 picks are inserted per second, and so, to measure cloth-fell movement with sufficient accuracy, at least 10 frames per weft must be captured. This means that the camera should support a frame rate of at least 90 fps; the camera used to measure the cloth-fell movement met that specification.

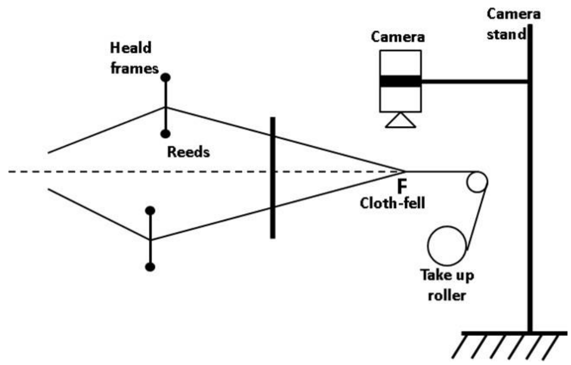

Fig. 6: Experimental setup to measure the cloth-fell position

B. Determination of material parameters

The elastic moduli of the warp sheet and cloth are essential to the calculation of the theoretical cloth-fell movement. As no instruments are available to measure the elastic moduli of the whole warp sheet and fabric at once, they were calculated for a known number of warp threads and fabric samples of predetermined widths using a universal tensile strength tester; the results were extrapolated to the entire warp sheet and the woven fabric. Here, the scalability of the warp sheet and the cloth are assumed to be linear and without contradictions of Hooke's law.

Twenty-eight warp sheet samples (20 cm long by 5 cm wide) covering the entire sheet were tested on a tensile tester machine to obtain a stress-strain curve for each sample. Considering the linear segment of each sample, elastic moduli for the samples were calculated, and the equivalent elastic modulus for the entire warp sheet was obtained. If the elastic modulus of the jth warp sheet sample is given by EWj, then the elastic modulus for the entre warp sheet is given by

$$E_w = \frac{20}{l_w} \sum_{j=1}^{28} E_w^j \quad (12)$$

Similarly, the entire fabric width was covered by 28 fabric samples (5 cm in width by 20 cm in length). Then, based on the results of the universal tensile strength testing machine, the elastic modulus of the jth fabric sample is calculated and assumed to be equal to ECj. Thereby, the equivalent elastic modulus of the fabric is given by equation (13):

$$E_c = \frac{20}{l_c} \sum_{j=1}^{28} E_c^j \quad (13)$$

C. Measurement of cloth fell movement

The experimental setup illustrated in Fig. 6 was used to capture video footage while the loom operated at 525 picks/min. Initial tension was increased or decreased 5 kgf steps at each time to cover the warp tension range from 93 kgf to 128 kgf; the cloth-fell movement was recorded after establishing the set warp tension in operation. The recorded image was processed with the image processing toolbox of MATLAB® R2017b. The format was converted first to mp4 video file format, subsequently to grayscale and then to binary for convenient identification of the position of the cloth fell. Considering that the size of the actual video frame is 15.7 cm x 28 cm, the movement of the cloth fell was converted from pixels to millimeters. The fabric-fell movements at different initial tensions were summarized.

4. Results and discussion

Load elongation of the warp sheet samples (5 mm × 20 cm) was tested on a tensile testing machine to obtain a load-elongation curve for each sample. The curve obtained for sample 7 (before the breaking of many warp yarns) is illustrated in Fig. 7; the elastic modulus of the sample was calculated from the linear segment in which elongation obeys Hooke's law. The elastic modulus obtained for sample 7 is 0.0701 kN/mm. By repeating the same procedure, the elastic moduli for all 28 samples were calculated. The elastic modulus of the warp sheet samples has a mean value of 0.0697 kN/mm with a standard deviation of 0.00913 kN/mm. Using equation (12), the elastic modulus for the whole warp sheet was derived as 0.15613 kN/mm.

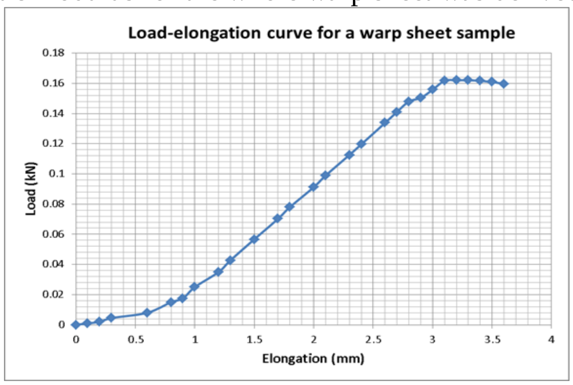

Fig. 7: Load-elongation curve for warp sheet sample 7

Similarly, the fabric specimen (5 mm x 20 cm) was tested on a tensile testing machine until complete breakage of the fabric specimen. The load-elongation curve of plain weave fabric sample 3 is given in Fig. 8, and the elastic region was used to calculate the elastic modulus of the full fabric woven on the loom based on equation (13). The elastic moduli for the fabric specimens show an approximately normal distribution, with a mean value of 0.082829 kN/mm and a standard deviation of 0.01213 kN/mm. Based on equation (13), the equivalent elastic modulus for the fabric woven is 0.29925 kN/mm.

There are two factors preventing the use of the tension meter to measure the tension when the machine was operated at 525 picks/min. One was low sampling rate—the tension meter could not take 50 readings/sec, and the cyclic variation of tension could not be measured. Further, the strain gauge sensor used in the tension meter is mechanical, and the device therefore undergoes a considerable amount of vibration during operation. As highly sensitive and accurate data could not be obtained with the existing tension meter, equation (6), which is well established in the literature, could not be used to determine the cloth-fell movement during weaving.

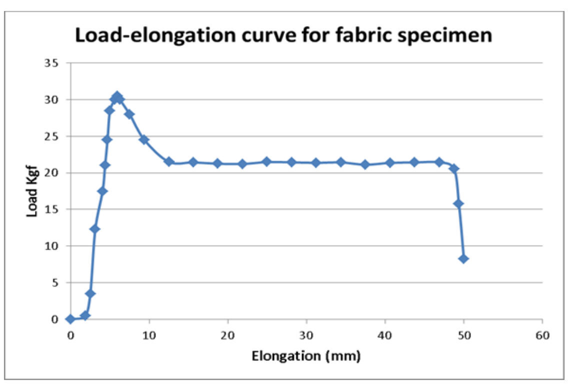

Fig. 8: Load-elongation curve for plain weave fabric sample 3

Various methods have been devised by researchers to measure the movement of cloth-fell, and among them, high-quality image processing was of interest due to its accuracy. The frame rate of the video camera used was 120 fps, and a minimum cloth-fell position of 13 could be read within one cycle with an accuracy of 0.15 mm (a 15.7 cm x 28 cm video frame was captured at a resolution of 1080*1920). The actual cloth-fell

Movement was experimentally obtained by taking video footage of fabric-fell movement with a high-speed, high-resolution video camera and subsequently applying image processing techniques. According to equation (8), cloth-fell movement depends on the initial tension. An experiment was repeated by varying the initial tension in 5 kgf steps over a range from 93 kgf to 128 kgf. The corresponding theoretical cloth-fell movement was calculated using equations (8) to (11) derived in this article and equation (7) found in the literature. Since the equation (8) is nonlinear, the value of (C1-C) was obtained using the Newton-Rapson method. Obtained experimental and theoretical values are summarized in Table 3.

Initial warp tension (kgf)	Total cloth-fell movement (mm)	
	Theoretical value	Experimental value
93	5.94124	6.12
98	5.57864	5.48
103	5.21604	5.24
108	4.85344	5.02
113	4.49084	4.42
118	4.12824	4.23
123	3.76564	3.79
128	3.40304	3.40

Table 3: Theoretical and experimental cloth-fell movement for various initial warp tensions

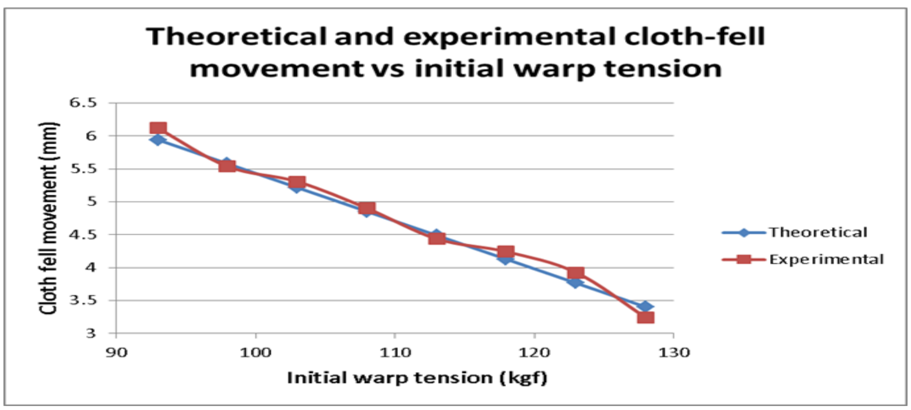

Fig. 9: Theoretical and experimental cloth-fell movement for various initial tensions

Theoretical and experimental cloth-fell movement against initial warp tension was plotted for comparison; the experimental results seem to be in close agreement with their theoretical counterparts. As the initial warp tension increased, cloth-fell movement gradually decreased due to mobility constraints imposed by the higher weaving resistance that resulted from the higher initial warp tension.

A t-test was performed to ascertain whether the difference between theoretical and experimental results was significantly high. The t-statistic for the difference between the theoretical and experimental yields was 0.4646. However, the critical value from the t-table for experiments with 14 degrees of freedom at a 95% level of confidence was 2.145. Hence, there is no statistically significant difference between the experimental and theoretical results at a 95% confidence level. Thereby, the accuracy of the derived model was proven, and the mathematical model was validated.

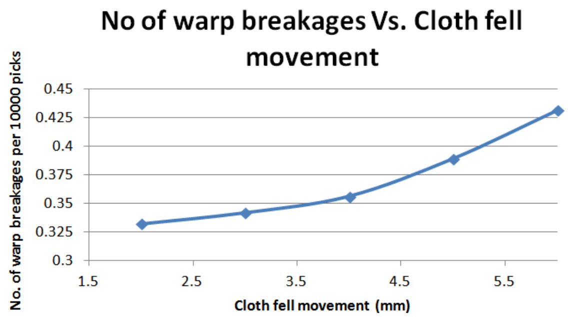

Fig. 10: Warp yarn breakages against cloth fell movement

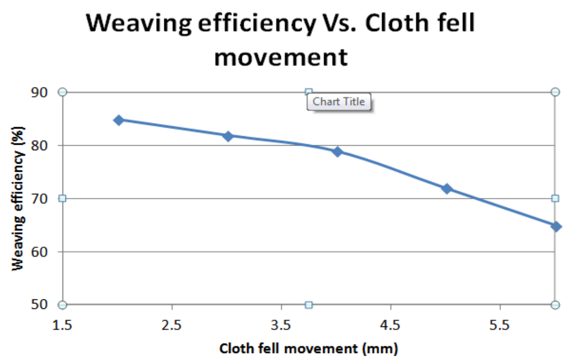

Fig. 11: Weaving efficiency variation with cloth fell movement

Cloth fell movement (mm)	Average noise level at 1m from loom (dBA)
0	77.8
2	83.8
5	86.3
10	89.2
15	93.1

Table 4: Average noise level for different cloth- fell movement

The effect of cloth fell movement on warp yarn breakages and weaving efficiency were experimentally investigated for a given initial warp tension. An increase of the cloth fell movement results in monotonous increment in warp yarn breakages at an inclined rate. Figure 10 depicts this relationship. When the cloth-fell movement increases, the weaving efficiency decreases at a greater rate as shown in Figure 11. However, zero movement of the cloth fell does not provide required pick density and cover factor. These parameters uniquely determine the quality of the fabric. Therefore setting the cloth fell movement to a minimum value to achieve the required pick density and cover factor is the weaver's challenge. Further, the noise level in front of the loom increases to a hazardous level as the cloth fell movement increases. This causes a significant wastage in energy, reduces weaver's efficiency and creates health hazards to the weaver. The experimental results of noise level were given in Table 4.

5. Conclusion

The literature on cloth-fell movement has been reviewed regarding theoretical and experimental aspects, and the scientific background and importance of cloth-fell movement have been described. To develop an accurate mathematical model for cloth-fell movement, material parameters (the elastic moduli of the fabric and the warp sheet), shed parameters (shed angle, shed geometry and the number of warp ends in the shed), loom parameters (initial warp tension and free length of fabric and warp) and slay mechanism parameters were considered.

Video footage captured by a high-speed, high-resolution camcorder was used to measure the position of the cloth-fell movement at various initial warp tensions when the loom was operated at its maximum rated speed. Image processing techniques were subsequently applied to the video footage at the frame level. The corresponding cloth-fell movement was determined at the initial warp tension at which the experiment was carried out. To validate the developed mathematical model, statistical analyses were performed, leading to the determination that there was no difference between the experimental and theoretical results at the 95% confidence level, which proved the model developed has an adequate level of accuracy. The model developed here can help even an inexperienced loom operator set the initial warp tension to maintain the cloth-fell movement, which determines the quality of the woven fabric, within an acceptable range. Hence, the findings of this paper have significant industrial implications. However, this study focused on an air jet loom composed of negatively controlled tappets and four heald shafts, and thus, future work is necessary to extend these findings to other loom types.

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