Warp tension analysis of narrow fabric weaving and designing of tension compensator to avoid start up marks

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Abstract— *Start up marks are one of the major defects on woven fabric and this defect occurs when loom restarts after stoppages due to warp tension variation at the time of start. This defect is more prominent in high speed looms and it is critical in manufacturing elastic tapes. In this paper, formation of start-up in elastic tape on a narrow fabric loom was analyzed mathematically and provided a practical technical solution to the problem. In mathematical analysis both continuous operational condition and stopping condition of a narrow fabric loom was taken into consideration and the developed mathematical model established a quantitative relationship between excess warp yarn length fed and the tension variation of warp yarn at the point of starting the loom. A system simulation was carried out using the model developed and compared with the experimental results to show the accuracy of the model. A tension compensating device was proposed to avoid formation of the startup marks. The effectiveness of the proposed solution was proven practically with a prototype developed.*

Keywords — *lastic tapes, narrow fabric loom, tension analysis, warp tension compensation, start up marks.*

I. INTRODUCTION

Apparel industrial sector acquired a rapid growth in the recent past to compete in the global market and this movement is mainly focused at achieving higher productivity with higher quality. In order to maintain high quality level in the end product, it is imperative to use good quality raw materials. As an essential part of the supply chain, raw material manufacturing for garment industry has been significantly developed and became one of the highest quality materials in the international market with no exception to the narrow elastic material. Still the full potential of productivity could not be met due to frequent fabric defects such as startup marks which are also known as irregular pick marks. Due to tension variations at stopping and starting of loom, pick density variation can be specifically observed in the elastic tape and it appears as a fabric flaw termed as start up mark. This defect is more prominent when the looms are operated at high speeds and it is crucial case in elastic fabric formation.

Startup marks lead to create colour variations during dyeing process therefore it is essential to remove startup mark portion from the elastic tape before dyeing. The existing solution for this problem is to cut elastic tapes to remove the defective part and rejoin each tape with plastic tag pins which is not a value addition process and such practice concedes a large sum of money as well as experiencing an inevitable material wastage. Material wastage is significantly high in case of elastic bands with a design as the entire repeat having defects should be removed as a waste. Further, the efficiency of packing is reduced approximately by 50%, when a joint is detected by the layering machine as it is required to stop and operator has to cut the joint and connect two ends with an adhesive tape. Further operator has to match needle edge to needle edge, wire edge to wire edge and face side to face side in this process. Further elastic fabric manufacturing is done in large scale to cater for the very high demand and frequently occurring startup marks is a serious manufacturing problem which needs an immediate and sustainable solution.

Depending on the nature, startup marks can be divided into two types namely open mark or thin start up mark and dense mark or thick startup mark. Open marks appear when there is decrease in pick density due to cloth fell go away from reed. At the instances of stoppage, warp tension decreases and open mark appears at the time of starting the loom. Dense marks appear when there is an increase in pick density and it occurs while the cloth fell moves towards reed. This phenomenon was described in the literature in the following manner. Thin start up mark appears as a result of lower warp tension while thick start –up marks are the result of higher warp tension, during restarting in comparison to steady state running tension [7]. The picks of synthetic yarn at cloth fell slip back when the reed moves back after beating up causing non-uniform pick spacing at the cloth fell. The backward movement of the picks at the cloth fell may occur due to both slipping and rolling back. Rolling back is easier than slipping back as it requires less energy. The release of energy stored in a twisted yarn promotes rolling back of inserted weft [9].

K. Greenwood, and W.T. Cowhig were honoured as the premier researchers who studied the startup marks in depth by publishing a series of research papers. In their first paper, a theoretical analysis of the factors governing pick was under investigation. Further, mathematical relationships between beat-up forces, cloth fell position, take-up rate and pick space were derived and analyzed in that paper [1]. Subsequently, this analysis was extended to explain the various causes of irregular pick spacing with respect to warp and fabric relaxing during the machine stoppage in the second paper [2]. Further, contribution of the effect of the length of warp, the fabric type and the type of let-off motion to the severity of start-up marks flaw were examined. Third paper was dedicated to an experimental investigation of loom and warp and indicated that effect of loom speed was so small for slight variations in it during running or after staring up did not cause any appreciable irregularity in the pick spacing [3].

The warp tension variations during initial picks after restarting the narrow fabric weaving machine from its running tension was the major reason for start-up marks. Further it was noted that the variation in warp tension was related to the inertia moment of the oscillating backrest [4]. In order to diminish the appearance of the startup marks, low tension in warp tension was proposed [5] and this was inapplicable to elastic fabrics in order to intact with the elasto-mechanical properties of such fabrics. The effect of different weaving conditions and loom settings on variation in pick spacing, which led to formation of startup marks of different severity, was analyzed and experimental tested with an image processing technique [6]. The effect of relaxation of warp and fabric on pick space variation was also under discussion of this research article. Tendency towards formation of start-up marks increases with fabric tightness and other factors such as stoppage time, stop position, warp let-off control and back rest damping [6].

Any disturbance in the cloth fell position was responsible for the variation in pick-spacing [10]. When the pick spacing is severe enough, it would lead to a flaw in the fabric. Most of the variations in pick spacing are caused by displacement of the cloth fell. The main sources of variations in pick spacing were identified as take-up motion, let-off motion and loom stoppage [11]. Any variation in the rate of take-up must be enough to make a change in pick spacing due to the change in cloth-fell position. Most of these types of variations were occurred due to mechanical issues such as eccentric or eccentrically mounted rollers or gear wheels and damaged or incorrectly shaped teeth of gears. Even though take – up motion was emphasized as a key factor responsible for start- up marks, the research works out so far revealed that the improper functions of let-off motion are caused to the variations in warp tension and it will lead to the variations in the cloth-fell position and pick-spacing [12].

When producing cotton or polyester fabrics, startup marks can be eliminated by using positive let-off motion instead of negative let-off motion. An elastic manufacturing on a narrow width loom has negative let off motion that means warp yarns are unwound from the weaver’s by means of tension applied by the take up motion and the tension variations in the warp in stoppages are unavoidable. Negative let off mechanism is essential to maintain a higher warp tension to achieve higher stretchability in elastic fabrics. Hence is more suitable to have negative let-off motion in elastic weaving and even with positive let of mechanism the defects made worse in addition to lead for poor stretchability. Hence simple solution to address the formation of start up marks in elastic fabrics is not feasible.

Short term variation, medium term variation and long term variation in tension was found in negative friction type let- off motion [14]. A narrow fabric loom with a negative friction type let- off motion attracted attention of researchers. The negative friction type let-off motion provides stiffness to the back rest and beam so that it would not float. When the backrest is fixed warp length and the fabric length remain constant [13]. Therefore during the loom stoppage the warp and the fabric tension will tend to reduce due to the relaxation of warp sheet and fabric, and some movement of the cloth fell also. The directions of the displacement of the fabric cloth fell depend on relative change in the elastic module of the warp sheet and the fabric [5].

Though the solutions found in literature to minimize the startup marks when producing cotton and polyester fabrics, no acceptable solutions could be found to address the startup marks in elastic fabrics. Further, to achieve higher efficacy of the looms multiple narrow elastic fabrics are simultaneously weave on a single loom where the simultaneous occurrence of the defect in all fabrics are inevitable and hence addressing the start up defects become more crucial. It was proven that the simple solutions were not practically viable. Many trial solutions adopted by the industry to minimize start-up marks but those could not be sustained due to several drawbacks and Table I shows the worked out solutions by industry.

TABLE I
WORKED OUT SOLUTIONS BY INDUSTRY

Implementation	Factors for failure
At the stoppage an extra warp length was compensated using three rubber bars.	At the restart position, it is unable to define the exact amount of warp yarn release.
Pneumatic cylinders were attached to each weavers beam and breaking mechanism was devised between cylinders and machine head. Therefore every stoppage, weavers' beams were stopped with the machine head.	High cost for pneumatic components. When the machine is under braking system, movement of weavers' beam for other desirable operation is impossible.
All weavers' beams were controlled with one large pneumatic cylinder.	Cost was reduced but not sustainable as it blocks the workings envelop.
Inverter was added to main motor to gradually increase the warp tension when restart the machine.	Only valid for sudden variations.

Most of the work reviewed and described above was useful in explaining how start-up marks are created and what factors are responsible in creating start – up marks, but none of the approaches leads to a sustainable solution. Those works were based on either with mathematical models, experimental models or laboratory experiments and basically focused at general fabric formation. In most cases shuttle looms were used for the experimental studies found in plethora of literature and small amount of literature focused in narrow width weaving on looms. Mathematical analysis was carried out for the generation of start-up mark in elastic tape considering both continuous operation condition and stopping condition of the narrow fabric loom [8]. In this publication, two authors of this paper were involved and they further extend the research to develop a sustainable solution. In this paper, a practical solution to avoid formation of the startup marks was proposed and the experimental tested the effectiveness of the proposed yarn tension compensation device using the prototype developed.

The remaining part of the article is structured such as way that a brief outline of the mathematical modeling is given in section II – Mathematical model. Section III-Methodology is dedicated to discuss the scientific approach of the development of the solution strategy. Results are given in the next section while section V is devoted for the discussion. With the concluding remarks in Section VII, the article will be winded up.

II MATHEMATICAL MODEL

2.1 Narrow fabric loom setup

Narrow fabric elastic loom under consideration is comprised of four weaver's beams, a negative friction let-off mechanism, two sets of back rests, fabric formation zone and take up roller. The unwound warp yarn from the weaver's beam is passes through the two sets of back rests before entering the fabric formation zone which is demarcated by separators to separate all warp yarns into four sections. The woven elastic tape is pulled out by the take- up roller as shown in Fig.1. In the negative let-off mechanism driving force is provided by the tension of the warp yarn and it is regulated by the friction between rope and beam flange as given in Fig.2.

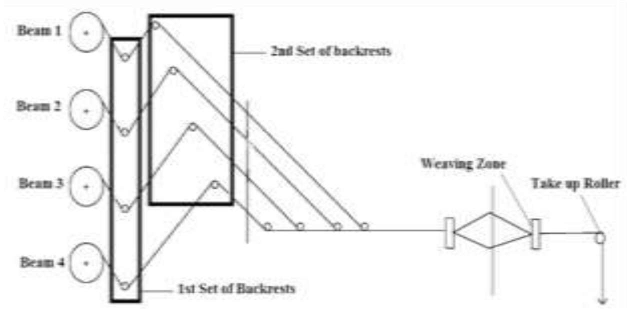

Fig.1(a) Sketch of Narrow Fabric Loom

Fig.1(b) Narrow Fabric Loom

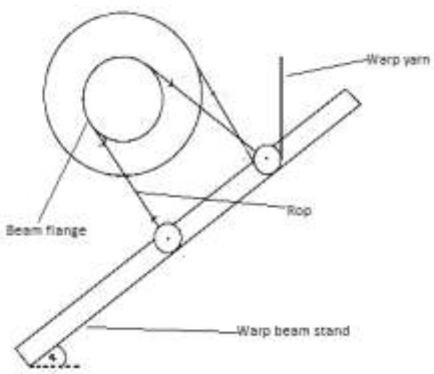

Fig.2. Warp Tension Mechanism

2.2 Overview of the model

At the time of stoppage, a torque on weaver's beam is exerted by the tensioned warp yarns in the negative let off mechanism. Due to the inertia of the weaver's beam, it rotates further and unable to stop with the machine head. With this additional rotation, tension drop is experienced in warp yarn and at the restart position pick density variation can be observed in elastic tape.

The mathematical model found in [8] quantitatively explains the factors which influences the excess yarn length during the very first pick insertion when the machine restarts. The unstrained length advancement per weft can be expressed as a first order differential equation given in (1)

$$\frac{dl_{f0}}{dt} = (2\varepsilon_f - 1)l_f\frac{d\varepsilon_f}{dt} + (1 - \varepsilon_f)\frac{dl_f}{dt} \quad (1)$$

where l_{f0} is the unstrained length advance per weft, l_f is the strained length advance per weft and $\varepsilon_f$is the strain of the yarn at take up.

The mass outflow rate $\frac{dm_{out}}{dt}$ can be expressed as

$$\frac{dm_{out}}{dt} = \rho_o A\frac{v_f}{(1+\varepsilon_f)} \quad (2)$$

where v_f is the speed of the take up roller, A is the cross section of the unstrained yarn, and ρ_o is the linear density of the unstrained yarn.

The above stated relationships govern the continuous operational conditions of the narrow fabric loom. At the point of power failure no yarn takes out from the control region and output rate of change of mass is equal to zero. This yields a mathematical relationship for the speed of the take up roller at the point of power failure and it can be expressed as

$$\frac{R\omega(1+\varepsilon_f)}{1+\varepsilon_i} = v_f \quad (3)$$

where R is the radius of the weaver's beam, ω is the rotational speed of the weaver's beam and ε_i- is the strain of the in yarn and $\varepsilon_f$is the strain of the yarn at take up.

In negative let-off mechanism, at the time of stoppage, the weaver's beam is further rotated until its moment in balanced with torque created by the frictional force. The frictional energy loss is taken into consideration and considering the energy conservation the following equation can be derived.

$$\frac{1}{2}I_{eq}\omega^2 + \theta R T_w = \theta R F_R \quad (4)$$

Where θR is the excessive length which enters to the control region because of the further rotation of the weaver's beam after machine head stoppage. F_R is the frictional forces in the weaver's beam, I_{eq} is the equivalent moment of inertia of the weaver's beam, R is the radius of the weaver's beam, and ω is the rotational speed of the weaver's beam. By eliminating the angular speed of the beam, excessive length moves into the control region can also expressed by the relationship stated below.

$$\theta R = I_{eq}\left(\frac{1+\varepsilon_i}{1+\varepsilon_f}\right)^2\frac{v_f^2}{2R^2(F_R - T_w)} \quad (5)$$

Where T_w is the total tension of the yarns. If E is the Young's modulus of the warp yarn, then the relationship in equation (5) can be expressed using measurable quantities and the rearranged equation can be given as

$$\theta R = I_{eq}\left(\frac{AE+T_w}{AE+T_f}\right)^2\frac{v_f^2}{2R^2(F_R - T_w)} \quad (6)$$

III METHODOLOGY

3.1 Validation of the model

Using equation (6), for different T_w values in the practical range, the excessive yarn length entering into the control region is calculated and tabulated. Experimental the warp tension is measured with a tension meter. Data set of ten tension readings were used to calculate the average tension of a warp yarn. As the beam radius is subjected to change, the average beam radius was measured in several instances when the practical T_w values equal to the values used for system simulation.

Practically it is difficult to measure excessive length of the warp which is entered into the fabric formation zone. The defect size is depended on that excessive length entered into the fabric formation zone and the excessive length should be in the fabric in the vicinity of startup marks. Therefore using pick density variation at startup mark, the practical excessive length for each case was measured. The calculated practical readings and the corresponding system simulation values were compared and thereby justify the validity of the model.

3.2 Yarn tension compensation system to avoid start up marks

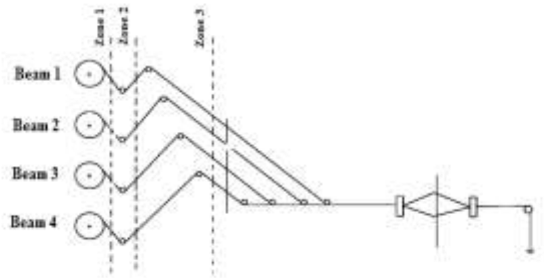

Fig.3: Different measuring zones of warp yarn tension

In order to have an in-depth insight into the yarn tension variation in different zones and weaver's beams depicted in Fig. 3, yarn tension was measured at different zones of the beams when starting stopping and in continuous operation. The minimum and maximum yarn tension in continuous operation before implementing the tension compensating device was obtained and these values are used in control algorithm of the yarn tension compensation at the time of restarting the loom.

A prototype of warp yarn compensation system was developed. It worked on the principle of closed loop control system and sense of intelligent is imparted to the system about the variation of tension calculated by system simulation using the developed mathematical model. The prototype was developed with one beam and the warp yarn tension was measured by a load cell which is of 1mg accuracy and 300g of load limit. Sensor is connected to the backrest to measure the warp yarn tension continuously. The picture of the prototype developed to compensate the warp yarn tension variation is given in Fig. 4

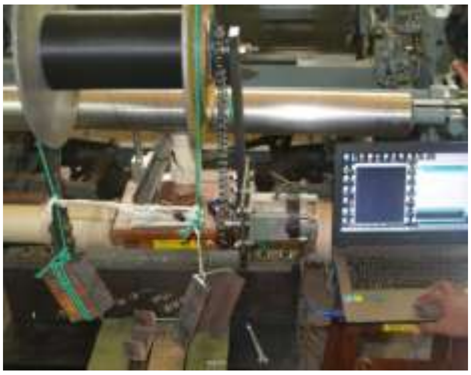

Fig.4: Picture of the prototype for warp yarn tension compensator

A motion sensor was used to detect the loom in continuous operation. If no motion is detected over a period of 500ms, loom is assumed to be stopped. During running stage of the loom, warp yarn tension was read by an arduino board, which act as the motion controller, display it and calculate the average of the warp yarn tension using a data window of five readings. During running of the loom, servo-motor runs in passive mode. Once detected that the loom is stopped, controller scans through the recorded average warp yarn tension until stable value within the range given by system simulation is found. This value is considered as the average warp yarn tension under continuous operation. Upon restore of power in case of power failure, servomotor drives back the beam until an average warp tension in continuous operation in last instance is obtained. Upon establishing that tension, a green light is on so that the loom can be restarted with the start switch of the loom.

IV RESULTS

4.1 Model validation

The equivalent moment of inertia of the experimental weaver's beam I_{eq} was calculated from basic formula given in equation (7)

$$I_{eq} = \frac{1}{2}[2m_1 r_1^2 + m_2 r_2^2 + m(R^2 + r_2^2)] \quad (7)$$

The parameters m_i and r_i are depicted in Fig.5.

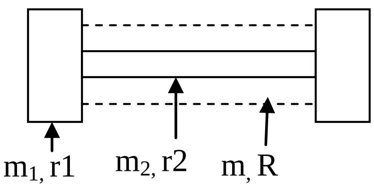

Fig.5. Moment of Inertia of weaver's beam

The following parameters were used to calculate the moment of inertia of the weavers beam and

E - 1.97 x 105N/cm2
v_f- 0.025 m/s
T_f- 70 cN/ warp
F_R - 183.34N
No of warps in the weaver's beam - 240

The excessive yarn length entered into the fabric formation zone was calculated using system simulation technique and it is depicted in the Table 1.

TABLE I.
Theoretical Values For Excessive Length

T_w (cN)/warp	R (cm)	θR(mm)
52	24	0.219
55	20	0.363
60	18	0.592
62	12	1.524
65	6	1.938

The practical values obtained as per the procedure discussed under 3.1 was given in the Table II.

TABLE II
Practical Values For Excessive Length

T_w (cN)/warp	R (cm)	θR (mm)
52	24	0.2
55	20	0.4
60	18	0.7
62	12	1.6
65	6	2.1

Figure 6 gives a brief comparison of the system simulation results calculated using the model developed and the corresponding experimental results obtained. The concurrence of the two results obtained is shown that the model developed is adequately accurate and the validity of the model for practical purposes

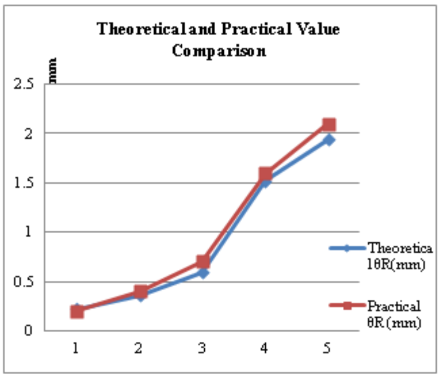

Fig.6: Comparison of theoretical and practical values

4.2 Yarn tension experimentation results

The yarn tension variation with respected to the time for different beams at various points along the yarn path were measured and plotted. Figures 7, 8, and 9 show the variation of yarn tension for beam 1, 2 and 3 when running, stopping and restarting. Though four of beams are mounted on the narrow fabric loom, we obtained the reading with three beams for the convenience of obtaining measurements with the tension meter due to space limitation in taking certain readings. Due to shedding action, warp tension is varied frequently.

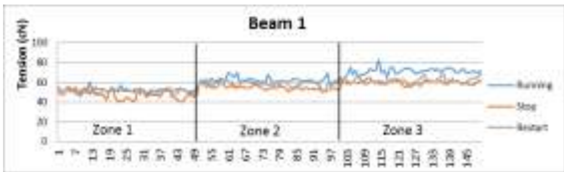

Fig. 7: Tension variation of weaver's beam 1

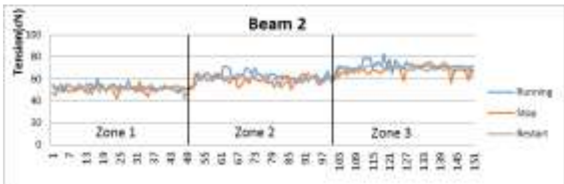

Fig. 8: Tension variation of weaver's beam 2

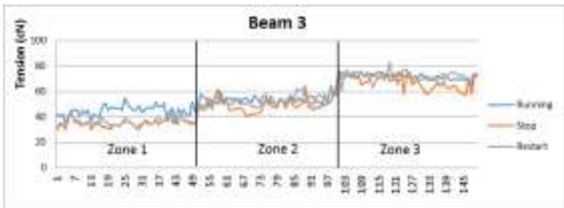

Fig. 9: Tension variation of weaver's beam 3

The percentage of average tension variation at different beams can be tabulated in Tables III, IV and V,

In tables

A = Reduction % of running to stopping

B - Increment % of Stopping to restarting

Zone 1		Zone 2		Zone 3	
A	B	A	B	A	B
7.77%	5.88%	12.07%	7.04%	15.91%	2.93%

Table III-

Percentage variation of tension values in Beam1

Zone 1		Zone 2		Zone 3	
A	B	A	B	A	B
3.17%	1.02%	5.69%	0.60%	5.99%	2.06%

Table IV

Percentage variation of tension values in Beam 2

Zone 1		Zone 2		Zone 3	
A	B	A	B	A	B
22.23%	3.97%	8.22%	8.03%	6.41%	6.61%

Table V

Percentage variation of tension values in Beam 3

It was noted that the restarting condition warp tension is slightly higher than the that in stopping condition. Further, warp tension in running condition is higher than the warp tension in stopping condition. When moving from zone 1 to zone 3, the yarn tension is observed increasing for all the beams.

As the warp tension variation in running to stopping condition is higher in zone 3, warp yarn tension is mounted on the second set of backrest to measure the warp tension of zone 3. The warp yarn tension in running, stopping and restart conditions was measured after installation of the warp yarn compensation system and the results were plotted in Fig. 8.

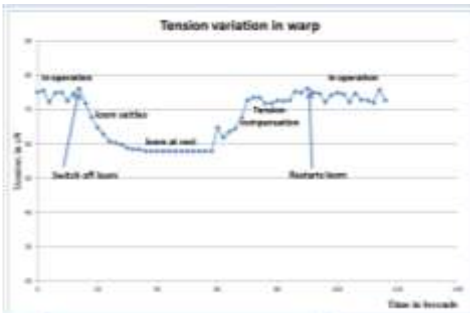

Fig. 10: Warp yarn tension variation after installation of warp yarn compensation system

V. DISCUSSION

When restarting the loom, machine head start working but weaver's beam is yet to be started as the warp tension is required to raise beyond a threshold point at which weavers beam start rotating. When the yarns are pulled by the tension exerted by take up roller, tension of warp yarns are gradually increased. Hence at the restarting point, tension of warp yarns are slightly higher than that in stopping condition. After certain time, force applied by the warp yarns is slightly higher than the force apply by the frictional forces of the beam and the beam rotates as the loom achieves it's running condition.

When the loom is stopped due to various reasons a certain warp length is further unwound from the weaver's beam due to moment of inertia of the beam. Due to which warp yarn tension in the fabric formation zone is reduced. This scenario leads to generate lower warp tension at stopping condition.

With the intention of investigating the tension variation along the warp yarn, the tension was measured at three selected points along the warp yarn path. In Zone 1 warp tension was taken for warp yarns directly unwound through the weaver's beam, in Zone 2 warp tension was measured after first back rest and in Zone 3 tension was obtained after second back rest. It can be observed that tension values were increased from Zone 1 to Zone 3 and it can be easily understood by Fig.7 through Fig.9. That means warp yarn tension was increased along the warp yarn due to increase of contact points from weaver's beam to the fabric fell.

When compared the theoretical values of warp tension with its corresponding practical values, practical values were slightly higher than that of theoretical values. Practical values were measured using the start-up mark which created on the elastic tape in particular instance by assuming excessive length which enters to the weaving zone should be woven in the fabric. But because of the tension applied by the take-up roller can pull more amount of yarn from the weaving zone than unwound excessive length during the stoppage. Therefore practical values are always slightly above the theoretical values. Further, constant frictional forces were assumed in the theoretical model but in practical situation this frictional forces can be varied and hence experimental values are expected to be deviated from theoretical values.

As depicted in Fig.10, at the 20th second, power to the loom was switched off.. As a result, gradually warp yarn tension was reduced and settled at a value of 58cN. When the warp yarn tension compensator is in action, weaver's beam rotates back by the servo motor and warp yarn tension increases. However, during this time, warp yarn tension is subjected to small variation but not as in continuous operation. Due to beat up action, yarn tension in zone 3 is significantly varies in the continuous operation and it could be clearly noted in Fig.10

VI. Conclusion

The aim of the research is to find sustainable solution to eliminate the appearance of start-up mark defect when restarting the loom. It was achieved through a carefully designed warp yarn compensating system. In order to design a warp yarn compensating system, an in-depth review of literature was carried out to identify the reasons to formation of startup marks and mathematically analyzes the formation of startup mark on a narrow fabric elastic loom. A mathematical model was developed to calculate the excessive length entering into the control region once the loom is stopped and before stopping the weavers beam. The developed model was used to calculate excessive length and compared the same with the practical reading obtained. Though the practical values are slightly higher than the theoretical values, both follow the same pattern with closer proximity and thereby proved the accuracy of the developed model.

The developed mathematical model was used to design a tension compensation system to bring the warp yarn tension to the initial tension at the time of stopping the loom and thereby successfully eliminate startup mark defect. So the mathematical model developed has a greater importance not only in academic aspect, but also in practical aspect and it was proven with the developed tension compensator. Effectiveness of the warp yarn tension compensator was justified by switching off the loom and restarting the loom after compensating the warp yarn tension.

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