International Journal of Engineering and Advanced Technology (IJEAT)
ISSN: 2249-8958 (Online), Volume-4 Issue-3, February 2015

Tension Variation in Sectional Warping, Part I: Mathematical Modeling of Yarn Tension in a Creel

Eask Fernando, R. U. Kuruppu

Abstract: ***The warping process is one of the weaving preparation processes to produce weaver's beams which uses on weaving machines to produce grey fabrics. In sectional warping several hundreds of yarn from supply packages placed on a creel are wound onto a sectional warping drum as sections and then beaming off all warp yarns from the drum to the warper's beam, which is used for fabric production with or without the subsequent process known as sizing. The uniform and even yarn tension in warping process is vital to produce high quality fabrics on looms with high efficiency. The authors attempted to theoretically interpret in terms of mathematical modeling the warp yarn tension in the yarn path of the creel with due consideration to various parameters in sectional warping. Further theoretically model the warp tension variation according to the geometrical position of the package on a sectional warping creel. This paper reports a study of tension variation of cotton yarn unwinding from the supply package up to the exit point of the creel of a Kakinoki sectional warping machine. Authors have developed a mathematical model to analyze tension variation within the warping creel for the packages with variable diameters at different positions. Based on the developed mathematical model, tension was calculated at various places along the yarn path.***

Index Terms— ***Sectional warping, creel, tension model, geometrical position, yarn unwinding***

I. INTRODUCTION

Modern high speed looms with different weft insertion systems demand formation of clear shed, uniform warp tension and sufficient strength to provide continuous production and required fabric quality. The direct and sectional warping can be considered as specific processes to produce a particular type of package for weaving which consists of several thousands of yarns with a length of several thousands of meters. The defects occurred in the warping process carry forward on to the weaver's beam. Therefore the quality of warping up to a great extent influences the productivity of the weaving machine and the quality of fabric produced [1]. The warping process is the last weaving preparation process in which tension of individual warp yarn can be controlled. The variation in tension of individual or group of yarns in warping cannot be eliminated in subsequent processes. For instance, total tension of the warp sheet should be increased in order to increase the tension of warp yarns which have low tension. However, if gaiting tension of some warp ends or sections in the weaving machine is different from the required tension, then warp ends already having adequate tension are changed.

Manuscript published on 28 February 2015.
***** Correspondence Author (s)
Dr. Eask Fernando, Department of Textile and Clothing Technology, University of Moratuwa,, Katubedda, Moratuwa ,Sri Lanka.
Dr. R. U. Kuruppu, Adjunct Professor of the School of Fashion and Textiles of RMIT University, Australia.

As a result woven fabric produced with that kind of warp sheet has variations in pick density, appearance, cover factor and impaired in quality due to high warp breakages. In addition, warping process should not impair the physical-mechanical properties of yarns, otherwise technological process of sizing and weaving would be affected [2]. The sectional warping process is intended to produce warper's beam for stripe and check fabrics, high quality fabrics with short runs and warp yarns for which sizing is not required. Therefore sectional warping process is a vital technological process for the formation of high quality fabric. However warp yarn tension of a warper's beam produced by sectional warping is having more tension variations than a back beam produced by direct warping. In sectional warping certain number of ends available on the creel as a section is first wound onto an intermediate drum (Fig. 1). Each yarn from supply packages placed at different heights and different distances from the drum is gaited through a balloon controller device, two zone tension device, various guiding elements, warp stop motion device, yarn distributer plate and reed. This number of ends is only a fraction of the total number of ends necessary on the warper's beam. After winding the required length in section, it is cut and tied up onto the upper surface of the section. Ends coming from the creel are used to wind the second section adjacent to the first section. The process is continued until the required number of yarns for the warper's beam is wound on to the drum. Then all sections on the drum are transferred on to an empty waper's beam. [1].

A. Yarn Tension in Sectional Warping

To wind yarns onto the drum a compact package with some tension in yarn winding, is required. However excessive tension when winding impairs physical and mechanical properties of warp yarns, numerous number of

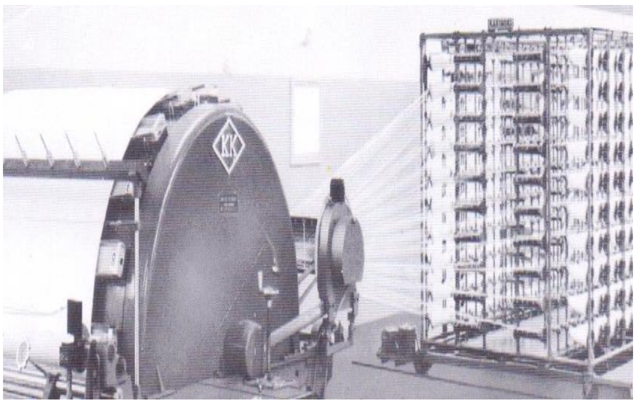

Fig. 1: Sectional warping machine

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breakages in subsequent processes can occur. Low tension in winding of the warp can cause unstable bulky package and it causes to disturb the proper process of fabric formation [3]. Uneven warp yarn tension on the warper's beam leads to create uneven warp winding density and uneven lengths of warp yarns which can generate high waste and breakages in sub sequence processes. In addition, cone or cheese packages are placed on a creel at different geometrical positions according to the axis of the warping drum. As a result, yarn length from the packages to the warping drum varies. Therefore tension of yarns can be different from package to package and the appearance of stripe and checked fabrics made out of such a warper's beam would be impaired and to have slight variations in colour for dyed fabrics [4]. Further, uneven warp yarn tension could lead to uneven pulling force to rotate back beams, warper's beam or warping drum. When the warp package rotates, the maximum loads are imposed on warp yarns which are already under tension for unwinding of warp yarns from back beams in the sizing creel, weaver's beam in weaving and sectional warping drum in sectional warping. In the meantime low loads are imposed on less tensioned warp yarns and those yarns could even be stress relaxed. Even when diameter of the warper's beam or back beams diminishes in sizing or weaving, warp yarn tension should be uniform across the width of the beam and also along the beam. By adjusting the weights on disc tension controller can help partially to compensate the yarn tension variation. However, this method is time consuming and a tedious work as this is a stepwise manual compensation method and it is not very accurate as it depends on the diameter of each package, correct weight of the disc and the correct timing of placing the dead weight. The warp winding tension at the warping drum depends on several factors, such as unwinding tension at the surface of the cone or cheese, friction between various devices of the creel and the warping machine with the moving yarn along its path, the tension given by the tension device, floating length or free hanging length of the yarn from the package to the drum and the geometrical position of the cone. The variation of warp package diameter causes tension fluctuation in the warp sheet over the drum in sectional warping. Number of researchers investigated the warping process shows that tension variation during warping has significant influence on weaving process. In this research, effect of warp yarn tension variations on the quality of woven fabrics were investigated [5]. Author discussed factors influencing on yarn tension during over end yarn withdrawal and conducted an experiment to define a relationship between yarn tension and speed of unwinding [6]. Research papers of AT Cooray [7] and [8] attempted to derive a mathematical model the over end yarn withdrawal from a cone. In research work [9] authors emphasized that the yarn tension in the process of warping significantly influenced on the warp breakages in weaving. Further he mentioned that the underestimating the influence of yarn tension could cause heavy damages to the subsequent processes. The experimental research [10] shows that by achieving uniform tension in weaving, yarn breakages in warping was reduced by 67% and in weaving by 29%. In the paper (5), author tried to mathematically analyze various factors which could affect on yarn tension in sectional warping. Behavior of yarn tension due to friction effect in the two zone tension device in weft winding process was further analyzed in the research work [11]. So far a detail analysis of exact model of yarn tension variation along the yarn path of the sectional warping machine remains not completely investigated by researchers. Therefore, it is necessary to theoretically analyze the influence of geometrical gaiting of cones on warp tension and also warp stretch to produce weaver's beam. The authors attempt to address this gap in this paper. The results are also substantiated with experimental results.

II. THEORATICAL ANALYSIS OF WARP TENSION

In the process of sectional warping, tension variation takes place at yarn unwinding from the stationary package in the creel, to the tension device, due to surface contact between the yarn and various device and guiding element of the warping machine along the yarn path and due to technological and geometrical parameters of sectional warping. The warp creel of the Kakinoki sectional warping machine shown in (Fig.2) has a symmetrical shape. It consists of 10 horizontal and 10 vertical bars on one side so that it accommodates 100 packages on either side and it is symmetrical. Referring to Fig. 3, the warp yarn (2) from cone (1) passes through the balloon eyelet (3) and tension device (4). Subsequent to the tension device, it goes through the stop motion device (5) and distributer plate which is placed symmetrical to the creel along the centre axis of the creel.

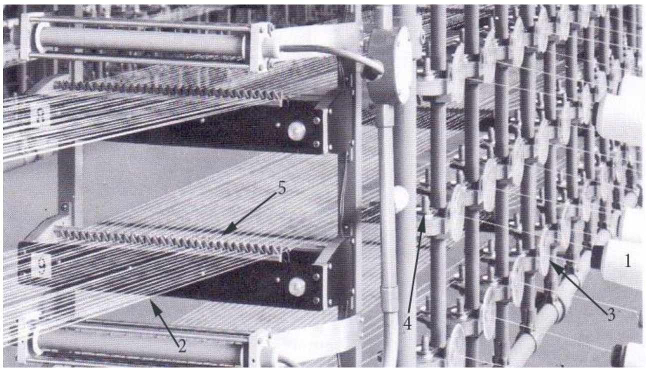

Fig. 2: Kakinoki Warping Creel

According to the yarn path, set of equations were derived in respect to selected Cartesian coordinate systems to define the geometrical positions of the warp yarn, which in turn can be used to define tension of each yarn along its path.

A. Yarn Unwinding Tension at the Balloon Controller

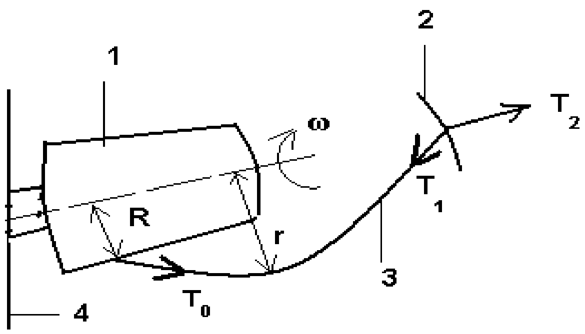

Fig. 3: Yarn unwinding from a cone

Figure 3 shows the path of warp yarn (3) unwinding from the cone (1) installed in the warp creel (4) and it passes through the balloon controller (2).Yarn tension between the cone and the balloon controller depends on factors such as diameter of the package, unwinding speed, balloon height, angle of yarn unwinding, balloon diameter, frequency of rotation of the balloon, distance between the package and the balloon controller eyelet, yarn unwinding tension at the surface of the cone, coefficient of friction between yarn and the cone surface, resistance of air and yarn count. However, investigation on influence of package diameter on yarn unwinding tension is an important matter to be considered when selecting the method of warping. Though a number of published research on yarn unwinding tension, the equations are quite impracticable when calculating yarn tension at the balloon controller as they include many unknown parameters that are difficult to estimate and readily unavailable. Considering parameters of the yarn unwinding process of a cone, yarn tension at the balloon can be expressed in a pragmatic way by the formula given below [12].

$$T_1 = T_0 e^{\mu\varphi} + mV_{un}^2 + \frac{m\omega_b{}^2(r^2 - R^2)}{2} ------ (1)$$

Where, $\omega_b = \omega - \omega_n$

T_1 is the yarn tension at the balloon controller; T_0 is the yarn unwinding tension from the surface of the cone; μ is the coefficient of friction of unwinding yarn against the surface of the cone; ϕ is the angle of wrap of unwinding yarn with the cone surface; V_{un} is the yarn separation speed from the package; m is the mass of yarn length of the balloon; ω_b is the actual angular speed of the balloon; ω_n is the angular speed of the spindle; ω is the angular speed of the yarn balloon; R is the current radius of yarn unwinding and r is the radius of the yarn balloon. In order to define T_1 from the equation (1), it is necessary to define T_0, μ and φ. Due to surface contact between unwinding yarn and the balloon controller eyelet, yarn tension T_1 changes to T_2 as given in equation (2).

$$T_2 = T_1 e^{\mu_1 \alpha_1} ---------- (2)$$

Where T_2 is the yarn tension after the balloon controller; μ_1 is the coefficient of friction of unwinding yarn against the balloon controller eyelet; α_1 is the angle of contact between the yarn and the eyelet. Maximum and minimum values of yarn tension at the balloon controller was calculated from equations (1) and (2) using the following data μ=0.3-0.35; φ=0-π/2; m=0.02g for 20 tex; m=0.04g for 40 tex V_{un} =200-400 m/min; when R=45-105mm, r=37.2-75.1 mm and when speed is 200 m/min, ω_b =200-230 sec^{-1} and speed is 400 m/min; ω_b =400-465 sec^{-1} and given in the table 1.

Table1.Calculated maximum and minimum yarn tension(T_2) at the balloon controller

Yarn tension at the balloon controller((T_2),cN	yarn tension at the point of cone un winding(T_0)cN & Yarn count			
	0.7cN (20 tex)		1.02cN(40 tex)	
	Speed of Sectional warping		Speed of Sectional warping	
	200 m/min	400 m/min	200 m/min	400 m/min
T_2min	1.83	3.01	3.20	6.53
T_2max	3.29	5.47	5.48	11.32
ΔT	1.46	2.46	2.28	4.79

B. Warp Yarn Tension after the Tension Device

Yarn tension received at the top of the balloon further increases as yarn moves along the gaiting line of the warp creel. Yarn unwinding from the cone after the balloon passes through yarn guiding elements and due to friction against those surfaces, yarn tension is increased.

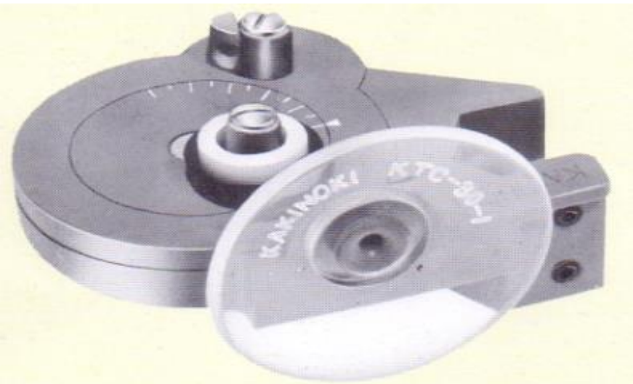

Fig. 4: Tension device

Two-zone disk type tension device shown in Fig.4 was used to give necessary winding tension to obtain required specific density of winding and compact package. Settings of the tension device depend on the type of yarn and required density of winding.

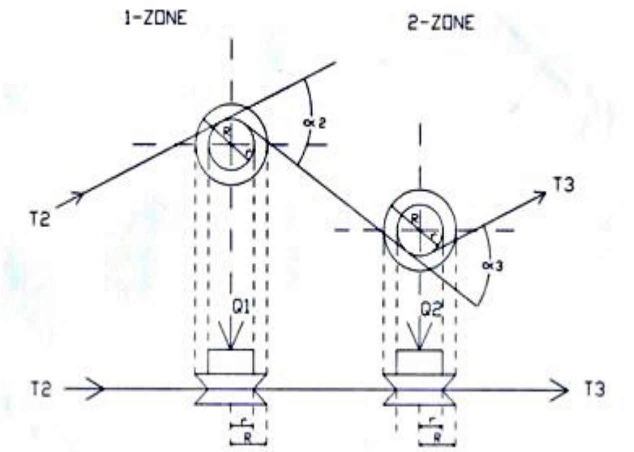

Fig. 5: Sketch of a Yarn path through two zone tension device

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Few researchers calculated the tension variation of a yarn at the tension devices experimentally and analytically. The equation used to define the output tension of the two-zone multiplicative tension device is given below.

$$T_3 = T_2 e^{(\mu_2\alpha_2+\mu_3\alpha_3)} + fa_1Q_1(1+e^{\mu_2\alpha_2})e^{\mu_3\alpha_3} + fa_2Q_2(1+e^{\mu_3\alpha_3}) - (3)$$

Where,

$$a_1 = \frac{R}{\sqrt{R^2-r^2}\ \sin\frac{\alpha_2}{2} - r\cos\frac{\alpha_2}{2} + R};$$

$$a_2 = \frac{R}{\sqrt{R^2-r^2}\ \sin\frac{\alpha_3}{2} - r\cos\frac{\alpha_3}{2} + R} - (4)$$

T_3 is the yarn tension after the tension device; T_2 is the yarn tension before the tension device; μ_2 and μ_3 are the coefficients of friction of yarn against the tension post tension post I and II respectively; r is the radius of the tension post; α_2 and α_3 are the bending angles of yarn over tension post I and II respectively; f is the coefficient of friction of yarn against the dead weight; Q_1 and Q_2 are the axial pressures exerted by dead weight of tension device I and II respectively and R is the radius of contact circumference of the washer (Fig.5). The equation (3), yields the output tension of warp yarn coming out from the tension device, and it is mainly depends on the wrapping angles of tension post 1 (α_2) and post 2 (α_3), as other parameters remain approximately constant. Maximum and minimum values of yarn tension after the tension device was calculated from equations (3) and (4), using the following data μ_2=0.3; μ_3=0.3; α_2=770; α_3=1100; f=0.3; Q_1=Q_2=4.5 cN; R=12mm; r=6mm and tension values are as given in Table 2.

Table 2: Calculated yarn tension (T_3) after the tension device

Input yarn tension of the tension device(T_2)cN	Yarn count(100% cotton)			
	20 tex		40 tex	
	Speed of Sectional warping		Speed of Sectional warping	
	200 m/min	400 m/min	200 m/min	400 m/min
	T_3min	T_3max	T_3min	T_3max
T_2min	7.24	9.48	9.85	16.19
T_2max	10.02	14.17	14.23	25.44
ΔT	2.78	4.69	4.38	9.25

C. Warp Yarn Tension at the Warp Stop Motion Device of the Creel

Since the warping creel carries hundreds of cones depending on the creel capacity, yarn paths are different from cone to another. Further, cone position in the creel is also different for each cone. Warp ends pass through guiding element d, and guiding element C of stop motion device and subsequently pass through yarn distributor shown in Fig 6 d.

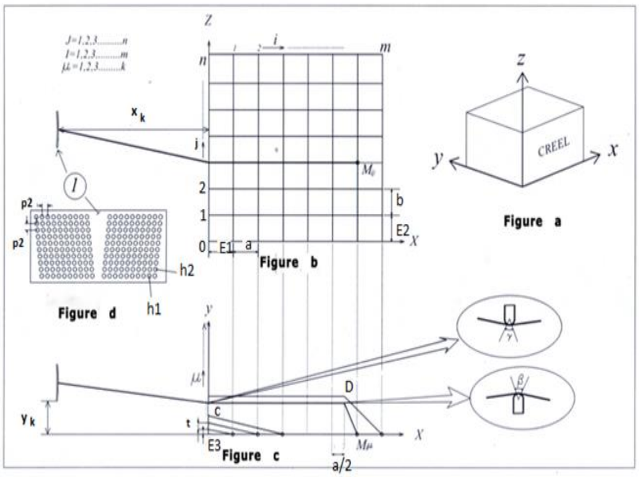

Fig. 6: Yarn path of M_{ij} cone of the creel

Supply packages are placed on columns having a pitch *a* and rows having a pitch *b*. The warp yarns from the same row of the creel are distributed at the stop motion device with pitch *t* parallel to the y-axis. Then same set of warp ends pass through the distributor plate with coordinates (X_k,Y_k) in a row having pitch between two eyelets p_1. The warp end is bent by an angle γ between D and distributor plate, and thereby the warp tension after the creel is changed. In order to define the yarn path precisely for mathematical modeling, a 3D Cartesian coordinate system is defined with respect to creel such that X-axis is defined horizontally along the creel. Y- axis is defined across the creel in the direction of width, while Z- axis defines vertically and z- coordinate is the vertical height of the creel from the ground level as shown in Fig.6 a. Figure 6 illustrates the precise yarn path from M_{ij}^{th} cone as shown in the end elevation (Fig. 6 b) and plan (Fig. 6 c). Mij cone is located in jth row and ith column of the creel having (m x n) number of cones in either side. The yarn is subjected to change its path at point D in vertical plane only for the yarn cones located after fifth column and at point C in 3D plane for all yarn cones. Considering the tension movement at point D, the yarn tension after the eyelet T_{di} can be expressed for the ith column yarn packages as follows, when 6 ≤i ≤ 10

$$T_{Di} = T_{3i}e^{\mu\beta_i} \text{ ----------(5)}$$

Where, $\beta_i = \tan^{-1}\frac{E_3+t(i-i)}{\frac{a}{2}+a(i-6)}$,

β_i is the contact angle between the ith yarn and the guiding element d, E^3 is the distance to the first column of the creel from the y-axis along the x- axis.

The tension of the ith yarn at C when 6 ≤i ≤ 10

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$T_{Ci} = T_{Di}$----------------(6)

Yarn tension of i[th] package in the same row at C, when $1 \leq i \leq 5$

$T_{Ci} = T_{3i} e^{\mu \Phi_i}$-------------(7)

where, $\Phi i = \tan^{-1} \frac{E_1 + a(i-i)}{E_3 + t(i-1)}$,

E_1 is the distance to the first warp yarn from the z-axis along the x-axis, Φ_i is the bending angle of i[th] warp end at the second tension post.

The Maximum and the minimum values of yarn tension of a selected row at the stop motion device was calculated from equations (5), (6) and (7), using the following data: t=10mm, a=22mm, E_1=32cm, E_3=7cm, μ=0.3.

Minimum of T_{3i} and maximum of T_{3i} were taken from Table 2.

Table 3: Calculated yarn tension (T_{ci}) at the stop motion device (exit point of the creel)

yarn tension after the tension device of $_i^{th}$ yarn (T_{3i} cN)	Yarn count(100% cotton)			
	20 tex		40 tex	
	Speed of Sectional warping		Speed of Sectional warping	
	200 m/min	400 m/min	200 m/min	400 m/min
	T_{ci}min	T_{ci}max	T_{ci}min	T_{ci}max
T_{3i} min	7.60	9.95	10.34	17.0
T_{3i} max	15.60	22.10	22.20	38.0
ΔT	8.0	12.65	11.86	21

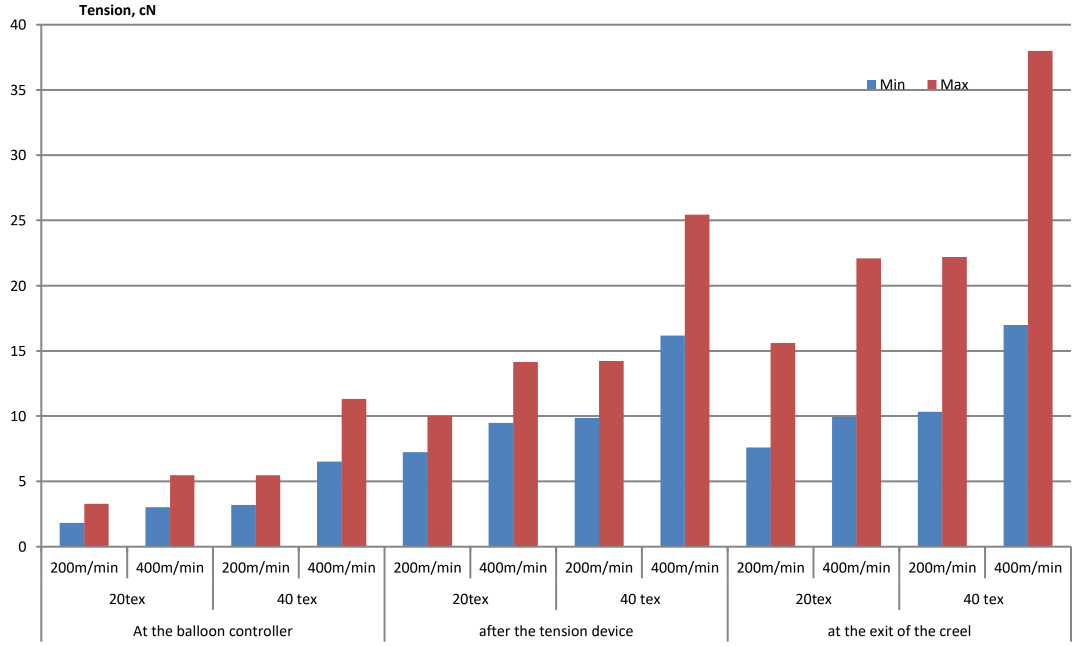

Fig. 7: Graph of tension variation along the yarn path on the creel for 20tex and 40 tex counts which speeds of 200m/min and 400m/min

III. DISCUSSION

In the fabric formation process, the warp yarn tension varies during the loom cycle due to primary and secondary motions. Above variations are uniform for the whole warp sheet and necessary for the fabric formation. However, tension variation across the warp sheet of a weaver's beam increases warp breakages and also leads to fabric defects. Hence, tension variation across and along the warp sheet in warping should be further investigated. It is imperative to mathematically analyse tension of warp yarns along the path from the cone to the drum during the sectional warping process to minimize tension variations. Average tension fluctuation of 1.46 cN and 2.28 cN (Table 1) take place at the balloon controller for yarns having counts 20 tex and 40 tex respectively at a warping speed of 200m/min.

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However, when the speed of warping is doubled, then fluctuation was increased up to 2.46 cN and 4.79 cN for same counts respectively. Further calculated yarn tension after the tension device was also increased. As a result tension difference between maximum and minimum values were increased up to 2.78 cN and 4.38 cN for 20 tex and 40 tex yarns respectively at a speed of 200 m/min and shows difference of 9.25 cN for same yarns at a speed of 400m/min (Table 2). Unwinding tension of warp yarn from supply packages vary by 8.0 cN for 20 tex count when the loom runs at a speed of 200 m/min and the same is 11.86 cN for 40 tex. Further, at a machine speed of 400 m/min, tension variations were12.65 cN and 21cN respectively at the exit point of the warping creel (Table 3) for yarn counts of 20 tex and 40 tex. Mathematical analysis shows that there is a significant tension variation along the yarn path on the creel during the process of warping.

IV. CONCLUSION AND FUTURE WORK

The presence of tension variations along and across the weaver's beam impairs proper formation of the woven fabric and it leads to serious deterioration in fabric quality. Especially critical, in high quality fabrics such as stripe and check as well as in technical textiles. Further this scenario leads to impair the loom efficiency too and hence tension variation is a stumbling block to the weaving industry. In order to have an in depth theoretical understanding of tension variation in weaver's beam along and across, the authors attempt to develop a mathematical model for tension variation in winding process of the weaver's beam. The key feature underlying the derived equations is that it can be conveniently and practically used to calculate the yarn tension at different location of the yarn path, even certain path segments such as in balloon where the practical tension measurement is infeasible. The tension in subsequent path segments where tension measurement is feasible was derived considering the tension of previous path segments. As such correctness of the mathematical model of yarn tension for path segments where tension measurement is not possible can be verified with the tension calculated using the model for yarn segments where tension measurement is feasible. In this research, yarn tension at different path segments from the supply package up to the exit point of the creel were theoretically calculated based on the model developed in addition to evaluate a permissible range for tension variation according to the position of the package at the creel. Further, authors will present an analysis of warp tension variation using experimental results in the sectional warping process for the packages on the creel at different positions. Thereby, the validity and the accuracy of the mathematical model will be justified. In this paper, authors attempt to model the tension variation in the sectional warping. Based on the mathematical model developed, the average tension variation between supply packages on the same row was significant. In addition, the tension variation between packages was increased along the yarn path up to the exit point of the creel (Fig. 7). Further Fig. 7 shows warp yarn tension variation along the yarn path for 20 tex and 40 tex count and for warping speeds of 200 and 400 m/min. According to the mathematical analysis it proves that there is significant tension variation across the warper's beam in sectional warping. The importance of maintaining uniform tension during sectional warping to improve the fabric formation process was emphasized. Therefore it is recommended to design and develop an automatic tension control system based on the model developed for sectional warping if high quality fabrics were to produce and increase in loom efficiency and fabric quality.

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