An Experimental Technique to Determine the Permissible Warp Tension Variation At the Required Pick Density

TSS Jayawardana, EASK Fernando, GHD Wijesena

Abstract**:** ***Weaving is considered to be the most versatile means of manufacturing fabric. Due to versatility, process control is mandatory to ensure the quality of the woven fabric becomes a diverse task with a broader scope. With the advent of technology speed of weaving has been drastically increased due to which variation in warp tension becomes an inevitable fact for value-added technical products. Further, variation in warp tension results in different pick density which causes a shade variation due to different amounts of dye penetration along with the fabric. Maintain constant pick density throughout weaving is considered as the most important aspect. The pick density is greatly affected by the warp gaiting tension at which the fabric is woven and experiment results revealed that the warp gaiting tension is considerably changed when the beam is weaved down. Authors attempt to statistically analyze the quantitative relationship between the warp gaiting tension and the pick density. However, due to the high level of variability of warp gaiting tension along the warp with slightly scattered nature of experimental data, setting up a relationship with adequate accuracy is beyond achievable. Hence the warp gaiting tension is first grouped using a statistical technique and established the relationship for each group. The level of accuracy for each model is evaluated at 95% of the confidence interval and thereby determined the permissible tolerance in warp gaiting tension under which the required pick density could be still achieved.***

Keywords**:** ***pick density, warp gaiting tension, statistical grouping, analysis of variation, regression models.***

I. INTRODUCTION

Despite the advances in knitting technology weaving technology is still considered as the most versatile method of fabric manufacturing. It ranges from plain weave to 3D weaving encompassing technical and smart textiles. Process controlling during weaving is mandatory to obtain an output with desired qualities and otherwise cause irreversible deformations in the fabric formed. Regular pick density of the fabric is a key quality parameter of concern and it highly depends on the warp tension which is considered as the most important factor that affects weaving performance and fabric property. Fundamentally, weft yarn traverses to-and-fro across the warp sheet in the loom and leaves behind a trail of weft (pick) at each passage in weaving and hence this process comprised of three primary actions named shedding, picking, and beating up, performed in strict rotational sequence in addition to two supplementary secondary motions termed as taking up and letting off which make sure the fabric fell maintains in the same position when weaving proceeds. The action of raising and lowering the warp yarns is known as shedding while passing the weft through the shed is called picking. Subsequent to the insertion of each pick, the pick of weft has to be pushed forward by a reed, a type of closed comb through which all of the warp yarns are drawn, to a point adjacent to the previous pick is called beating-up. The cyclic variation in warp tension during the weaving process has a significant influence on end properties of the final product, the woven fabric. The let-off system significantly contributes to maintaining an average constant warp tension amidst the momentary warp tension that undergoes sudden peaks, especially during shedding and beat-up. Though warp tension undergoes a cyclic change in the weaving cycle, the warp tension during beat up is the critical parameter is to achieve the required pick density and cover factor. The warp gating tension means the tension of the warp between the weaver's beam and the cloth-fell. Increased warp gaiting tension causes an extension of woven fabric and in turn, this causes the fabric fell to move towards the backrest leading to an increase in weft density while increasing the weaving resistance. On the other hand, an increase in weaving resistance for a given weaving configuration (warp tension, physical properties of warp and weft, acceleration and inertia mass of the slay mechanism) would also cause to reduce in weft density. Hence, the effect of warp tension on fabric properties may be at a dynamic equilibrium determined by the fabric structure being woven as well as the frictional properties of the warp yarns. As such the influence of warp yarn tension on the variation of pick density grabs the attention of the researchers in the recent past. Certain researches attempted to establish a qualitative relationship with warp tension and weft density [3]. The quantitative reasons for warp yarn tension variation were identified as the effect of loom settings[1,12], shed crossing timing and its consistency [2], the cloth fell movement [8,14], beat-up force [9,10,11,13], weave structure and backrest settings [5,6] are under the investigation for pick density variation in weaving and its consequences [4,7].

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These have been the areas of interest for several researchers and novel instrumental arrangements have been implemented to monitor gaiting warp tension on a loom in the light of other fields with the change of fabric structure and its effect on pick density. Therefore, it is imperative to maintain uniform initial warp tension throughout the weaving process as the beam weaves down. The warp tension is subjected to change along the warp due to change in inherent tension with the variation of beam diameter and also a change across the warp sheet. In addition to this, for the given specification of a fabric, for example, density, composition, and yarn count of warp and weft yarns as well as certain physical and mechanical properties of warp and weft yarns determine the initial position of the fabric fell. These phenomena are definitely contributed to change in pick density and in turn the quality of the fabric. In this paper, the authors attempt to statistically analyze the experimental warp yarn tension variation and its effect on pick density.

II. METHODOLOGY

After removing from the woven fabric from the loom, it is subjected to reversible deformation of warp ends results in higher pick density. When the increase in pick density exceeds two percent than the estimated value ended up with higher consumption of weft yarn especially in blended fabrics. So data are gathered for a correlation analysis of pick density of fabric in relaxed form and the warp gaiting tension at which the fabric was woven.

EXPERIMENTAL SETUP

The experiment was conducted under laboratory conditions on an air jet loom (Make: Tsudakoma, model: ZA 203) with poly/cotton warp and weft yarns with 16 Tex count. When the fabric was being woven, dynamic warp yarn tension T_i across the warp beam is measured at 10 different points with the yarn tension meter with the following specifications.

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

MEASUREMENTS

The beam diameter was measured with a laser sensor with an accuracy of 0.5mm while a tag is attached near the cloth fell indicating the diameter of the warp beam. The experiment was repeated for 12 different warp diameters. After removing the fabric from the loom, it is allowed to relax under a conditioned environment of 25^{0}C of temperature and 65% of relative humidity over 48 hours. At the tagged positions, pick densities P_w are counted.

ALGORITHM AND APPROACH

As the results are too much scattered, identification of a relationship with an acceptable level of statistical significance is hence impossible. Therefore warp gaiting tension is clustered into simplified structures that portray relationships, and not revealed otherwise. In this clustering, correlation coefficients were used for measuring similarity as the intension is to envisage a relationship. The detailed calaculations are given under results and discussion.

III. RESULTS AND DISCUSSION

Table- I: Pick density variation with initial warp tension and warp beam diameter variation

Diameter of warp beam(mm)	Pick density P_w (picks/10cm)	Mean warp tension T_i (cN)	Standard deviation (cN)	CV (%)
700.6	230	30.1	0.14	0.465116
649.7	231	30.2	0.18	0.596026
603.2	232	30.9	0.15	0.485437
554.1	233	31.2	0.21	0.673077
502.8	233	31.9	0.19	0.595611
447.6	234	33.1	0.22	0.664653
405.1	235	33.8	0.17	0.502959
349.8	236	34.9	0.12	0.343840
301.6	236	35.1	0.28	0.797721
252.5	237	35.9	0.31	0.863510
200.4	238	36.7	0.34	0.926431
153.3	239	37.2	0.37	0.994624

Table I summarizes the statistics of initial warp tension across the warp sheet as the diameter of the warp beam weaves down and the corresponding pick density measurement per 10 cm of the woven fabric in a relaxed form. As per readings, initial warp tension across the warp sheet is subjected to vary but not significantly as the coefficient of variation is less than 1% due to the fact that the crosswise variation cannot be compensated by the let-off mechanism

When studying the statistical characteristics of average warp tension along the beam, a significant variation is noticeable with the coefficient of variation as high as 7.63% even in presence of a warp tension regulatory system due to various reasons. The analysis of statistical data showed that the variability of warp tension is up 19.43% of the average value signifying a clear irregularity in data. The fundamental principle of statistical studies in the application of correlation analysis for the considered factors is assumed as uniform [15]. Hence before calculating the correlation factors among the average warp yarn tension and pick density with the variation of warp beam diameter, it is necessary to separate a sufficiently uniform set of data in groups and carry out regression analysis for each group. The aim of this exercise to classify into different groups based on the average warp yarn tension across the beam hereafter the same is referred to as warp gaiting tension so as to get an optimized correlation between the pick density and the warp gaiting tension at the weaving stage. Since the set of data has a positive trend without a significantly noticeable separation between sets of data, a serious limitation would exist in achieving successful results by means of clustering algorithms such as K-means clustering. Hence, the method of grouping structure of statistics specifically developed for product quality assessment and forecasting [15] is applied to separate into different groups based on warp gaiting tension. This is a normalized form of grouping structure based on the coefficient of variation and it can be given as,

$$K_i = \alpha\beta_i / [n * \left(CV_{T_i} - CV_T * \sqrt{\alpha}\right)^2 - \beta \quad (1)$$

$$\alpha = 1 - \left[\frac{\sqrt{n + 4t^2} - \sqrt{n}}{2t}\right] \quad (2)$$

$$\beta_i = \left[CV_{T_i} * CV_T * t\right]^2 \quad (3)$$

Where K_i is the proportion of the i^{th} group to the entire set of warp gaiting tension, n is the dimension of the set of warp gaiting tension, CV_{Ti} is the coefficient of variation of the group of the warp gaiting tension set, CV_T is the coefficient of variation of the entire set of warp gaiting tension data and is the critical value obtained from t-table at an acceptable level of significance for the difference in mean value by groups. An appropriate value for CV_{Ti} is determined by equation (4) such that the intra-group coefficient of variation is almost invariant and the intra-group coefficient of variation is a minimum.

$$CV_{T_i} \leq \frac{CV_T * n\sqrt{\alpha} - CV_T * t\sqrt{n\alpha(1+0.5}}{n - (CV_T * t)^2 * (1+0.5\alpha)} \quad (4)$$

The values for α and β_i required in equation (1) are yielded by equations (2) and (3) respectively. In this case, the value is set to 4 and calculate α and thereby the lower limit for CV_{Ti}. After selection of an appropriate value for β_i, the value of K_i is determined until the entire set of warp gaiting tension data is encompassed by the groups while minimizing the intra-group coefficient. The values derived for each K_i, the group sizes, and the intra-group coefficient of variation are tabulated in Table II.

Table II: Values of K_i and group sizes

Group number	K_i	Group size $(K_i * n)$	Intra-group CV
1	0.4166	4.99	0.024097
2	0.2500	3.00	0.02674
3	0.3333	3.99	0.025438

The standard deviation among the intra-group standard deviation is 0.002064 and also the maximum intra-group coefficient of variation is as lower as 0.02674 signifying that the existence a higher degree of homogeneity and uniformity within each group. The warp gaiting tension data put into groups are summarized in Table III.

Table III: Summary of statistics of the grouped warp gaiting tension data

Group num ber	Range of beam diameter (mm)	Range of Tension variation along the beam (cN)	Middle point of the range	Mean value of the group	Sd of the group	(Sd/span)
1	700.6-502.8	30.1-31.9	30.5	30.86	0.535413	0.4462
2	447.6-349.8	33.1-34.9	34.0	33.93	0.907377	0.5041
3	301.6-153.3	35.1-37.2	36.15	36.23	0.921502	0.4388

From the statistics of warp gaiting tension data given in Table III, a close agreement exists between the middle point of the warp gaiting tension range of each group and the mean value of each group implying that no significant skewness in the distribution of data within each group and suggests an adequate uniformity of warp gaiting tension within groups. Per unit span of warp gaiting tension data in each group has almost equal value provides a promising statistical evidences that the grouping is fair to adequately ensure the uniformity of data distribution among the groups. To show that the mean warp gaiting tension of each groups are significantly different from mean of entire set of warp gaiting tension data, Z statistics for the mean warp gaiting tension for each group is calculated as per equation (5) and compared against the critical obtained from the standard normal distribution table at 5% of the significance level. These are given in Table IV

$$Z_j = \frac{|\bar{T} - \bar{T}_j|}{\sqrt{\frac{\sigma_T^2}{n} + \frac{\sigma_{T_j}^2}{n_j}}} \text{---------}(5)$$

Where Z_j is the Z- statistics of mean in group j, $\bar{T}$ and σ_T^2 are the mean and variance of all warp gaiting tension data in all three groups, $\bar{T}_j$ and $\sigma_{T_j}^2$ are the mean and variance of the warp gaiting tension in group j for $1 \leq j \leq 3$.

Table IV: Z statistics of mean warp gaiting tension in each group

Group number	Z statistics	Critical value at 5% level of significance
1	3.3047	1.96
2	0.5721	
3	3.2353	

From the above Z statistics, there is no significant difference holds out between the mean value of group 2 and the mean warp gaiting tension of the entire set of data along the warp as beam weaves down while a significant difference exists between the mean values of warp gaiting tension in group 1 and group 3 as compared to mean warp gaiting tension of the entire set of data. Hence the difference among the mean warp gaiting tension of each group is statistically established and confirmed the unevenness of warp gaiting tension among the groups.

Similarly, the Fishers criterion is used to check the statistical difference invariance of each group using F statistics and compared it against the critical value obtained from F tables. From Table 5, it is evidenced that the difference between the variances among groups is recognized as insignificant.

Table V: F-statistics for the ration of variance between two groups

Between groups	F statistics	$F_{n_j}^{n_i}(p = 0.95)$
1-2	$\frac{\sigma_{T_2}^2}{\sigma_{T_1}^2}$=1.6947	10.65
1-3	$\frac{\sigma_{T_3}^2}{\sigma_{T_1}^2}$=1.7211	9.98
2-3	$\frac{\sigma_{T_3}^2}{\sigma_{T_2}^2}$=1.0156	39.17

Having statistically confirmed that there is homogeneity within the groups and heterogeneity among the groups, the effect on warp gaiting tension on pick density is investigated by means of linear regression analysis applying group wise.

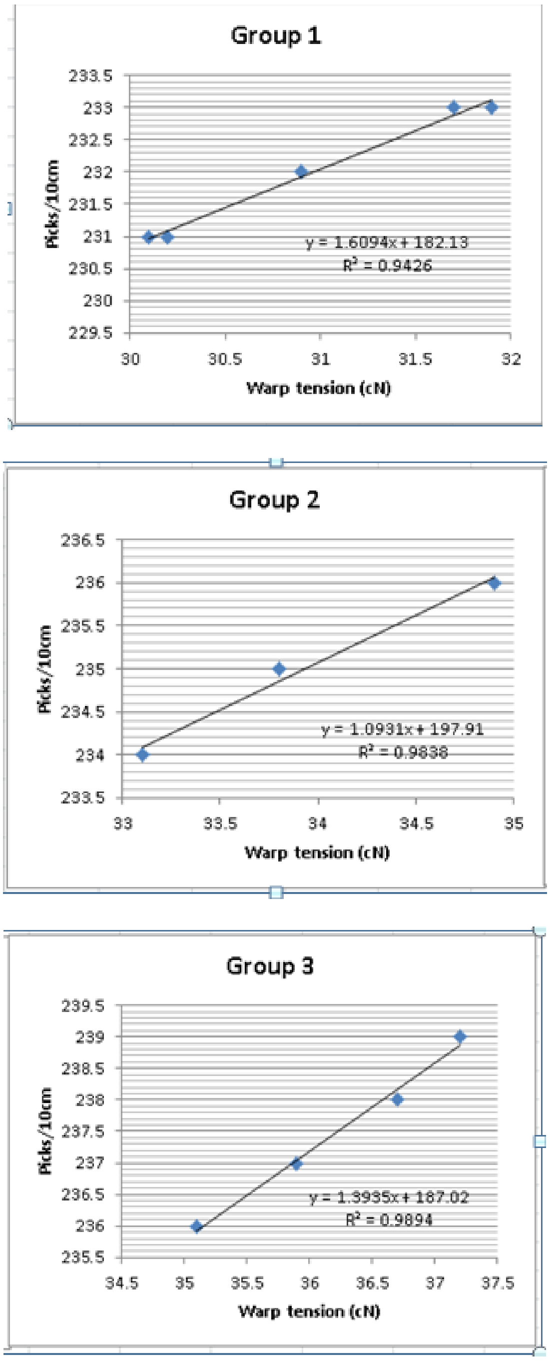

Fig.1: Pick density vs. warp tension for groups 1 through group 3

Figure 1 shows the pick density per 10cm against the gaiting warp tension for each group. The R-squared values which indicate the degree of association of the linear trend line fixed between $\,$ l and $\,$ for group 1, group 2, and group 3 are 0.9426, 0.9838, and 0.9894 respectively and hence linear approximation is given by

$P_w^{(1)} = 1.6094T^{(1)} + 182.$,

$P_w^{(2)} == 1.0931T^{(2)} + 197.$ and

$P_w^{(3)} = 1.3935T^{(3)} + 187.$ for group 1, group 2 and group 3 respectively can be considered as sufficient approximations.

The linear regression model to predict weft pick density as according to the warp gaiting tension can be written as

$P_{Wi} = aT_i + b + \varepsilon_i$----------------(6)

Where ε_i is the residual which is assumed to be normally distributed with zero mean and σ_ε^2 variance. The residual variance σ_ε^2 can be expressed as

$\sigma_\varepsilon^2 = \sigma_{P_w}^2 - (\sigma_{P_wT}^B)^2$----------------(7)

Where $\sigma_{P_w}^2$ is the variance of pick density and $\sigma_{P_wT}^B$ is the dispersion of equalized density value which is equal to

$(\sigma_{P_wT}^B)^2 = \gamma_{P_wT}^2 \sigma_{P_w}^2$--------(8)

Where $\gamma_{P_wT}^2$ is the coefficient of regression between pick density P_W and the warp gaiting tension T.

Equation (7) and (8) yield the relationship

$\sigma_\varepsilon^2 = \sigma_{P_w}^2 (1 - \gamma_{P_wT}^2)$ --------(9)

The accuracy of the forecasted pick density in group j at a 95% confidence interval is determined by the equation (10) [16].

$\Delta P_W^{(j)} = t_{0.975} \sigma_{P_w}^{(j)} \sqrt{(1 - (\gamma_{P_wT}^{(j)})^2}$-------------(10)

Where $t_{0.975}$ is the critical value obtained from the standard t-distribution table and the value is equal to 2.201.

Using the regression lines fitted for each group, it is possible to determine the predicted pick density value at any given warp tension. If the calculated pick density has a decimal value as in almost every case, the pick density value can take either the largest lower integer value or the smallest upper integer value. This provides a permissible limit to float the warp gaiting tension under which the desired pick density could be achieved. Due to prediction tolerance also, this permissible limit is further widened. Parallel to the theoretical regression line two lines are drawn to accommodate the calculated tolerance. A horizontal line segment is drawn at any ordinate value which is equal to the required pick density until two tolerance lines are cut and drop normal to the horizontal axis at the points of intersections and, thus find the permissible limits of variation of warp gaiting tension.

Using the equation (10), the accuracy of the forecasted pick density is calculated for each group, and using the above method, permissible tolerance in warp gaiting tension is determined. The results are summarized in Table VI.

Table VI: Accuracy of the forecasted pick density and permissible tolerance in warp gaiting tension

Group number	Coefficient of determination ($\gamma_{P_wT}^2$)	Average pick density ($\overline{P_W}$)	Standard deviation of P_W	Tolerance in Pick ΔP_w	Permissible tolerance in tension(ΔT)
1	0.9426	231.8	1.3038	0.612261	0.7609
2	0.9838	235.0	1.0000	0.249467	0.4565
3	0.9894	237.5	1.2910	0.260515	0.3739

For instance, the estimated warp density at the mean warp gaiting tension for the second group is 232.47 picks per 10cm. Even with the prediction tolerance pick density of the filament is within the range of 232-233 and it is associated with the permissible change in weft gaiting tension less than 0.46 cN. That means the variation of the warp gaiting tension should not exceed 1.35% of the originally installed warp gaiting tension of the loom. Similarly, for group 1 and group 3, the permissible warp gaiting tension variation should not go beyond 2.47% and 1.03% of the initial warp gaiting tension respectively

IV. CONCLUSION

Experimentally it was revealed that the pick density, which is essential to be an invariant quantity in terms of quality aspect even when the beam weaves down, is a function of warp gaiting tension at which the fabric is woven. As the warp gaiting tension along the beam is considerably scattered with a positive trend and hence setting up a relationship with adequate accuracy is unachievable due to lack of uniformity of warp gaiting tension. First, warp gaiting data is classified into three groups using a statistical technique and statistically verified that the adequacy of homogeneity in intra-groups and heterogeneity among groups. Then a quantitative relationship between the warp gaiting tension and the pick density was established Groupwise and the level of accuracy for each model is evaluated at 95% confidence interval. Thereby determined the permissible tolerance in warp gaiting tension under which the required pick density could be still achieved and also what percentage of the initial warp tension is tolerable to achieve a constant pick density which is a key quality concern. With the experimental data gathered under laboratory conditions, warp gaiting tension is classified into three groups, but with modern machines under a factory environment, the number of group size may be less than that as the loom is under continuous production. However, this technique can be applied to any machine as a methodology and thereby find the permissible warp gaiting tension variation intact with the required quality. Therefore the findings have important industrial implications.

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