Relaxation function experimental study of the warp strain at slow and regular weaving motion

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Abstract. The combination of the nonlinear rheological models to the simple pendulum in the conditions of the forced oscillations simulates the action of the let-off motion with weights. The experimental study considers the dynamic balance during the unfolding of the warp in function of the adjustments of the let-off motion. The stress of the warp threads carries out the mechanical transition from the loom’s adjustments towards the fabric quality. A rotatable plan of factorial experimentation indirectly explores the process of interaction of threads during the intersection.

1. Introduction

In order to arrive at practically applicable solutions, according to tradition we separately consider the quality of the yarns, the weave and the weaving technology as the main factors conditioning the general quality of the fabric. Technological management or optimization of the weaving cycle provides for the variation of various machine parameters, the complex influence of which determines the interaction between the warp yarns and the picks. At this initial research stage, we consider the behaviour of the yarns at the time of levelling the frames because of warp pulling and weft density.

During the weaving cycle, the textile threads are subjected to the action of the working bodies of the loom at the expense of the driving force. The technological mode is based on the tense elastic state of the main threads and the main weave regulator simultaneously controls and regulates the set parameters. Unlike other organs of the loom, this is the only mechanism that interacts and whose action depends on the current state of the processed raw material.

The objective of this article is the mechanical characteristic of the fabric as a function of the warp tension. Also, this is an operation of a let-off weave regulator with weights. The aim is to establish the reactions of the mechanism at different settings. The methodological goal is directed towards determining the limits of machine settings and their functional control through the stages of optimization. The tasks performed include the description of the experiment, the realization of the experimental plan, the laboratory examinations and the statistical processing of the data, the composition of the experimental models and the analysis of the results.

2. Research

The tests are carried out on the weaving machine "MAV-S-RPC-185". The simplicity of the mechanisms of the longitudinal movement of the warp threads eliminates parasitic effects, figure 1.
The technological impact of the weaving machine, achieved by warp unwinding and picking, defines the stress state of warp yarns. For one article reviewed, technological optimization consists in modifying controllable impacts, such as machine settings.

The "MAV" system let-off motion is characterized by diversity and stability of the settings, the only spring of which is the chain. This system of levers functions as a balance that maintains the technological regime by balancing the warp tension applied to the thread carrier and the loaded weights. We match the let-off scale to constant weights by the formula:

$$T_{ch} = \left( \frac{P_d k}{n} \right) m l = \left[ \bar{F}_d + \bar{F}_{ch} = 0 \right] \Rightarrow \begin{cases} P_d = \text{const}; n = \text{const}; k = \text{const} \\ m = \text{tab}(1,\ldots,6,\ldots,11\text{cm}) \\ l = \text{tab}(2,4,6\text{cm}) \end{cases}$$

(1)

The functioning of the let-off regulator with weights consists in the opposition and in the balancing of the spring force of the tensioned warp threads with the constant gravitational force of the applied mass, fig. 1. The combination of a lever system and an elastic connection receives a cyclic load from the driving machine bodies. The operation of the mechanism is considered by dividing it into three working groups: drive, rheological element and lever system.

The periodic drive of the working bodies in the weaving machine follows the principle of fabric formation and represents the transformation of the rotational movement into reciprocating movements [1]. The warp threads receive the linear motion, which is characterized by the angular velocity of the main shaft and the vertical stroke of the threaded system. As a result, the warp threads periodically receive relative elongation $\{\varepsilon_m\}$, with amplitude and frequency according to the design and speed of the machine:

$$\varepsilon_m = \varepsilon(f_0)\sin\omega t$$

(2)

Rheological model: general character of the nonlinear longitudinal deformations of the textile threads is modelled by the analogy series of elastic springs and viscoelastic shock absorbers [2]. The peculiarities of linear textiles require the sequential connection of Maxwell's fluid, which symbolizes the behaviour of twisted fibres $\{\varepsilon_f, \tau_f\}$, with the solid body of Kelvin-Voight, representing the behaviour of the warp threads multitude $\{\varepsilon_y, \tau_y\}$.

The stresses and strains of the threads are distributed in the yarns and fibres according to their properties and together form the reaction of the warp.
\[ \varepsilon_{\omega} = \varepsilon_f + \varepsilon_y, \]
\[ \tau_{\omega} = \tau_f + \tau_y \]  

(3)

The general viscoelastic behaviour of the base is explained by the different distribution of the external load in the textile structures. While the stress \( \tau_f \) applied to the fibrous analogue is distributed uniformly, the final elongation \( \varepsilon_f \) of the rheological model of the thread is the sum of the elongations of the elastic and viscoelastic elements:

\[
\frac{d\varepsilon_f}{dt} = \frac{1}{E_f} \frac{d\tau_f}{dt} + \frac{1}{\eta_f} \tau_f, \quad \varepsilon_f = \varepsilon_f^e + \varepsilon_f^\eta \\
\tau_f = \tau_f^e + \tau_f^\eta
\]

(4)

The set of main threads reacts back by means of the same total elongation \( \varepsilon_y \) and total stress \( \tau_y \):

\[
\tau_y = \eta_y \frac{d\varepsilon_y}{dt} + E_y \varepsilon_y, \quad \varepsilon_y = \varepsilon_y^e + \varepsilon_y^\eta \\
\tau_y = \tau_y^e + \tau_y^\eta
\]

(5)

Differential equations (4) and (5) of the rheological model reflect the simultaneous influence of the elastic and reducing components in the elongation of the warp.

Lever system: transmission circuit of the regulator is reduced to two groups of levers located on both sides of the observed rheological analogue. The motor impulse passes through the whole mechanism and opposes the torque generated by the concentrated mass. The lever with the applied mass, thus connected to the rheological element, builds the model of a pendulum subjected to forced oscillations.

The dynamic equilibrium of the completely mechanical system is found in the equalization of the dynamic moments of gravity and of the rheological element applied to the loaded lever:

\[
\vec{P} = m \vec{g} \\
\vec{M}_p = \vec{P} \wedge k \vec{e}_k \\
\{D_{\omega,1}\} = \{D_{\omega,2}\} \\
\vec{F}_{\omega} = S_y \vec{\tau}_{\omega} \\
\vec{M}_{\omega} = \vec{F}_{\omega} \wedge l \vec{e}_k
\]

(6)

The level of gravity, or the angle of the lever with the horizontal, fulfils the basic equation of forced oscillations:

\[
\frac{d^2h}{dt^2} + \frac{\eta_\omega}{D_{\omega,1}} \frac{dh}{dt} + \frac{E_\omega}{D_{\omega,2}} h = f_0 (\varepsilon_\omega) \sin \omega t
\]

(7)

Evaluation of the synthetic model: presence of models with mathematical description direct the forecast for the behaviour of the studied mechanical system mainly to the influence of the possible machine settings and neglect of the constant parameters. As a result, it can be expected that the increased dynamic torque will lower the average level of the lever, as well as reduce the amplitude of its oscillations.

Experimental work was performed on a weaving machine "MAV-S-RPC-185". The main regulator has a negative drive and a dependent action with respect to the set machine mode.

The integral force of the tensioned base creates a torque around the axis of the cross, whose unauthorized rotation and unscrewing of the base is prevented by the gear: worm - gear. The control piston with the roller performs a reciprocating motion under the action of the propeller and periodically drives the worm.

The position \( H \) of the control roller relative to the axis of the piston determines the stroke of the piston and finally - the rotation of the main cross. The control roller is the actuator of the automatic adjustment, and the occupied moment height \( h \) reflects the control signal obtained from the dynamic equilibrium of the mechanism.
Automatic control: warp threads rest on the traction cross cylinder $pf$ and by means of the generalized force $T_{ch}$ of their tensioned state they create a torque $M_{pf}$ around the axis $O_3$ of the traction cross lever. Changes in the stresses of the main threads change the torque balance in the regulator and cause the guide lever to rotate and move the current level of the control roller.

Machine settings: transmission function of the lever system depends on the position of the connecting rod on the free arm $m$ of the traction lever and on the adjusting arm $l$ of the guide lever. The ratio $l/m$ connects the mass and rheological torques and its value determines the average level of static balance between the tensioned warp $T_{ch}$ and the applied weight $P$. The size of the masses $\sum m_i$ and their location $k$ on the guide lever determine the torque $M_p$ of the symbolic pendulum. The change in the machine setting of the static balance between the force of gravity and the tension of the base is determined by the design parameters of the regulator:

$$T_{sh} = P \cdot \frac{k \cdot m}{n \cdot l} \Leftarrow \begin{cases} \frac{F_d}{F_k} = 0 \\ m = \text{tab}(5.16 \text{cm}) \\ l = \text{tab}(5.79 \text{cm}) \end{cases}$$

Observable parameters: the position of the guide lever is the main metric factor, which is the result of mechanical control and automatically adjusts the regulator by the height of the guide roller. This combines the instantaneous result of dynamic equilibrium and the regulatory response of the mechanism.

Conducting experiments: in the first stage, we studied the static equilibrium of the mechanism under conditions of minimum angular velocity of the main shaft of the loom. In the period of one weaving cycle, we currently measured the distances between the cotton axis and the control roller. The obtained values in tabular form make up the diagram of the level of the roll depending on the interaction between the working bodies of the loom and the textile threads, fig. 3.

We measured the running tension of the warp threads by a mechanical "Deuta-Werke" tensiometer between the beam and the thread carrier when closing the shed of warp threads. The weaving machine is warp loaded with cotton type whose yarns are twisted ring spun yarns and the weft is OE yarn of cotton, Table 1.

| Tableau 1, Caractéristiques des fils |
|-------------------------------------|
| Valeurs nominales                  | Caractéristiques de laboratoire |
|-------------------------------------|--------------------------------|
| Masse linéique, tex                | Torsion, $m^{-1}$ | Force maximale, cN | Allongement, % |
| Tt + composition                   | Tt | $\sigma$ | Tk | $\sigma$ | $F_{max}$ | $\varepsilon$ | $\sigma$ |
| 26x2, 33/67-Vi/Pest                | 53.84 | 0.726 | 316.7 | 18.97 | 1165.5 | 59.573 | 15.42 | 0.5807 |
| 28x1, 100-Coton                    | 29.20 | 0.405 | 356.5 | 51.98 | 315.52 | 33.973 | 5.14 | 0.6167 |

The weave pattern is canvas/plain weave for the entire experience.

Experimentation plan: Functional independence and convenient access to settings allow controlled variation of factors in the spherical exploration domain. The generalized parabolic shape of the rheological behaviour of textile products requires modelling at the 2nd degree response surface. These conditions oriented the present
research towards the factorial experimental design at isovariance by rotation whose polynomial model for the k-th mechanical property acquires the form:

\[
\hat{Y}_k(X_1, X_2) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_{12} X_1 X_2 + \beta_{11} X_1^2 + \beta_{22} X_2^2
\]

(9)

The preliminary tests revealed the practical limits of the experimental field of interest. The calculated values of the natural variables make up the Experiment Matrix, Table 2.

Table 2, Plan d’expérimentation

| Facteurs         | Niveaux des facteurs |
|------------------|----------------------|
|                  | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  |
| Duitages-Dd, d/cm| -1 | +1 | -1 | +1 | a  | 19 | -a | 15 | 0  |
| Balance, m/l     | 1/4| 1/4| 4/4| 4/4| 0  | 6/4| 0  | 6/4| a  |

3. Results

Running the experiment: technological conditions of the study base ensured the practical realization of the planned experiment. Randomization of variants and accurate reproduction of planned parameters are part of the customary procedures that we followed in adhering to standard requirements for sample preparation. In the middle of each variant, we measured the tension of the warp threads at different places across the width of the warp and of the threads threaded in different frames.

Following the main theme, the research considers the behaviour of the fabric during tensile loading in warp and weft directions. As a result, we organized, apart from two couples, qualitative indices describing the mechanical behaviour by the maximum tensile force and the corresponding elongation.

Composition of the experimental models: Statistical processing of laboratory data yielded estimates of the mechanical property acquires the form:

Based on the experimental results and by the known algorithm of regression analysis we calculated the coefficients of the polynomial models. The response surface equations passed the alternative dispersion analysis as against the meaning of the coefficients, as well as for the veracity of the models. Preliminary tests correctly determined the experimental centre and area of interest and we obtained models adequate for the maximum number of significant regression coefficients, Table 4.

Table 4, Coefficients des modèles polynomiaux

| Coefficients de modèles | b_0 | b_1 | b_2 | b_{12} | b_{11} | b_{22} | v  | F_v |
|-------------------------|-----|-----|-----|--------|--------|--------|----|-----|
| Tension de chaîne : Y1 (X1) | 140.88 | 38.195 | 47.614 | 10.00 | 2.999 | 14.249 | 7  | 0.5714 |
| Force – Y2(X1)         | 1131.2 | 17.56 | 39.55 | 24.75 | 9.45  | 22.45  | 7  | 5.35  |
| Allongement, Y3 (X1)   | 26.961 | 1,958 | -0.533 | -1.356 | 1.911 | -0.0131* | 8  | 3.727 |
| Force – Y4(X1)         | 270.974 | 34.517 | 10.351 | 5.55 | 1.804* | -8.679* | 8  | 6.029 |
| Allongement, Y5 (X1)   | 8.622 | 0.412 | 0.366 | 0.109 | 0.414 | 0.0659* | 8  | 5.781 |

Interpretation of models: by having validated models, we can access the graphic interpretation of the results. The equations, intrinsic to bi-factorial planning, plot three-dimensional response surfaces. This visualization shows the characteristic trends in the functional variation of the observed properties in dependence on the factorial variables. The use of existing graphics applications presents in understandable form the experience performed.

Discussion: state of stress of the warp threads reflects in almost linear form the technological parameters of the weaving cycle, figure 4. With the enlargement of the picks comes the increase in tension, so the increased
draft of the let-off motion scale increases the tension. The influence of the let-off motion predominates the variation of the picks. The minimum voltage corresponds to the minimum factorial levels and the maximum voltage is a result of the simultaneous maximum levels of the factors. The centre of the experimental area defines the mean values of the chain tension. The maximum tensile force (the force maxF) per chain increases in the paraboloid area of response to clearly manifested factor interactions, figure 5.

Figure 4, Warp stress state

Under the conditions of minimum weights, the increased draft leads to a sharp increase in strength. At maximum edits, we observe a parabola symmetrical at least in the centre of the factor: let-off motion balance. The let-off pull opposes the weft insertion. We observe a decrease in force at increased debit and the increase in force is at reduced debit. The minimum value of the force is at the maximum weft density and the maximum debit. The combination of the maximum levels of the factors gives the maximum value of the maximum force. The existing middle zone occupies the diagonal in the experimental domain.

Figure 5, Warp direction breaking force

The maximum tensile force per weft is characterized by the linear increase as a function of the draft and by parabolic evolution according to the pickings, figure 6. At a minimum, the variation of the draft leads to the parabolic reaction of the force with a maximum at the centre. At the maximum output the force grows harmoniously up to the common maximum.

Figure 6, Weft direction breaking force

As the weft density increases, the strength increases and the draft increases the slope. The minimum factorial levels define the minimum value of the force and the maximum levels - the maximum value.

The percentage elongation at maximum force (the elongation $\epsilon$ (maxF)) per chain describes the response surface to the concave character. The minimum zone and the single maximum are clearly illustrated there, figure 7.

Under small weft conditions, draft increases elongation, while at high weft density, high elongation is a result of increased debit. The elongation according to the dispensing depends mainly on the action of the let-off
motion. At maximum draft, the aspect ratio is parabola with a minimum in the centre. The minimum draft conditions the abrupt increase in elongation with increasing weft density.

*Figure 7, Breaking elongation by warp*

The warp elongation response surface represents asymmetric paraboloid at the minimally manifested area, Figure 8. The reduction in warp debit results in a harmonious increase in elongation without considerable influence on the weft density. The variation of the weights is related to the parabolic evolution of the elongation, the minimum of which occupies the central zone. The minimum elongation is a result of the minimum draft and the "average weft density. The maximum elongation reflects the combination of the maximum factor levels.

*Figure 8, Breaking elongation by weft*

The results show that at each stage of the weaving cycle the position of the roll corresponds to the instantaneous stress of the warp. There is a clear difference between the maximum level of the roll, which corresponds to the compaction of the weft, as well as the sinusoidal movement of the guide lever as a result of the periodic elongation of the main threads.

In the second stage, we studied the dynamic equilibrium of the controller at normal speed. Using an additional scale mounted on the vat, we marked the minimum and maximum levels of the roll for a short period of time. The changes in the machine settings follow the combinations of a planned factorial experiment with two independent factors: the torque and the lever ratio of the transmission element. The obtained results were used for the construction of the three-dimensional graph with two surfaces, fig. 9.

4. Conclusion

The interaction between warp and weft during the crisscrossing is not subject to direct observation. The planned experiment substitutes the impossible measurement of the physical parameters and indirectly describes the mechanical events in the fabric structure.

*Figure 9, Dynamic oscillations of the let-off motion roller*

The explored properties react differently to changes in settings. The stress state of the chain incorporates the machine impact. It was the only technological factor that directed certain inferences, valid in the field of experimentation of interest. The tension of the warp threads increases the maximum tensile force of the fabric, as well as the elongation per weft, but reduces the elongation per warp. This sequence of procedures is applicable to the optimization of fabric articles.

The surfaces show the averages of the two end levels of the guide lever for a relatively large number of consecutive weaving cycles. The reactions of the mechanism of the main regulator clearly differ depending on the change of the machine settings.
Discussion: main feature studied is the amplitude of the roll. From the position of the roller in static conditions, the instantaneous influence of the respective mechanism can be estimated.

At normal speed, the effects of the kinetic moments of the inertial elements are manifested. The amplitude of the dynamic oscillations of the roller is represented by the difference between the two surfaces. The change of factors leads to the simultaneous change of the amplitude and the level of dynamic equilibrium. The increase in torque leads to a decrease in the level of the roller, as well as a reduced cyclic movement of the guide lever. The reduced amplitude is explained by the increased moment of inertia of the lever and the increased internal deformation and reduced viscoelastic properties of the rheological element.

Increasing the lever ratio mainly affects the level of dynamic equilibrium and in this case, the level of the roller increases under the predominant action of the base voltage.

**Key words:** weaving mechanics, let-off motion, rheological model

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