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Theoretical and Experimental Beat-up Investigation

Abstract
The main aim of this investigation is to determine experimental and theoretical methods of beat-up force measurement. The application of a theoretical fabric formation model is analysed in the article, which also investigates the changes in the warp tension and beat-up forces in the weaving loom. In order to define the reliability of the model, the theoretical and experimental results of beat-up and warp tension force were compared. The beat-up force was investigated during the experiments on the Acutis weaving loom, measuring the bending of the reed by the original gauge device mounted on the slay and warp tension force with the Rothschild R-1192 strain gauge device. The data was written onto a computer hard disk with a PCI PC-20 Data Acquisition Board. The same setting data of the weaving loom was also used in the theoretical analysis of the model. A comparison of the experimental and theoretical data was made. It was established that the experimental beat-up force measuring method proposed is suitable for investigating beat-up force. The results of theoretical warp tension force research and the results of the weft tension force research can also be used in further theoretical research of the fabric formation process.

Key words: *warp tension, beat-up force, beat-up gauge, beat-up theory.*

Introduction

While studying the process of a fabric's formation on the weaving loom, it is very important to know what additional deformations arise in the system warp-cloth at the moment of the beat of the weft. The experimental method is complicated enough. In this case, the anchorage of the sensitive gauge device is the main problem. The reed is the one place in the loom which is directly bound up with the beat-up process and can be used for measuring beat-up force. For this reason, the deformation of the whole reed or part of it can be used. As the beat-up force at the moment the cloth formation propagates into the loom setting system (the warp-cloth system), it can be stated that the process of reed deformation should be analogous to that of warp tension. However, a great difference between the experimental data of reed deformation and that of warp tension has been observed [1]. Thus, it is probable that other factors acting at the moment of beat-up also exist (for example, vibration of the reed), and these basically influence the tension of the loom setting system. Other authors [2-12] also draw similar conclusions, that the most obvious methods of measuring beat-up force are sensitive to inertia effects due to the reed's acceleration.

Beat-up Measuring Method and Device

In this case, the beat-up force was measured by applying the rigidity of the reed, i.e. the deflection of the reed during the beating of the weft. A sensitive gauge displacement device was fixed on the rigid bracket (Figure 1), which was mounted on a slay by a distance X from the reed. The reed bends during the beating of the weft, and distance X changes by value Δx. The results of the reed bending were sent to the computer hard disk by the PCI PC-20 Data Acquisition Board.

As mentioned above, in the case of normal weaving it is impossible to measure the beating resistance accurately because the deflection of the reed during the beating of the weft is influenced not only by the beat-up force but also by other side effects. In order to define the development of beat-up force, it was decided to use the following method for its experimental measurement:

- to disconnect the mechanisms of shedding, delivering of warp and withdrawing of fabric (weaving without weft),
- to record the displacement of the reed (named as function f_1) when the cloth fell is in the normal position, and
- to record the displacement of the reed (named as function f_2) when the cloth fell is withdrawn a good distance away for evaluating the reed's vibration during the beat-up process.

Analysing the difference of the functions f_1 and f_2, it is possible to investigate the development of beat-up force. So, the experimental beating resistance force F_{pr} can be obtained by eliminating the vibration of the reed, i.e. the function f_2. Evaluating the rigidity of the reed, the beating resistance force F_{pr} can be calculated by the following equation:

$$F_{pr} = F_1(\Delta x) - F_2(\Delta x) = \\ = C_{reed}\left[f_1(\Delta x) - f_2(\Delta x)\right] \quad (1)$$

where:
C_{reed} - the coefficient of the reed rigidity,
Δx - the displacement of the reed during beating.

The symbols, their descriptions, and all loom setting values not explained in the text are defined in Table 1, presented together with some of the parameter values used for the theoretical calculations.

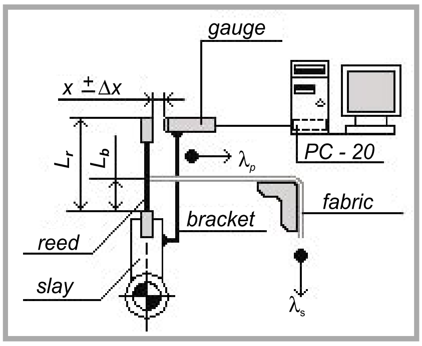

Figure 1. *Beat-up gauge device.*

Table 1. Symbols, their descriptions, and loom setting values.

Symbols in the equations presented	Descriptions of the symbols	Values of weaving loom setting for theoretical investigations
φ	movement angle of the vibratory back rest system (see Figure 2)	-
α	movement angle of the vibratory back rest itself (see Figure 2)	-
β	instantaneous angle of the main shaft (see Figure 2)	-
c_m	rigidity coefficient of the warp part situated between the weaver's beam and back rest	-
c_{ms}	rigidity coefficient of warp part situated between back rest and cloth fell	-
c_{ma}	rigidity coefficient of the whole system of the weaving loom setting	-
λ_p	function of warp deformation during beat-up (see Figure 2)	-
λ_z	function of warp deformation during shedding (see Figure 2)	-
λ_t	function of warp deformation during delivering of warp (see Figure 2)	-
λ_s	function of warp deformation during withdrawing of fabric (see Figure 2)	-
S	function of slay displacement (see Figure 3)	-
β_{pr}	rotation angle of the main shaft (see Figure 3)	-
φ_{sl}	damping factor of the vibratory back rest system depending on internal friction of the yarns	57.3 1/s^2
α_{sl}	damping factors of the vibratory back rest itself	20.2 1/s^2
c_{sp}	rigidity coefficient of the back rest system loading spring	27.14 N/mm
P	initial loading spring force of the vibratory back rest system (see Figure 2)	3693 N
h_{sp}	arm of the loading spring force (see Figure 2)	0.0715 m
θ	angle of the position of back rest lever to the vertical line (see Figure 2)	90 degrees
I_{kr}	inertia moment of back rest system	2.01 kgm^2
m	mass of the back rest	34 kg
c_{metm}	coefficient of warp rigidity	200 N/m
c_{aud}	coefficient of fabric rigidity	120 N/m
n_m	the number of warp ends	2142
T_m	warp linear density	45.5x2 tex
S_1	ends setting	124 dm^{-1}
S_2	picks setting	160 dm^{-1}
β_{ca}	heald cross advance	60 degrees
n_{st}	frequency of rotation of the main shaft	3 s^{-1}
K_0	initial warp tension force of the vibratory back rest system	1685.86 N
K_{0S}	specific initial warp tension force	8.745 mN/tex
r	back rest radius (see Figure 2)	0.062 m
L_{kr}	length of back rest lever (see Figure 2)	0.158 m
L_{metm}	length of warp between the weaver's beam and the back rest	0.534 m
L_{ba}	length of warp between the back rest and the cloth fell	0.97 m
S_{pr}	displacement of the cloth fell (see Figure 3)	2.9 mm
S_{max}	maximum displacement of the slay (see Figure 3)	86 mm
β_s	phase of the slay (see Figure 3)	120 degrees
h	shed height	30 mm
y_{kr}	back rest position with respect to the cloth fell	5 mm
ρ	instantaneous radius of weaver's beam	0.25 m

Theoretical Model of the Warp Tension and Beat-up

A theoretical way of analysing the beat-up process is also possible. For this reason, the general mathematical model described in [13-17] can be used. If the back rest of the loom (Figure 2) is assumed to rotate freely in its bearings, any variations of the warp and the cloth that occur during shedding and beating-up, delivering a warp to the weaving area and withdrawing a fabric from the weaving area, will cause the vibration of the back rest system at an angle φ, and the back rest at an angle α. In this case, the vibration of the back rest system involves the changes in deformations of the warp-cloth system during shedding λ_z, beating-up λ_p, delivering of warp λ_t, and withdrawal of fabric λ_s. During the formation of the cloth, the initial warp tension force K_o changes as well. Hence [13]; for a given situation, the warp tensions forces K_1 and K_2 (Figure 2) can be expressed by the system of the equations from (2) to (5):

$$K_1 = K_0 - \lambda_{ver} c_m - \lambda_t c_m \tag{2}$$

$$K_2 = K_0 - \lambda_{horr} \cdot c_{ma} + (\lambda_z + \lambda_s) \cdot c_{ma} + \lambda_p \cdot c_{ms} \tag{3}$$

$$\lambda_{ver} = \varphi L_{kr} \sin\theta + \alpha r \tag{4}$$

$$\lambda_{horr} = \varphi L_{kr} \cos\theta + \alpha r \tag{5}$$

equation (6) is presented seperataly,

$$\alpha'' = \frac{K_1 - K_2}{mr} - \alpha_{sl} \alpha' \tag{7}$$

$$L_1 = L_{kr} \cos\left(\frac{\pi}{2} - \theta + \xi\right) + r \tag{8}$$

$$L_2 = (L_{kr} \cos\theta - r) \cos\xi \tag{9}$$

The coefficients φ_{sl}, α_{sl}, c_{metm}, and c_{aud} can be obtained by special vibration equipment [17] or directly on the weaving loom. The rigidity coefficients of various zones of the weaving loom setting system c_{ms}, c_m, c_{ma}, can be calculated using the following equations:

$$c_{ms} = \frac{c_{metm} n_m}{L_{metm}} \tag{10}$$

$$c_m = \frac{c_{aud} n_m}{L_{ba}} \tag{11}$$

$$c_{ma} = \frac{c_{ms} c_m}{c_{ms} + c_m} \tag{12}$$

Then, a modification of equations (2) and (3) is performed, the functions of shedding λ_z, delivery of warp λ_t, and withdrawal of fabric λ_s equating to zero.

$$K_1 = K_0 - \lambda_{ver} c_m \tag{13}$$

$$K_2 = K_0 - \lambda_{horr} c_{ma} + \lambda_p c_{ms} \tag{14}$$

The product $\lambda_p c_{ms}$ describes the changes of warp tension at the beat-up moment in the mathematical model; the function λ_p is defined considering the slay construction of the weaving loom. On the Acutis rapier weaving loom over certain period of time, the slay follows the sine law corresponding to angle β_s of the main shaft. When the slay is in the backward position, it does not move for a certain period of time. The motion law of the slay of the Acutis rapier weaving loom and the

$$\varphi'' = \frac{1}{I_{kr}} \left\{ K_1 L_1 + K_2 L_2 + P_m L_m - \left(P + \varphi\, h_{sp} c_{sp}\right) h_{sp} \right\} - \varphi_{sl}\, \varphi' \tag{6}$$

Equation 6

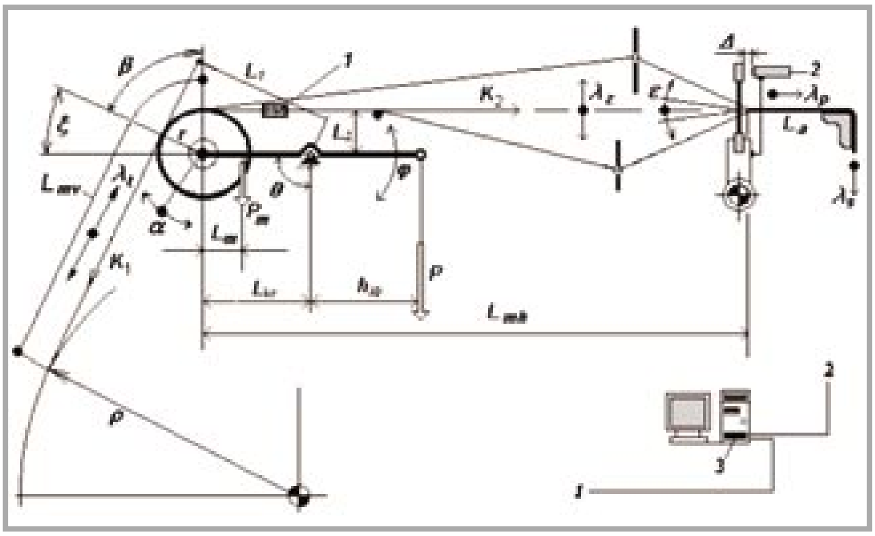

Figure 2. Setting system of the weaving loom: 1 - warp tension gauge, 2 - original beat-up gauge device mounted on the slay, 3 - PCI data acquisition board PC-20.

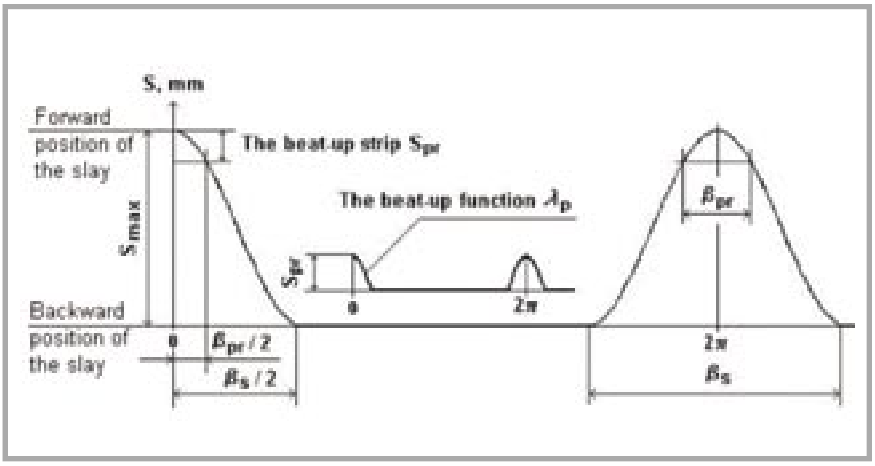

Figure 3. The slay motion law of rapier weaving loom 'Acutis' and the function of warp deformation λ_p during beating-up.

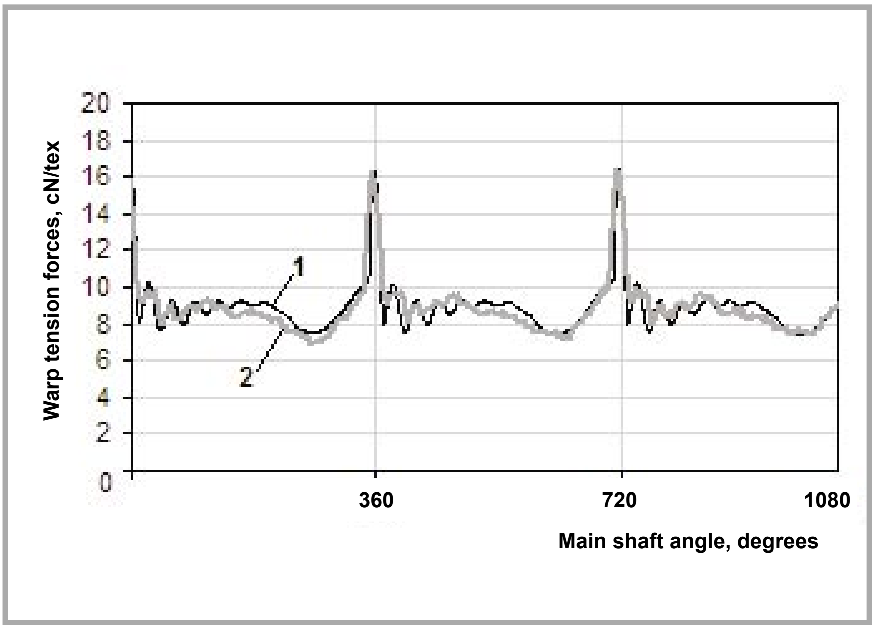

Figure 4. Development of the warp tension force behind the back rest: 1 - theoretical, 2 - experimental.

function of warp deformation λ_p during the beating-up is presented in Figure 3. The beat-up function of warp deformation λ_p can be explained as follows. The reed contacts the cloth fell during the period that corresponds to the rotation angle β_{pr} of the main shaft. Two vertical lines are drawn in the $\beta_{pr}/2$ distance from the forward position of slay, and the result which are the crossing points with the reed's motion curve is noted. The presumption is made that these crossing points characterise the moments when the reed will touch and break away from the cloth fell. The upper part of the reed's motion curve corresponding with the beat-up strip width S_{pr} was used as a function of warp deformation λ_p during beat-up.

As in Figure 3, this function can be described by the following equations:

- during the interval corresponding to the angle of the main shaft β=0 and $\beta=\beta_{pr}/2$

$$S = S_{max} \sin\left(\frac{\pi}{2} + \frac{\beta\pi}{\beta_{pr}}\right) \qquad (15)$$

- during the interval $\beta=2\pi-\beta_{pr}/2$ and $\beta=2\pi$

$$S = S_{max} \sin\left(\frac{\pi}{2} + \frac{(\beta - 2\pi)\,\pi}{\beta_{pr}}\right) \qquad (16)$$

then

$$\lambda_p = S_{pr} - (S_{max} - S) \qquad (17)$$

Function λ_p is calculated according to formulas (15) and (16), if:

$(S_{max} - S) \leq S_{pr}$, otherwise $\lambda_p=0$.

It is possible to study the changes in warp tension during the beat-up process by solving equations (13-17) together with (4-9). This kind of method of theoretically investigating the beat-up process would match the case of weaving investigating the beat-up process which was described above, that is to say, when weaving without weft, as well as the unconnected mechanisms of shedding, delivery of warp and withdrawal of fabric. It simulates the real weaving process if, during the cycle of fabric formation, the same last weft would be beaten up over and over and the system warp-fabric would be deformed.

Discussion of the Experimental and Theoretical Results

Experiments were carried out on the Acutis rapier weaving loom. Cotton 45.5x2 tex yarns were used for warps. In Table 1 the values of the weaving loom setting are presented. During normal weaving, the warp tension force was measured using the Rothschild R-1192 strain gauge device. The original software of the cloth formation on the weaving loom was made for theoretical investigations. The results of experimental warp tension were written onto the computer hard disk with the PCI PC-20 Data Acquisition Board. After comparing the experimental and theoretical results (Figure 4), one can see that the curves are similar not only in a qualitative but also in a quantitative way. So, the presumption can be made that the general theoretical model has been rightly chosen, and after some modification described in the theoretical part of this article, it may be used for investigating the beat-up force.

During the beat-up force experimental investigations, warp tension force was also measured using the Rothschild R-l 192 strain gauge device, and the beat-up force was measured using the device 2 (Figure 2) described earlier (Figure 1).

Although the development of the tension and beat-up forces must be the same, a great difference between the experimental data of reed deformation and warp tension was obtained. It was thus necessary to establish the basic side-effect factors acting at the moment of beat-up which influence the tension of the loom setting system. On the Acutis rapier weaving loom, which is supplied by a cam slay movement mechanism, the reed-dwell phase is a characteristic feature (Figure 2). If, say, the fell is withdrawn a good distance away from the forward position of the slay, and the shedding, delivery of warp and withdrawal of the fabric mechanisms are disconnected, whereas the weft is not inserted, the gauge displacement device 2 will not record the reed displacement. However, it was established that the reed vibrates during the experiment (Figure 5a, curve f_2). An analogous experiment was done with the fell restored to the normal position. This case is shown in Figure 5b, curve f_1. After superposing these curves

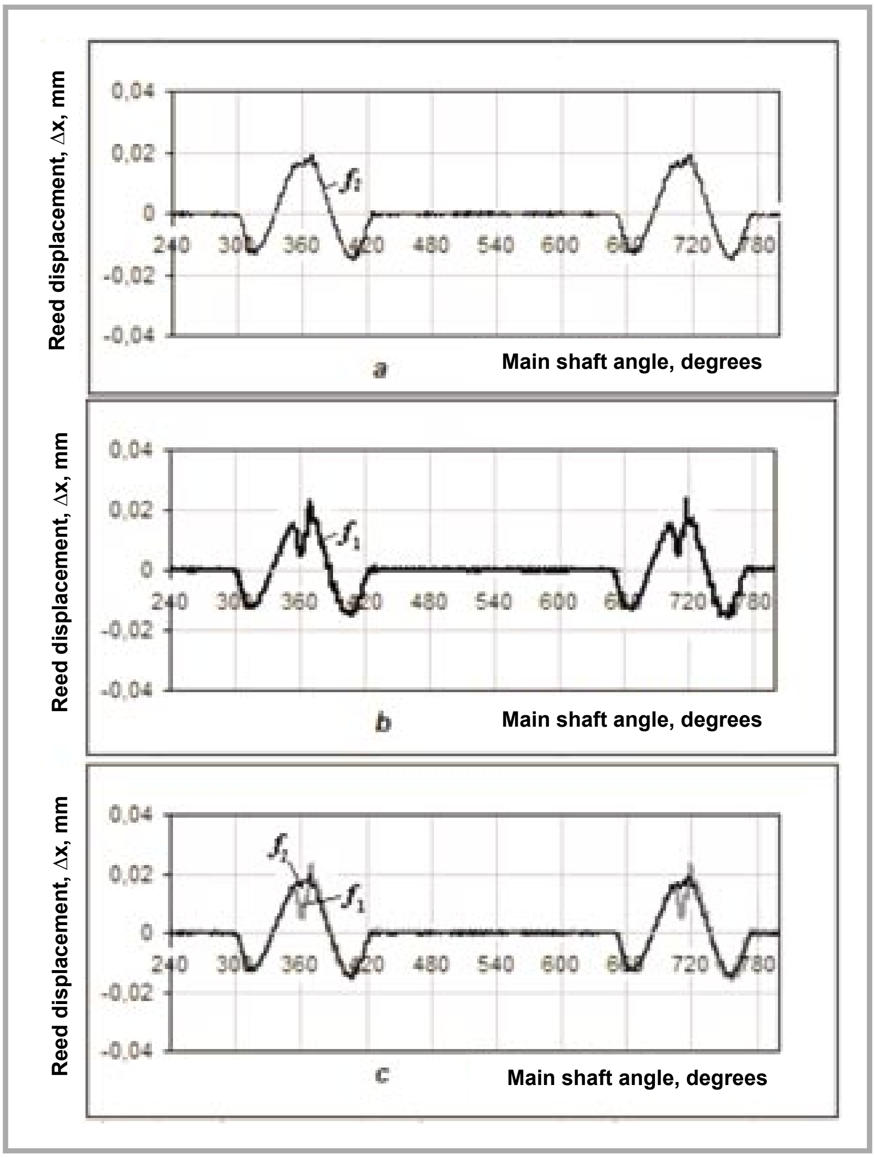

Figure 5. Weaving without weft: a - reed displacement when cloth fell is withdrawn a good distance off, b - reed displacement when cloth fell in the normal position, c - comparison of curves f_1 and f_2.

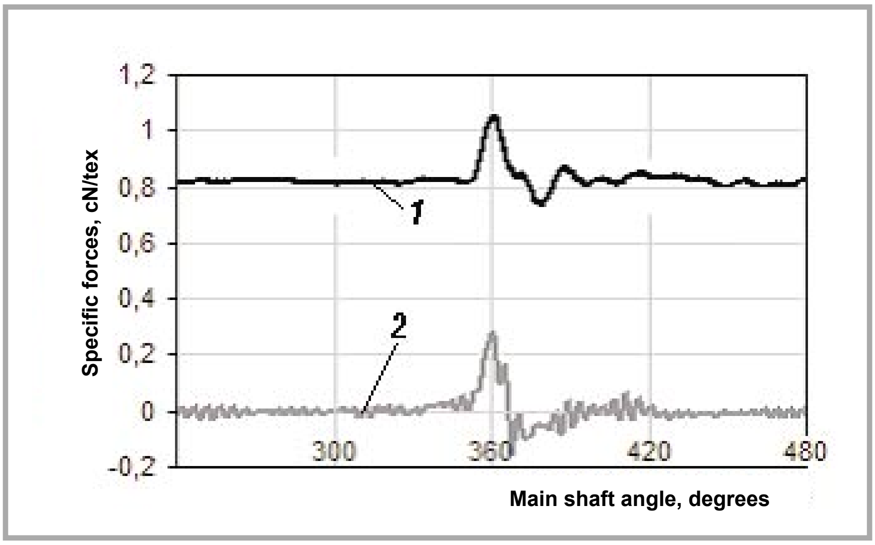

Figure 6. Comparison of beat-up resistance and warp tension forces during weaving without weft: 1 - warp tension, 2 - beat-up resistance.

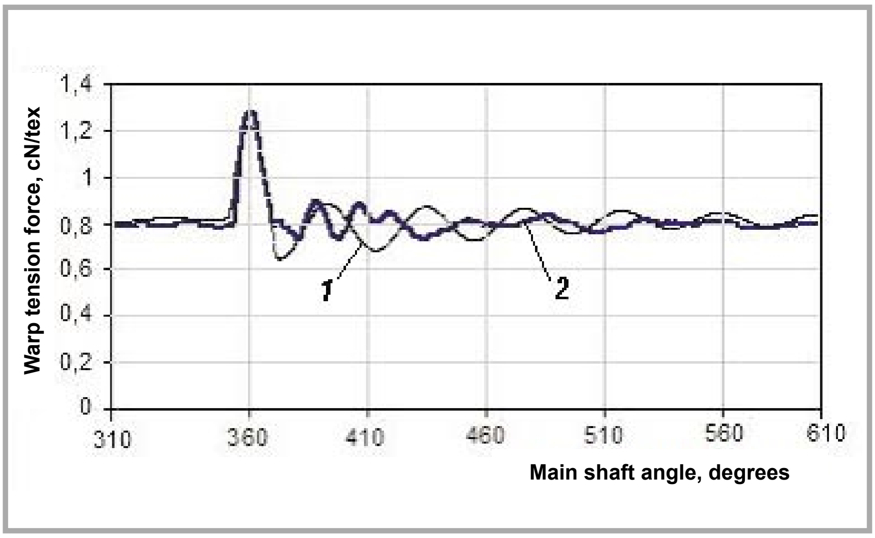

Figure 7. *Comparison of the theoretical and experimental warp tension during weaving without weft: 1 - theoretical, 2 - experimental.*

(Figure 5c, curves f_1 and f_2), one can see that the reed vibration deforms the data of the beat-up force measurement. Therefore the experimental investigations of the beat-up force must be carried out by the two-stage method described in the section 'Beat-up Measuring Method and Device'.

The experimental beating resistance force F_{pr} was obtained by using functions f_1 (displacement of reed during weaving, with the cloth fell in the normal position) and f_2 (displacement of reed during weaving, with the cloth fell withdrawn a good distance away) and calculated by equation (1). The results are shown in Figure 6, curve 2. In this case, after comparing the warp tension force data (Figure 6, curve 1) and the beat-up resistance data (Figure 6, curve 2), it is possible to see that curves are similar in a qualitative way.

A theoretical investigation of the beat-up force was made using the same original software of the cloth formation on the weaving loom. After comparing the theoretical and experimental results from Figure 7, it can be stated that the curves are similar in not only a qualitative but a quantitative way as well. The small disagreement of the curves after the beat-up moment can be explained by the influence of reed vibration, which is not evaluated by the theoretical model. So, it can be presumed that both the experimental and theoretical beat-up force evaluation methods are suitable for investigating beat-up force, although the theoretical method is preferable. The vibrations of the reed are damped from the side of the fabric in the case of normal weaving, and that is why large errors are possible while changing the rotation frequency of the main shaft.

Conclusions

A new beat-up force measuring device and experimental beat-up resistance measurement method, as well as a theoretical beat-up resistance evaluation method, have been presented.

Both the experimental and theoretical beat-up force evaluation methods are suitable for investigating the beat-up force, although the theoretical method is preferable. The vibrations of the reed are damped from the side of the fabric in the case of normal weaving, and that is why great errors are possible while changing the rotation frequency of the main shaft.

The results of theoretical warp tension force research, as well as those of weft tension force research, may be used in further theoretical research of the fabric formation process.

References

1. *S. Rutkauskas, J. Katunskis. Beat-up Investigation during Cloth Formation. Kaunas University of Technology. Materials of the Conference ‚Technology and Design of Textiles', Kaunas, 2003, pp. 23-26 (in Lithuanian).*
2. *Greenwood K., Cowhig W.T, Vaughan G.N., The position of the Cloth Fell in Power Looms. Part I. J. Text. Inst, 1956, 47, T 241.*
3. *Greenwood K., Cowhig W.T, Vaughan G.N., The position of the Cloth Fell in Power Looms. Part II. J. Text. Inst., 1956, 47, T 255.*
4. *Greenwood K., Cowhig W.T, Vaughan G.N., The position of the Cloth Fell in Power Looms. Part III. J. Text. Inst., 1956, 47, T 274.*
5. *Greenwood K., Vaughan G.N. The Beat-up Force and Pick Spacing. J. Text. Inst., 1957, 48, T 39.*
6. *Plate D.E.A., Hepworth K. Beat-up Forces in Weaving. Part I. J. Text. Inst., 1971, 62, 515.*
7. *Plate D.E.A., Hepworth K. Beat-up Forces in Weaving. Part II. J. Text. Inst., 1973, 64, 233.*
8. *Galuszinski S., The Effects of Fabric Structure on Beat-up Resistance in Weaving', Ph.D. Thesis, University of Leeds, 1978.*
9. *Nosek S., Teorie jednoproslupni a vice-proslupni tvorby tkaniny. I. cast. Dum techniky CSVTS Pardubice, 1988.*
10. *Nosek S., Teorie jednoproslupni a vice-proslupni tvorby tkaniny. 2. cast. Dum techniky CSVTS Pardubice, 1988.*
11. *Nosek S., Teorie jednoproslupni a vice-proslupni tvorby tkaniny. 3. cast. Dum techniky CSVTS Pardubice, 1989.*
12. *Islam A.T.M.S, Bandara M.P.U. Yam Spacing Measurement in Woven Fabrics with Specific Reference to Start-up Marks. J. Text. Inst., 1996, 87, 107.*
13. *Katunskis J. Problems in the Theory of the Woven Cloth Formation. Lengvosios pramones technologijos ir dizainas. Konferencijos pranesimu medziaga. Lietuvos mokslas ir pramone, Kaunas, 1997, pp. 238-245 (in Lithuanian).*
14. *J. Katunskis, G. Tiskeviciene. Investigation of the Warp Tension during Woven Cloth Formation. Kaunas University of Technology. AUTEX (Association of Universities for Textiles) Proceedings of International Conference ‚The Textiles: Research in Design and Technology', Kaunas, 2000, p. 207-212.*
15. *Katunskis J., Ludvig G., Jederan M. Mathematical Model of the Warp Tension and the Warp Let-off Motion on STB Looms, Part I. Magyar-Textiltechnika. 1981, 34 No 5, p. 228-231 (in Hungarian).*
16. *Katunskis J., Ludvig G., Jederan M. Mathematical Model of the Warp Tension and the Warp Let-off Motion on STB Looms, Part II. Magyar-Textiltechnika. 1981, 34 No 6, p. 313-315 (in Hungarian).*
17. *Matukonis A., Milasius V., Katunskis J. Audimas. Vilnius: Mokslas, 1983, p. 376 (Weaving: Textbook for students in Lithuanian).*

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