

Vibratory Thickening of Weft Threads in a Weaving Loom – Simulation Tests

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Abstract

A model of the beating-up force of a weft thread in a weaving loom was developed on the basis of the shed geometry. A dynamic model of the process of thickening weft threads was built and a multi-parameter simulation of vibratory thickening was performed. The effect of the dynamic parameters of the vibratory motion of the reed on the improvement in technological parameters of weaving was tested. The energy of vibratory beating-up was determined on the basis of the results of the simulations performed.

Key words: vibratory thickening, weft thread beating-up, modeling weft beating-up, weft beating-up force, beating-up energy.

sometimes limited by the strength of warp threads [4, 6, 9]. These tightly woven fabrics are often made of yarns of a high coefficient of friction, and of those in which increased adhesion occurs [1, 4], such as carpet fabrics and some technical fabrics. From a technical point of view, it is important to obtain high densities in a fabric with a relatively small beating-up force. The influence of the vibratory motion of a reed on the efficiency and dynamics of the thickening process is the subject of numerical analysis in this paper.

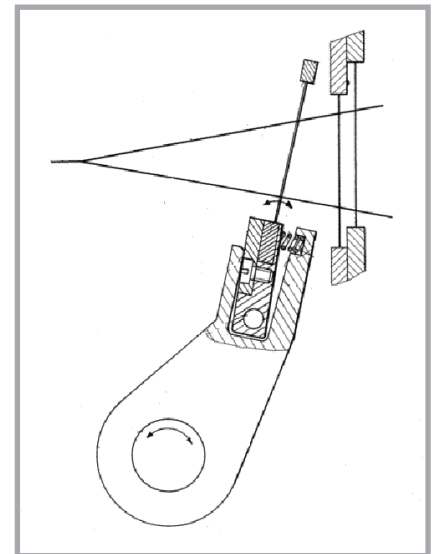


Figure 1. Slay mechanism with a flexible reed [10]

Introduction

The concept of a slay mechanism for a weaving loom with a flexible reed is not novel. The literature available presents specific constructional solutions, for example, the one shown in **Figure 1**. If a periodically variable exciting force acts in the area of the upper back of the reed, the mechanism is known as a vibratory slay mechanism. With the accurate frequency of changes in the values of the exciting force, the reed in the mechanism vibrates in resonance.

The vibratory slay mechanism is applied in the production of woven fabrics whose thickening, commonly known as beating-up, requires considerable force,

Modelling the resistance to the movement of weft threads on warp threads during the thickening process

During the process of thickening a woven fabric, the beating-up force Q_d was identified as that of the reed acting on weft thread moving towards the warp thread. In this process, there are two zones of interactions. The first one is the movement of a weft thread towards the warp threads y_1 . The second one is the movement of the edge of the woven fabric within the elasticity of the configuration: woven fabric-warp threads y_2 . A summary displacement of the edge of the

woven fabric from both zones, equal to the displacement of the reed y , is done with the same resistance force of the reed load on a weft thread. Therefore both of the zones create a serial configuration with two degrees of freedom.

$$y = y_1 + y_2 \quad (1)$$

As shown in **Figure 2.a**, the contact distance y_{1max} between the newly intro-

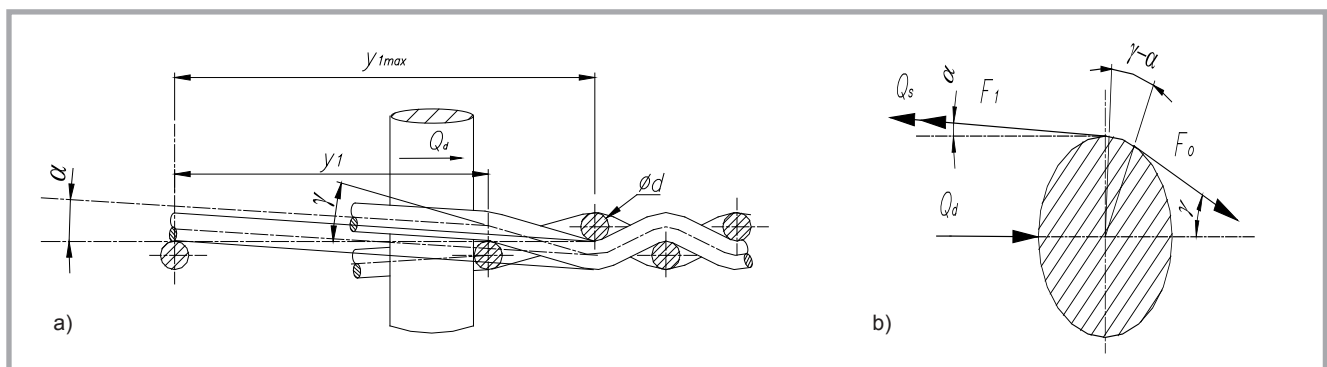


Figure 2. a) Geometry of the movement of a weft thread towards the warp threads, b) distribution of forces in a weft thread.

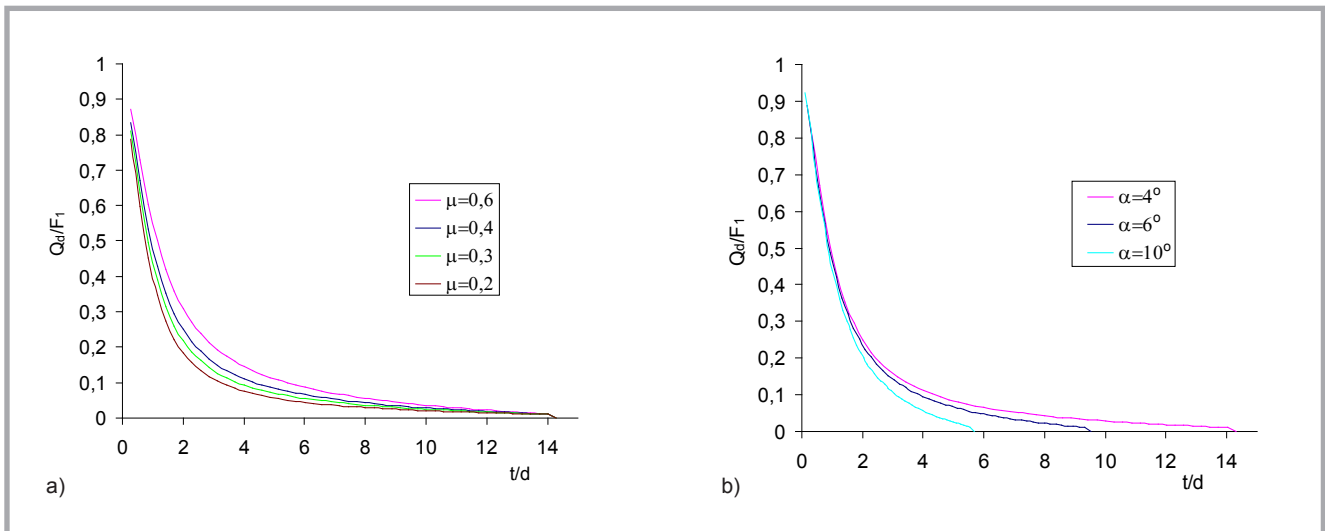


Figure 3. Ratio of the momentary beating-up force and the tension of the warp threads as a function of the momentary relative pitch: a) for various coefficients of friction between the threads ($\alpha = 4^\circ$), b) for various initial angles of the front side of the shed ($\mu = 0.4$), $Q_s/F_1 = 0.01$.

duced weft thread with the warp threads and the weft thread previously introduced is the theoretical maximum path of a weft thread on the warp threads. Of course, the actual displacement of the weft thread during the thickening process is smaller due to the pitch of weft threads in a woven fabric. From the geometry shown in **Figure 2.a**, the following dependencies arise:

$$y_{1\max} = \frac{d}{g \alpha}, \quad (2)$$

$$\gamma(y_1) = \arctg \frac{d}{y_{1\max} - y_1} = \arctg \frac{d}{t}$$

where: d -diameter of the warp and weft threads, t -momentary pitch of weft threads in a woven fabric. The distribution of forces on the weft thread (**Figure 2.b**) result from the following dependency:

$$\frac{F_1}{F_0}(y_1) = e^{\mu(\gamma(y_1) - \alpha)}$$

$$Q_d(y_1) = (F_1(y_1) + Q_s) \cos \alpha + (3)$$

$$- F_0(y_1) \cos \gamma(y_1)$$

where: μ - coefficient of friction of warp threads – weft thread; Q_s - adhesion force between the warp and weft threads [4] (assumed $Q_s = \text{const}$). Finally it was assumed that:

$$\frac{Q_d}{F_1}(y_1) = \cos \alpha - \frac{\cos \gamma(y_1)}{e^{\mu(\gamma(y_1) - \alpha)} + Q_s} + \frac{Q_s}{F_1} \cos \alpha \quad (4)$$

The solution of **Equation 4** as a ratio of the momentary beating-up force and tension of the warp threads as a function of the relative pitch is shown in **Figure 3**. On the basis of **Figure 2.a**, the relative pitch is in a relation to the movement of warp threads:

$$\frac{t}{d} = \frac{y_{1\max} - y_1}{d} = ctg \alpha - \frac{y_1}{d} \quad (5)$$

On the basis of the dependency Q_d/F_1 , it was found that this ratio depends mainly on the geometry of the shed and momentary position of the weft thread towards warp threads, while to a lesser degree on the frictional properties of warp and weft threads. When changing the angle of the front side of the shed, the character

of the Q_d/F_1 course within the range of smaller pitches is similar. The difference mainly relates to the range of the contact area of the weft thread and warp threads, resulting from the different distances of $y_{1\max}$.

It was assumed that the warp threads and woven fabric create a parallel configuration of two rigidities and damping [7, 8]. The configuration is shown schematically in **Figure 4** where: k_o , k_t – rigidity of warp threads, woven fabric; c_o , c_t - damping coefficient of warp threads, woven fabric. Taking into consideration the diagram, the force of the reed acting on the weft thread is the following:

$$Q_d(y_2) = y_2 \cdot (k_o + k_t) + \dot{y}_2 \cdot (c_o + c_t) \quad (6)$$

The force in warp threads in the front part of the shed F_1 is the sum of the pretension of the warp threads' Q_0 force resulting from the rigidity of the warp and that resulting from the rheology of the warp threads [7, 8].

$$F_1(y_2) = Q_0 + \frac{y_2 \cdot k}{\cos \alpha} + \frac{\dot{y}_2 \cdot c_o}{\cos \alpha} \quad (7)$$

Taking into account **Equations 1, 4, 6** and **7**, a system of four equations with four unknowns Q_d , F_1 , y_1 , y_2 was obtained. Two of the equations are differential, in which the unknowns are in the form of derivatives over time. A numerical solution of the configuration was obtained by means of a dynamic model, described in the next subchapter.

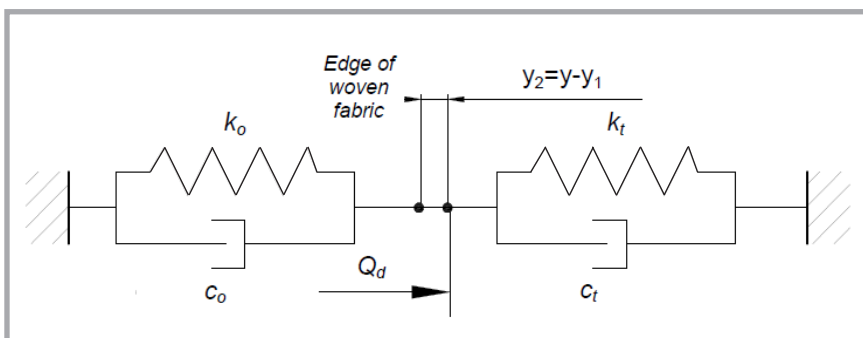


Figure 4. Parallel configuration – elasticity zone of warp thread-woven fabric configuration.

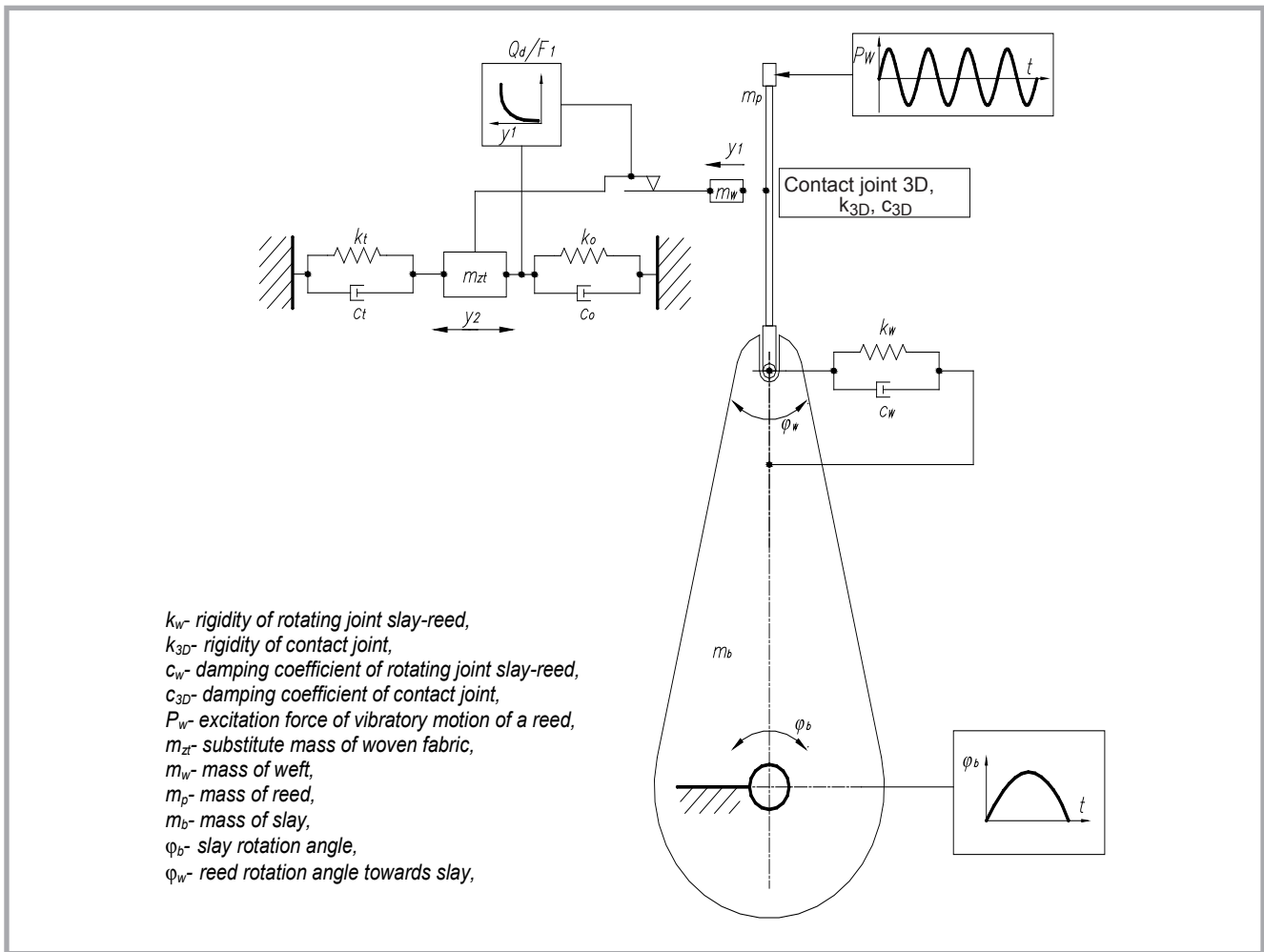


Figure 5. Model of thickening the weft threads with a dynamic excitation of reed motion.

Description of the numerical simulation model of thickening

Simulations of the process of thickening the weft threads with both rigid and vibrating reeds were performed using the dynamic simulation module of Inventor 2009 software [2]. The module uses the ANSYS WORKBENCH program and it is used for numerical simulation of the dynamics of assemblies of the rigid parts loaded with generalised forces and varying in time. The simulation model of the thickening zone developed, shown schematically in **Figure 5**, assumed two zones of interactions described previously.

The first zone, the movement of a weft thread on the warp threads, was defined as a sliding joint between units m_w and m_{zt} . The movement is accompanied by the beating-up force Q_d , described by equation (4) and warp tension force F_l , whose momentary values are determined by the program on the basis of equation (7). The second zone, the movement of the edge of the woven fabric, was defined

as a sliding joint between the m_{zt} unit and the loom frame. This movement takes place under conditions of the rigidity of the configuration: warp threads-woven fabric $k_o + k_t$ and resistance related to the rheology of threads $c_o + c_t$, according to equation (6). Between the weft thread and reed there is a joint of a 3D contact type, characterised by rigidity k_{3D} and damping coefficient C_{3D} . The sinusoidal kinematically forced rotation of a slay of mass m_b , towards the axis connected to the loom frame was assumed. This movement, φ_b , refers to half of the working cycle of the slay. The rotating joint is provided between the reed and slay at the lower back of the reed, characterised by an angular rigidity k_w and angular damping of coefficient c_w . It models the real possibility of bending the reed in order to conduct vibratory motion.

The vibratory thickening of weft threads was simulated in two variants of implementing the vibratory motion of a reed: dynamic and kinematic. The variant with a dynamic excitation assumed a sinusoi-

dal variable force P_w , applied around the upper back of a reed. This force, of specific frequency, leads to a resonant character of the vibratory motion of the reed [4, 6]. The courses of reed movement towards the slay simulated, with both a rigid and vibrating reed, are presented in **Figure 6** (see page 62). The courses show a decrease in the amplitude of vibratory motion of the reed during the beating-up phase, which is caused by an increase in damping in this area.

The second variant of excitation assumed a kinematic implementation of a sinusoidally variable vibration of the reed, without force excitation. In this case the dynamics of vibration of the reed is not discussed. In the assumptions, the configuration did not work in resonance conditions, which enabled to assess the influence of the frequency of the vibrating motion of the reed, or the number of strokes of the reed during the beating-up, on the effectiveness of vibratory beating-up.

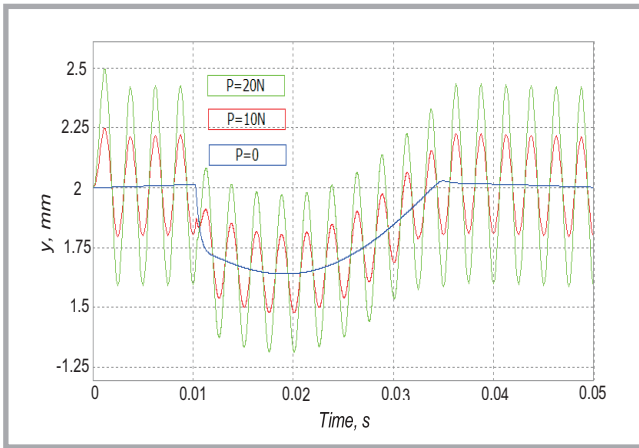


Figure 6. Momentary displacement of the reed towards the slay at the height of the woven fabric's edge, excited with a variable force of different amplitude.

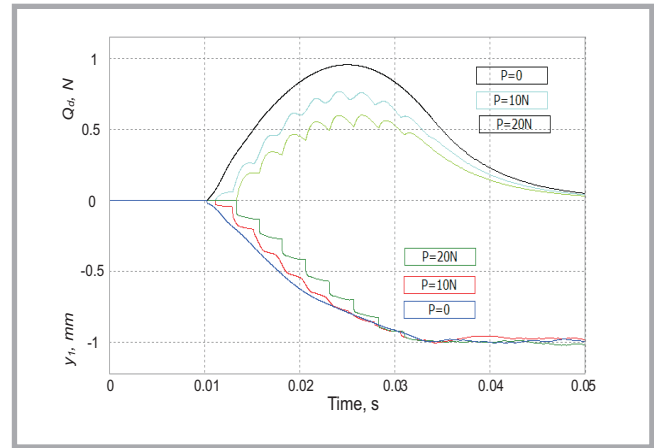


Figure 7. Momentary beating-up forces of five warp threads and the displacements of a weft thread on warp threads during the cycle of thickening the wefts with a rigid and vibrating reed excited dynamically with a variable force of different amplitude.

Simulation analysis of the influence of reed vibration on the efficiency of thickening the woven fabric

The influence of the dynamic parameters of the vibratory motion of a reed on the effectiveness of thickening weft threads was analysed. The efficiency of thickening was defined by reaching the highest possible density of wefts, with a minimum dynamic load of warp threads by means of the beating-up force [5, 9]. Based on the dynamic model developed, simulations of the thickening cycle of weft threads were performed, successively changing the parameters of the reed's vibratory motion. The simulation was carried out for a frequency of slay movement $f_b = 10 \text{ Hz}$, which corresponds to the efficiency of modern looms. The resonant frequency of the reed vibratory motion was equal to $f_w = 400 \text{ Hz}$. Exemplary courses of the momentary dynamic load of the warp threads with a beating-up force and corresponding dis-

placements of a weft thread towards the warp threads in conditions of different values of the excitation force amplitude are shown in **Figure 7**.

Based on the results of the simulations performed, a decrease in the maximum dynamic load of the warp threads with a beating-up force was noted, along with an increase in the value of the dynamic parameters: the amplitude of the excitation force, as well as the amplitude and frequency of the vibratory motion of the reed. Simulation results in terms of percentage reduction of the beating-up force are presented in the form of graphs in **Figure 8**. A significant reduction in the load of warp threads was observed for large values of the amplitude of the force exciting the vibratory motion of the reed ($P = 20 \text{ N}$) or the amplitudes of reed motion within the range $Y = 0.4 - 0.6 \text{ mm}$. The reduction in the warp threads' load was positively affected by the upper range of frequency of the vibratory motion of the reed ($f_w = 600 - 800 \text{ Hz}$). It

was noted that thickening with a vibrating reed can diminish the load of the warp by even 30%.

In the next stage of the study, simulations of the thickening cycle with the use of a rigid reed and one vibrating at a constant maximum dynamic load of the warp were performed. The simulations were carried out under conditions of different values of the following parameters: the amplitude of the exciting force, amplitude of the vibratory motion of the reed and the frequency of the vibratory motion of the reed. Exemplary courses of momentary displacement of the weft thread towards the warp threads and the corresponding dynamic load of the warp threads under conditions of different amplitudes of the exciting force are shown in **Figure 9**.

On the basis of the results obtained, it was found that the maximum displacement of weft a thread on the warp threads increased, rising with an increase in values of the parameters of the dynamic

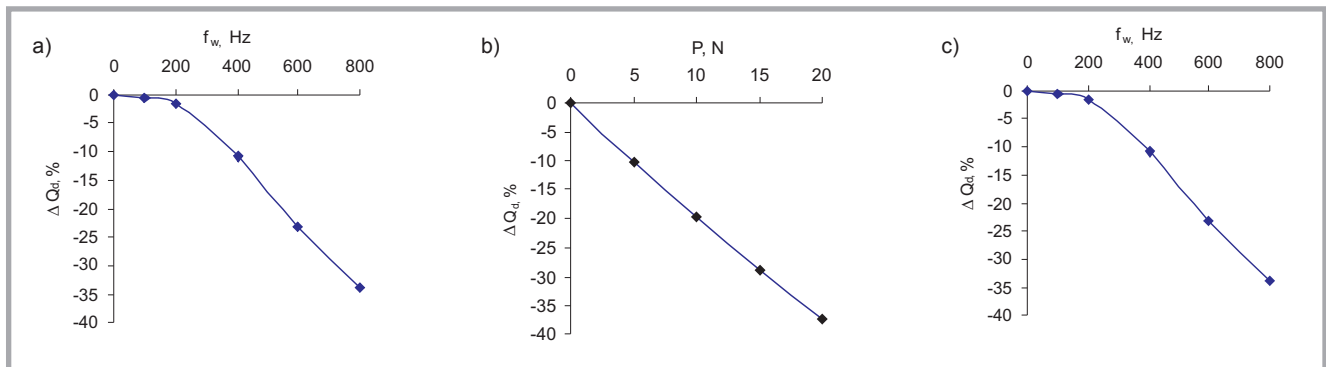


Figure 8. Relative decrease in the values of the dynamic load of warp threads with a constant thickening of woven fabric produced using a vibrating reed, excited: a) in a dynamic way with a variable force of different amplitude, b) in a kinematic way with a variable motion of different amplitude ($f_w = 400 \text{ Hz}$), c) in a kinematic way with a variable motion of different frequency ($Y = 0.3 \text{ mm}$).

vibratory motion of the reed analysed: amplitude of the exciting force, as well as the amplitude and frequency of the vibratory motion of the reed. The thickening of weft threads in the woven fabric produced depends on the value of the displacement of the weft thread on the warp threads obtained, according to the relationship:

$$Z = \frac{L}{t} = \frac{L}{y_{1\max} - y_1} \quad (8)$$

where: Z - thickening, L - length of the section tested (assumed $L = 10 \text{ mm}$).

Results of the simulation performed are shown in the form of graphs in **Figure 10**.

On the basis of the graphs, a significant increase in the thickening of weft threads for relatively high amplitudes of the excitation force of the reed's vibratory motion ($P = 20 \text{ N}$) and high amplitudes of the reed motion ($Y = 0.4 - 0.6 \text{ mm}$) were noted. The improvement in the thickening of weft threads obtained was influenced by the upper range of the frequencies of the vibratory motion analysed ($f = 600 - 800 \text{ Hz}$). Finally it was found that thickening with a vibratory reed enables to increase the thickening of weft threads by even 30%, without increasing the load of the warp threads.

Energy balance and demand for power during thickening with a vibrating reed

One of the main technical parameters characterising the thickening of a woven fabric with a vibratory reed is the energy of beating-up the weft threads and momentary demand for power during the beating-up process. Unlike thickening

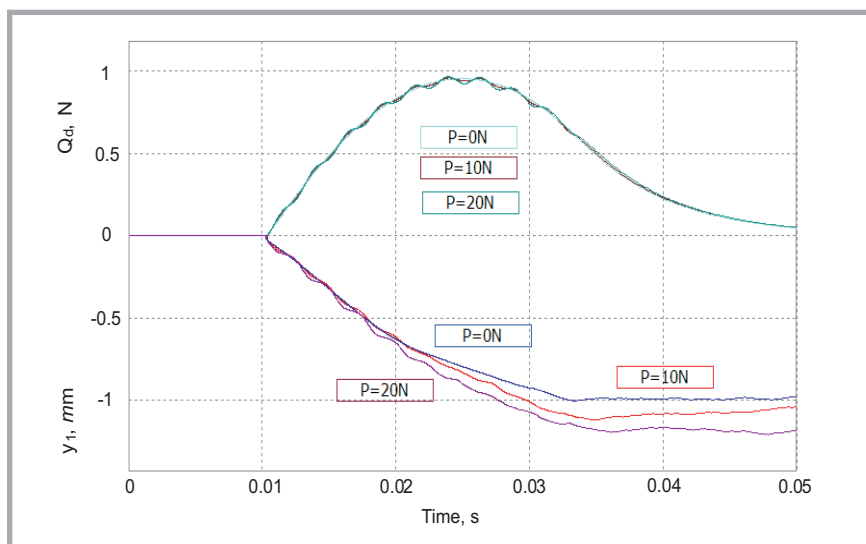


Figure 9. Momentary displacements of a weft thread on the warp threads and dynamic loads of five warp threads during the cycle of thickening the wefts with a rigid and vibrating reed excited dynamically with a variable force of different amplitude.

with a rigid reed, in which a slay is the only source of power, during thickening with a vibrating reed beside the slay, the excitation mechanism of the reed's vibratory motion is also a source of power [3].

The demand for momentary power of the exciting device of the reed's vibratory motion and that for the power of a slay was determined according to the dependence:

$$\begin{aligned} N_w(t) &= M_w(t) \cdot \omega_p(t) \\ N_b(t) &= M_b(t) \cdot \omega_b(t) \end{aligned} \quad (8)$$

where: $M_w(t)$ - driving moment of the reed, $\omega_p(t)$ - circular frequency of the vibratory motion of the reed, $M_b(t)$ - driving moment of the slay, $\omega_b(t)$ - circular frequency of slay motion.

A case of producing a woven fabric with the use of a rigid and vibrating reed of constant density was analysed, assum-

ing a kinematically forced vibratory motion of the reed. **Figure 11** (see page 64) shows exemplary courses of momentary demand for power to enforce the vibratory motion of the reed with a constant amplitude, determined according to dependence (8). Momentary values of $M_w(t)$ and $\omega_p(t)$ were obtained on the basis of the numerical dynamic simulation. The values of power calculated correspond to 100 warp threads. The corresponding width of the reed is expected to excite vibrations with one exciting device of motion.

The overlaying courses, marked in different colors, correspond to different values of amplitude of the vibratory motion of the reed. It was found that the peak values of power in the beating-up phase are much greater than those in the phases in which the reed is not in contact with the edge of the woven fabric.

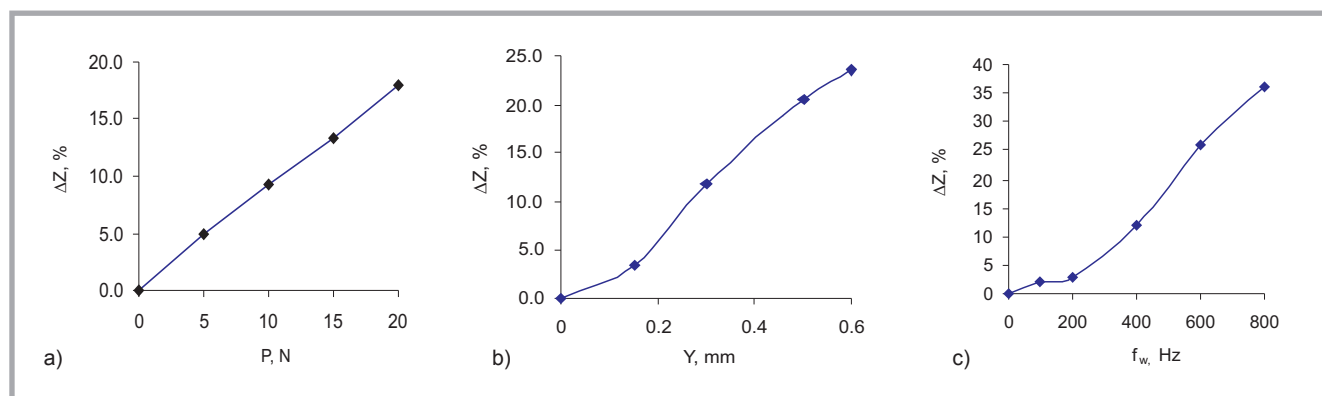


Figure 10. Relative increase in the thickening of weft threads obtained with a constant dynamic load of the warp, of a woven fabric produced using a vibrating reed excited: a) in a dynamic way with a variable force of different amplitude, b) in a kinematic way with a variable motion of different amplitude ($f_w = 400 \text{ Hz}$), c) in a kinematic way with a variable motion of different frequency ($Y = 0.3 \text{ mm}$).

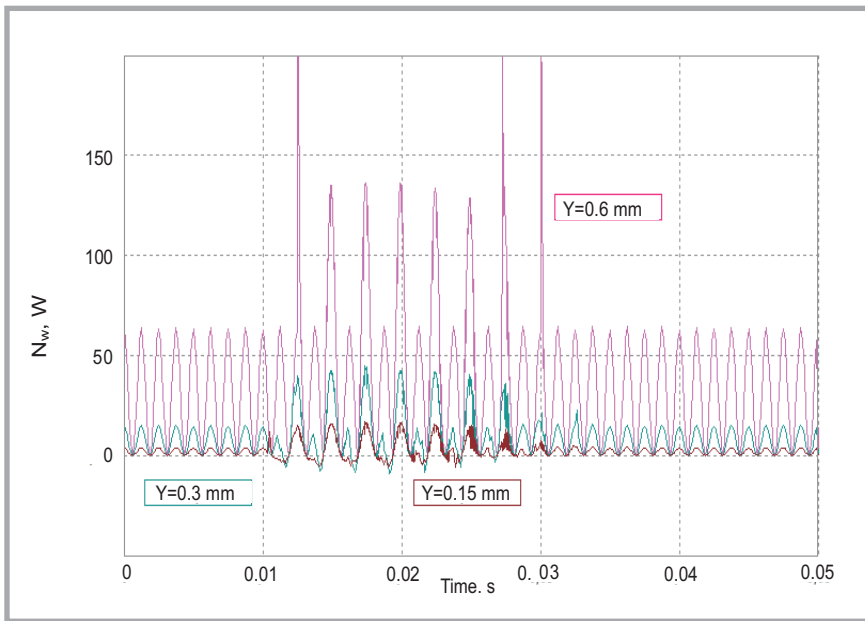


Figure 11. Momentary demand for power of the exciting device of the reed's motion during thickening with a vibrating reed of various amplitudes, $f_w = 400$ Hz, $f_b = 10$ Hz.

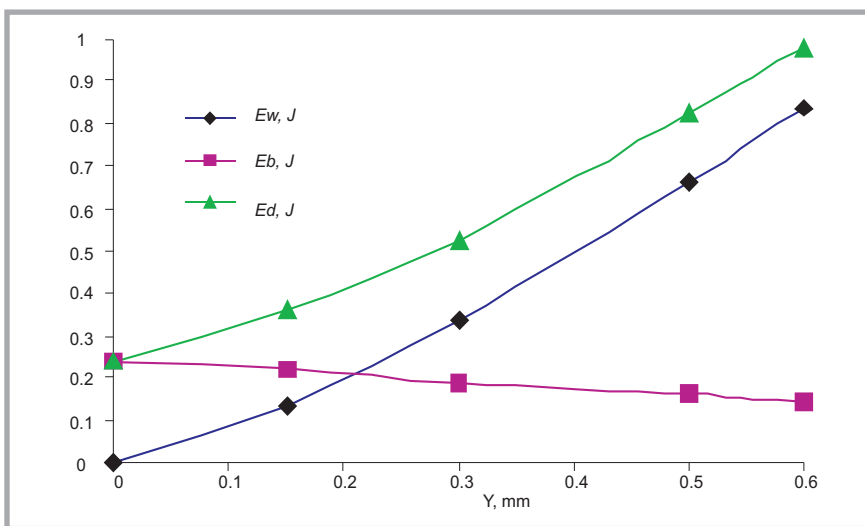


Figure 12. Energy of slay E_b , an exciting device for the vibratory motion of the reed E_w and total energy of beating-up E_d in one cycle of thickening the wefts.

The courses of momentary values of the power exciting device and the momentary power of the slay were averaged over the time in which the thickening cycle takes place. After multiplying the average values of power by the beating-up time, the energy of beating-up was obtained. The results are shown in graphs of the energy calculated as a function of the amplitude of the reed's vibratory motion, presented in Figure 12.

Analysing the courses, it was found that the energy of beating-up with a rigid reed, which comes only from the slay, is smaller than the total energy of beating-up with a vibrating reed, which consists of energy of the exciting device and the

slay. With an increase in the amplitude of the vibratory motion of the reed, the energy of the slay decreases slightly. At the same time, the excitation energy of the vibratory motion of the reed increases. For greater amplitudes of the vibratory motion of the reed, the excitation energy is greater than that of the slay.

Conclusions

1. The beating-up force depends mainly on the geometry of the shed and preliminary tension of warp threads, while to a lesser extent on the frictional properties of the warp and weft threads.

2. With an increase in the values of amplitude and frequency of the vibratory motion of the reed, the values of thickening weft threads in woven fabric produced with the use of a smaller beating-up force increase.
3. The thickening of weft threads with a vibrating reed enables to achieve a greater density of woven fabrics produced and to diminish the load of warp threads by even 30%.
4. There were no energy advantages connected with the vibratory thickening of woven fabrics. The total energy of the beating-up process with a vibrating reed (slay and exciting device) is greater than that of beating-up with a rigid reed.
5. The thickening of weft threads with a vibrating reed slightly reduces the energy of the slay, with a simultaneous increase in momentary demand for power of the driving unit.

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Received 05.07.2012 Reviewed 12.02.2013