Algorithm for the cams synthesis for the slay mechanism drive

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Abstract. The paper presents an algorithm for the synthesis of the law of motion of the weft beat-up mechanism intended for the production of closely woven fabrics, which are currently manufactured mainly on shuttle looms. These machines have such disadvantages as significant dimensions, strong vibrations and noise during operation, as well as low performance. Shuttleless looms are devoid of such disadvantages. However, production of closely woven fabrics on such machines can face a number of problems, such as increased vibrations, the machine tool turning off due to an increased beating-up strip and accelerated wear of mechanisms which, in turn, leads to a lower productivity and product quality. The conducted research allowed developing an algorithm for the synthesis of complex-profile cams of the slay mechanism drive. The use of the developed mechanism is theoretically proved and experimentally confirmed to provide the required performance and quality as well as to significantly expand the range of fabrics produced on STB shuttleless looms.

1. Introduction

Currently, the production of dense fabrics is mainly carried out on old shuttle equipment, which does not meet modern requirements for safety and operation. The quantitative characteristics of the main threads deformations in the process of yawning and beating-up are of particular importance for obtaining dense fabrics. A number of authors in their works dwell in great detail on fabrics production on shuttleless looms [1 - 5]. Thus, the works [6 - 12] present the results of studies of phenomena occurring in the process of weaving, and prove the possibility of obtaining analytical dependencies for the process of fabric formation. A complete study of the dense fabrics production on STB looms was carried out in [13]. The result of these studies was the implementation of new designs of shuttleless looms.

The authors of the works [14] investigated the dynamic characteristics of the motion of the driven mass as a rigid system, and also considered the concepts of "light" and "heavy" slay (the mechanism of the weft threads beating-up).

The paper [8] presents experimental data on stress studies in a cam-roller pair of a slay mechanism. The research resulted in a calculation formula including dynamic corrections and accounting for the
friction force. Developed method for determining the stresses in the "cam–roller" pair of the slay mechanism using specialized sensors [9]. In [14], the authors propose a method for synthesizing a slay mechanism using spline functions that take into account the malleability of the mechanism links. In [6, 12], the authors were the first to attempt linking the design parameters of the slay mechanism with the process capabilities of machine tools.

In the research paper [15], the author proposed engineering solutions to increase the resource of the slay mechanism in STB-type looms.

The authors in their work [16] conducted research aimed at finding possible ways to balance the forces on the main shaft using the cam unloaders. As a result of the experiments, the overall dimensions of the improved mechanism did not exceed the geometric parameters of the standard slay mechanism [16].

Machines with micro-projectiles can best meet modern requirements, but there is little practice of producing technical fabrics on this equipment [17, 18]. It is that when producing fabrics of a compacted structure on these machines should obviously result in the growth of the beating-up strip, which can lead to difficulties in trapping the edge. Since the production of technical fabrics on STB looms is constantly growing, it is necessary to determine the scope of the existing equipment updating. First of all, it is necessary to modernize the slay mechanism, which takes the main load at producing such types of fabrics. Since the need for technical fabrics is constantly increasing and the existing equipment does not meet modern requirements, this trend of research is timely and relevant.

Consequently, the purpose of the work can be formulated as follows: the synthesis of a special law of motion of the slay mechanism designed for the production of closely woven fabrics.

The slay mechanism (Figure 1a) works as follows: the cams 2, 3, fixed on the main shaft 1, transmit the movement to the slay shaft 5, which performs a reciprocating motion together with the rollers 4, blades 6, slay bar 7 and reed 8. The kinematic scheme of the slay mechanism (Figure 1b) is presented in a simplified form and includes: the axial distance $A_k$, the variable radius vector $R$ and the length of the rocker arm, $L$, which holds the roller.

![Figure 1](image)

**Figure 1.** Slay mechanism of the STB shuttleless loom:

* a - general view; b - kinematic diagram

2. **Materials and methods**

The synthesis of the law of motion of a slay mechanism must begin with the construction of its cycle diagram [1-5, 19 - 22]. It will include the following phases of motion: the slay move to the cloth fell (points a, b); the slay move in the forward position (triple: points b, d, e); the back motion (points e, c); the delay (see Figure 2).
54 degrees are assigned for the first phase of the motion (a, b); 27 degrees are assigned for the beating-up phase (b, d, e); 54 degrees are assigned for the back motion from the cloth fell (e, d). The projectile motion (the delay phase) is assigned 225 degrees. The synthesis of the slay mechanism law of motion starts with accelerations.

In this regard, we use the existing experience of synthesis and introduce additional conditions based on the specific task, i.e. the triple motion of the follower in the forward position. The following requirements conditioned the law of motion synthesis: the acceleration function must be continuous (without discontinuities of the first and second order); the acceleration curve must be smooth; the equality of the positive and negative areas of the acceleration curve must be observed.

The authors of the work performed the synthesis of the slay mechanism at the frequency of the main shaft rotation $n = 200 \text{ min}^{-1}$. In the first stage of synthesis, the acceleration curve at the rise and back motion is described by the cycloidal law. This is done only to simplify the choice of scale factors.

To achieve the research objective, we made a matrix of acceleration values on the basis of the proposed law, depending on the rotation angle of the cam shaft. The matrix further underwent cubic spline interpolation. The use of cubic spline interpolation allowed avoiding the problems that occur when cycloidal functions are combined.

The main parameters for the synthesis are: pusher stroke $H = 0.024 \text{ m}$; forward stroke is 54°; cloth fell motion in the forward position with amplitude $A = 0.00056 \text{ m}$ and phase angle 27°. The back motion of the mechanism is 54 °. The cycloidal law was used for the reed motion to the forward position (beating-up position) and back. The sinusoidal law was used in the forward position (the weft beating-up position). The resulting law of accelerations is shown in Figure 3 a, where the values of accelerations are plotted along the ordinate axis, and the angles of rotation are plotted along the abscissa axis. These accelerations were scaled. Based on the presented accelerations, we compiled a matrix of their values, processed it with a third-degree spline, performed an interpolation spline and scaling. After the positive and negative areas were aligned, we performed integration. As a result, we obtained the law of velocity change, which is shown in Figure 3 b. Next, according to the available graphical data, we made a matrix of velocity values and entered their values on the graph paying attention to the equality of positive and negative values areas as well as their smoothness and continuity. After integrating the presented matrix, we obtained the values of the displacements, which are shown in Figure 3 c.
3. Results and discussion

Figure 3 a, demonstrates that the acceleration curve has a pulsating character, which in the case under consideration will have a positive value; the period of their forced oscillations is close to the period of the natural oscillations of the slay system (the driven part of the mechanism). When the frequencies coincide and their oscillations are repeated many times, the reduced factor of the threads friction will also decrease, thus reducing the work required for the fabric formation. The movements have 3 distinct vertices, which provide triple movement to the follower (reed) in the forward position. Obtaining a general picture of the interaction between the mechanism and the fabric requires identifying the nature and magnitude of the process load, which were determined from the calculation of the displacement trajectory of the beating-up point (see Figure 4), where the process load moment Mt is plotted along the ordinate axis, and the angle of the main shaft rotation is plotted along the abscissa axis.

To determine the regularity of loads impact on the slay mechanism, we constructed a matrix of the total values of the inertial forces and forces from the process load; as shown in Figure 5, where the values of the moments from the inertia forces and the process load Ms are plotted along the ordinate axis, and the angle of the main shaft rotation is plotted along the abscissa axis. The inertial mass characteristics of the slay system were calculated using the Kompas 3D application software.
To implement the proposed law, we carried out the necessary calculations and constructed the cam profiles (see Figure 6).

![Figure 6. Profiles of the cams: a - main; b - closing](image)

The calculation of the contact stresses in the cam-roller pair is made according to the Hertz-Belyaev formula:

$$\sigma_{H} = 0.418 \cdot \frac{E \cdot E}{\sqrt{l \cdot \rho}}$$  \hspace{1cm} (1)

Design data are: elasticity modulus of the second order $E = 2.1 \cdot 10^5$ MPa; cam and roller contact length $l = 30$ mm; minimum radius of the cam curvature $\rho_{c} = 30$ mm; the radius of the roller curvature $\rho_{r} = 30$ mm.

$$\sigma_{H} = 0.418 \cdot \frac{8100 \cdot 2.1 \cdot 10^5}{30 \cdot 15} = 812.68 \text{ MPa}.$$  

Meeting the strength conditions requires the calculated contact stresses to be less than the permissible $[\sigma_{k}] = 1050$ MPa.
Finding the factor of the contact strength margin requires finding the ratio of the permissible contact stresses to the calculated ones: \( \mu = \frac{[\sigma]\mu}{\sigma^H} \approx \frac{1050}{812.68} = 1.29 \).

The calculation showed that the margin factor is greater than one by 29%, which means that the cam can withstand a given load and is suitable for the production of dense fabrics.

4. Conclusion

The following results are obtained.

1. We have synthesized the law of motion of the slay mechanism follower which provides triple motion of the cloth fell.
2. We proposed a new law of changing the process load which makes it possible to significantly increase the range of fabrics produced on STB looms.
3. The analytical dependences used in the synthesis of the law of motion of a given mechanism are brought to numerical values. The results are presented in the form of cam profiles (Figure 6).
4. The graph shown in Figure 5 demonstrates that the sum of the moments exceeds the moment of inertial force for the time of the process load operation. This suggests that the difference in moments should be balanced by the machine engine energy.

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