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Motion laws synthesis for cam mechanisms with multiple follower displacement

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Abstract. The research discusses the cam mechanisms design. The analysis of specialized literature indicates that the synthesis of the cam mechanisms laws of motion is currently done mainly by a standard set of acceleration curves. In some cases, the designer needs to synthesize a new acceleration law which should be task-specific and enforce a certain production step. The values of the technological loads and inertia forces loads generated by the mechanism are calculated to analyze the slay mechanism behavior in the production of closely woven fabrics. Mathematical packages MathCad and SolidWorks are used in calculations. As a result of the research, the authors propose the methodology for synthesizing the slay mechanism with multiple follower displacements for the point of contact between the reed and the fabric edge. Theoretical studies have been tested on a specific machine model (STB loom). The authors have synthesized the motion law of the filling threads beat-up mechanism for the production of strong fabrics. New basic and closing cam profiles are proposed. The results are designed to enhance the possibilities of the looms and to recommend the most efficient equipment operation modes for the producers.

1. Introduction

Currently, the production of closely woven fabrics for industrial and public consumption needs is mainly done on the shuttle looms. These machines have certain drawbacks, such as considerable dimensions, heavy vibrations and noise in the process as well as low performance. Shuttleless looms are devoid of such disadvantages. However, production of closely woven fabrics on these machines may encounter a number of problems, such as: increased vibrations, machine stoppage because of the increased beating-up banding, accelerated wear of the machinery. These factors reduce the productivity and quality of the fabric. The closely woven fabrics are used in various industries such as: mechanical engineering, aerospace industry, pharmaceutical and chemical industries, metallurgy, oil industry. They are also used for the filtration of molybdenum, tungsten, air, etc. The growing demand for the goods produced of such fabrics necessitates the production of them. Not only the equipment maintenance or the quality of the produced materials, but also human health may sometimes depend on the quality of fabrics production.

The industrial use of STB loom indicates that it is not possible to produce strong fabrics without considerable changes in definite mechanisms. The first mechanism to modernize is the filling thread beat-up mechanism (slay mechanism) containing cams in its drive since it is directly involved in the formation of fabrics. The cyclical graph of the machine ascribes a certain amount of time for its work to be taken into account in the synthesis of the motion law. Thus, some research [1 - 7] provides a synthesis of the cam motion laws for the acceleration forms that can be found in the specialized literature. In some cases, the designer needs to synthesize an acceleration law which should be task-specific and enforce a certain production step. In the given case it is the closely woven fabrics production. The purpose of this research is therefore to develop a new law of motion for the slay mechanism for the production of strong fabrics.

The laws of motion of the cam mechanisms, slay being one of them, are determined by the phase angle of the cam rotation, the magnitude of the rocker, and the necessary mechanism duration, expressed mainly by the contact stresses in the cam-roller pair, or the wear resistance of the pair.

The cam mechanisms synthesis comprises several stages: defining the motion law of the rocker for the follower swinging motion or the travel of the follower for progressive motion; defining the design or kinematic parameters. At present, the design of cam mechanisms is primarily performed on the basis of well-established laws. Many authors propose considering the motion laws of the followers according to the types: 1) dwell - rise - return - dwell; 2) dwell - rise - dwell. These laws can be represented by complete mathematical curves such as sinusoidal, cosine, rectilinear. Complex motion laws can be represented as consisting of simple mathematical curves combination. There are universal methods for selecting the motion laws of the follower; there are also families of the stereotyped laws with variable parameters whose characteristics vary widely [8 - 15], but in the given case they can not be applied because of the proposed law complexity. Polynomial laws cannot be applied owing to the high degree of polynomial (above 10) which results in transmission functions oscillations and, consequently, in the mechanism deterioration. This method is effective only with one fixed frequency of the cam rotation. The variational method [3 - 7, 14] can be used to describe the motion law of the cam mechanism follower. It can only be applied in particular cases. The most appropriate (in terms of universality, ease of computer use, unnecessary combining) is the choice of the follower motion law described by the third-degree spline [9 - 15], but in this case the process is time-consuming and requires expertise. The laws of acceleration displacement at the boundary sites need to be combined for the filling threads beat-up mechanism (slay) which has a complex reed motion trajectory (triple beat-up). This process is very labor-intensive and the accuracy of the combined curves is unsatisfactory. If this type of curve is inaccurately combined, there may be significant acceleration spikes, commensurate with the maximum acceleration values of the main motion.

2. Materials and methods

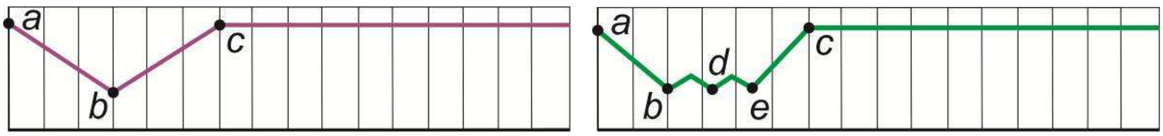
The authors of this research use the existing synthesis experience and introduce additional conditions based on the specific task, namely that of triple mechanism's follower motion in the front position to obtain closely woven fabrics. The whole synthesis process is suggested to be performed using a mathematical package. The cam mechanism's follower law of motion is independent of the kinematics and mechanism's structure; it is assigned by the designer. The following requirements are imposed on the laws of motion: the acceleration function should be continuous (without first and second-type breaks); the acceleration curve should be smooth; the equality of the positive and negative areas of the acceleration curves must be observed.

A synthesis of slay mechanism law of motion is proposed to be performed by assigning the acceleration change mode. For this purpose, it is necessary to define the values of the phase angles. The cycle diagram of the filling threads beat-up mechanism operation is shown in Figure 1 a.

According to the work cyclogram of the standard configuration loom with a single beating-up, the reed displacement from the initial position (point *a*) to the fabric edge (point *b*) is ascribed 70 ° of the main shaft rotative amount. At this point, the beat-up of the filling threads occurs and then the back motion is given at the interval from 70 ° to 140 ° (point *c*). The overall mechanism cycle of motion is

140 °. In addition, the nature of the technological load must be determined. Law of motion synthesis is proposed to start without considering the elastic properties of the mechanism. The authors of the work performed the synthesis of the slay mechanism at the frequency of the main shaft rotation with n =200 min^{-1} in the MathCAD package. The values of the phase angles are assigned in accordance with the loom cyclogram preservation. In the first stage of synthesis, the acceleration curve at the rise and back phases is described by the cycloidal law. This is done only to simplify the scale factors. In addition, the following conditions were observed in the synthesis of the acceleration law: the acceleration function should be continuous (without first and second-type breaks); the acceleration curve should be smooth; the equality of the positive and negative areas of the acceleration curve must be observed.

The authors also propose observing the condition of the mechanism having a repetitive cycle of the follower (slay system) in the front position. In this case, as noted previously, a triple displacement of the follower is necessary. The cyclogram of the multiple filling threads beat-up mechanism operation is shown in Figure 1 b.



a b

Figure 1. Cyclograms: a - Cyclogram of the machine work; b - Cyclogram of filling threads beat-up mechanism

According to the work cyclogram of the triple beat-up slay mechanism, the reed displacement from the dwell position (point *a*) to the fabric edge (point *b*) is ascribed 54° of the main shaft rotative amount. At this point, there is the first beat-up of the filling thread (point *b*), the back motion and the second beat-up (point *d*), and then the third beat-up (point *e*). The back motion is 54 degrees (point *c*). The overall mechanism cycle of motion is 135°.

To achieve the research objective, the authors created the 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 requirement of the positive and negative areas equality of the acceleration curve was observed in the matrix. The use of cubic spline interpolation allowed avoiding the problems that occur when cycloidal functions are combined.

3. Results and discussion

The auhors presented the general methodology and approach to synthesizing the mechanism laws of motion. The law of motion synthesis can be exemplified on the slay mechanism of the shuttleless STB loom designed to produce closely woven fabrics. The loom's design provides for triple beating-up of the filling threads to the fabric edges. The basic parameters for synthesis are: follower's motion H = 0.024 m; phase angle β = 54° (curve angle) forward running - 0°- 54°; motion with fabric edge in the front position: amplitude a = 0.00056 m; phase angle β = 27°. The back motion of the mechanism is β = 54°. The cycloidal law is taken to be the basic law for the displacement of the follower to the front position and for its back motion at the first stage of the synthesis. The sinusoidal law is chosen for additional front displacement. It is essential to observe acceleration curve smoothness and continuity compiling the values matrix. The laws for changing speeds and displacements are received by integration (Figure 2).

The picture demonstrates that the displacement curve has 3 explicit vertices which provide a triple motion of the follower in the front position. It was necessary to identify the nature of the technological load which, in turn, had been determined by the trajectory of the beat-up point displacement and in accordance with the resulting reed motion curve (see figure 3a) to obtain the overall picture of the mechanism and fabric interaction.

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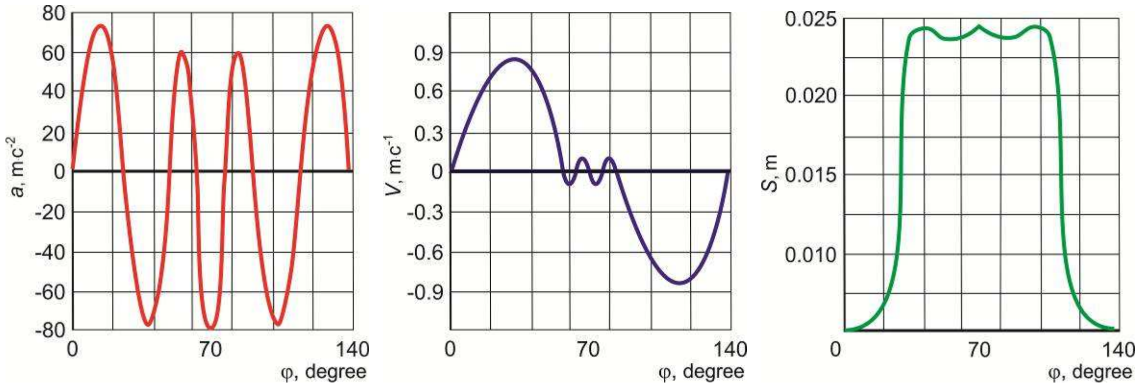
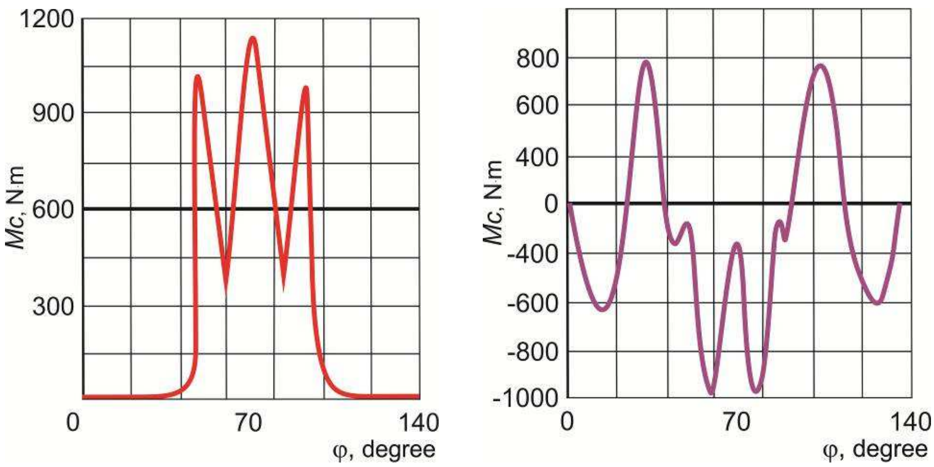


a b c

Figure 2. Kinematic characteristics of the filling threads beat-up mechanism for a new synthesized law: a - acceleration; b - speed; c – displacement

Using the acceleration change law, the authors received the curve of moment shifts caused by inertial forces. The curve was defined as the product of the follower system mass moment of inertia and its angular velocity. The inertial mass characteristics of the slay system are calculated using the SolidWorks package. As a result of the inertia force moments and the beat-up force, the autors received the cumulative moment graph that characterizes the pattern and magnitude of the load in the cam-roller pair.

Figure 3b presents a graph to get the overall picture of how the moment correlates with the forces of inertia and technological load.



a b

Figure 3. Moment graph: a - the curve of moment change owing to technological load; b - cumulative moment graph

The graph shown in Figure 3b demonstrates that for the time of the technological load operation the sum of the moments exceeds the moment of inertial force. This suggests that the difference in moments should be balanced by the machine engine energy.

To implement the proposed law, the authors conducted the necessary calculations and designed the basic cam and closing cam profiles (see Figure 4).

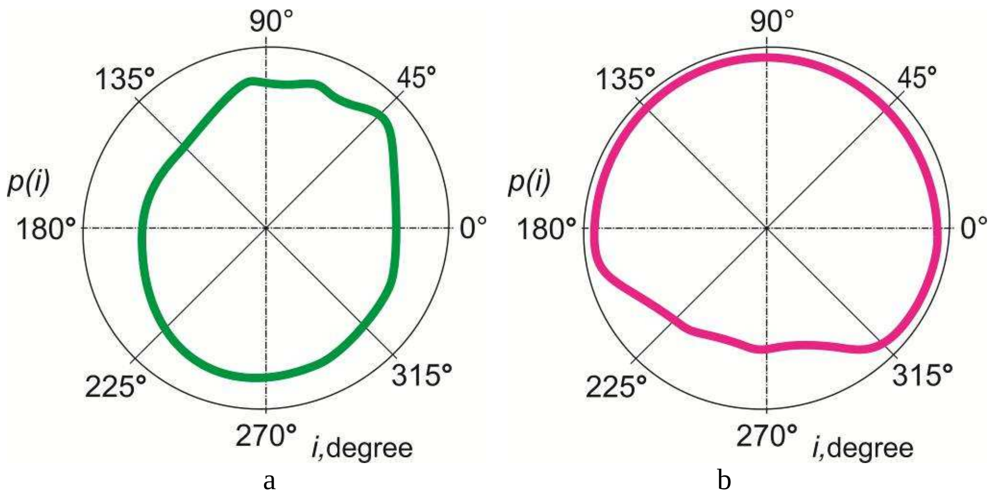


Figure 4. Cam profile: a - basic cam profile; b - closing cam profile.

4. Conclusion

The authors propose a new cam profile to provide the method of fabric production based on the principle of the slay system multiple action on the warp and fabric. It has advantages over the classical one because it is possible to achieve a considerable increase in the assortment of weaving equipment products without a significant design change and additional energy. The suggested method allows sequential energy supply to the fabric-formation zone. In addition, the interaction time of the slay system in the fabric-formation zone has been increased, which positively influences the fabric formation process and reduces the plastic deformation of the warp and fabric.

Conclusions

1. The authors have synthesized the law for the triple displacement of the follower in the front position.

2. The authors have proposed a new law of the technological load change.

3. The proposed analytical dependencies have acquired numerical values; the results of the calculations are presented in the form of the calculated cams.

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