COMPARATIVE ANALYSIS OF MATERIALS MOVEMENT MECHANISMS IN SEWING MACHINES

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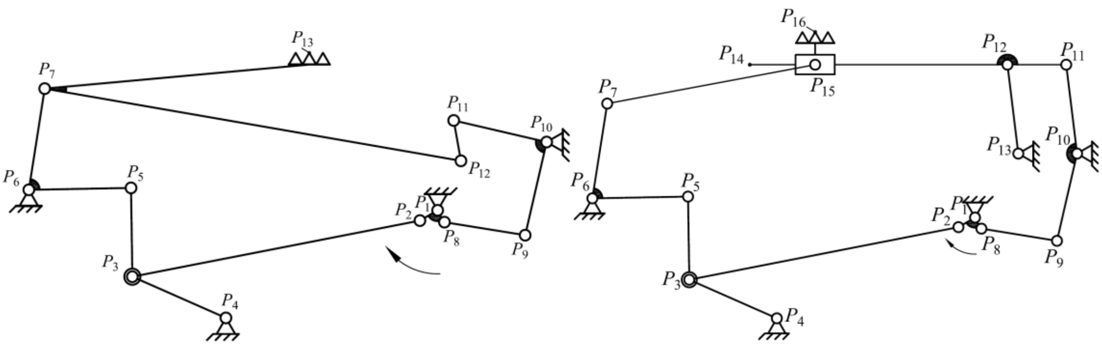
Abstract. Purpose. To compare the kinematic and dynamic characteristics of the mechanisms proposed by the authors with typical mechanisms for moving materials in sewing machines and assess their impact on material transportation quality.
Methodology. The study considers typical and author-developed mechanisms for material movement in sewing machines as described in [1]. Established methods of kinematic and dynamic analysis of mechanical systems are employed to establish comparison criteria.
Findings. The study determines the analog values of speed, acceleration, and jerks in vertical movements of the toothed rack in both typical and proposed mechanisms for material movement in sewing machines. It also examines the impact of force interaction within the toothed rack-material-clamping paw system on material transfer quality.
Originality. The authors establish the boundary values of kinematic and dynamic performance indicators for the new mechanism of material movement in sewing machines and compare them with typical mechanisms. The study confirms the feasibility of employing the new mechanism for material movement in sewing machines.
Practical Value. The new material movement mechanism ensures quality displacement processes, minimizes material damage, and maintains stitch length stability.
Keywords: material movement mechanism, acceleration, jerk, rigidity coefficient, damping factor.

Introduction. This work is a continuation of the research on the multilink mechanism for material transport in sewing machines, the metric synthesis of which is discussed in [1]. An essential component of the mathematical model during the investigation of dynamics is the analytical expressions of the main kinematic characteristics of the mechanism, determining the laws of motion of the mechanism in generalized coordinates, and solving partial problems under different initial conditions.

In the design of sewing machine mechanisms, analogs of the vertical velocity component of the working point of the working member are used - the so-called kinematic transfer function, which is of practical interest as it allows comparing mechanisms that are identical in structure or functional purpose. Kinematic transfer functions can be used for kinetostatic and dynamic calculations of sewing machine mechanisms, as well as criteria for optimality during parameter optimization of mechanisms.

Problem Statement. The authors of [1] have examined the proposed mechanism for material transport, in which all teeth of the feed dog have identical trajectories during operation. This allows reducing the depth of penetration into the material and improving the quality of transportation. Moreover, the improvement in transportation conditions in this mechanism is also due to better kinematic and dynamic parameters compared to conventional mechanisms. This work is dedicated to determining these parameters and comparing them with the analogous parameters of a typical material transport mechanism.

Research Results. According to [2], important indicators of the dynamics of cyclical mechanisms are the maximum values of such kinematic characteristics as acceleration and jerk, or their analogs: $\frac{d^2S}{d\phi_1^2}$ and $\frac{d^3S}{d\phi_1^3}$ (where S is the vertical displacement of the toothed rack; φ_1 is the generalized coordinate, which for cyclical mechanisms is the rotation angle of the main shaft). The first quantity characterizes the influence of inertial loads, while the second characterizes their impact properties.

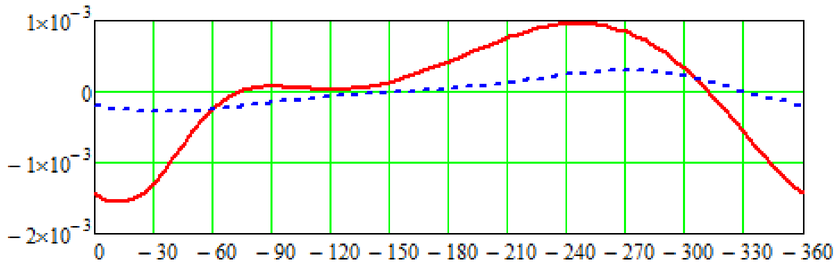


a **b**

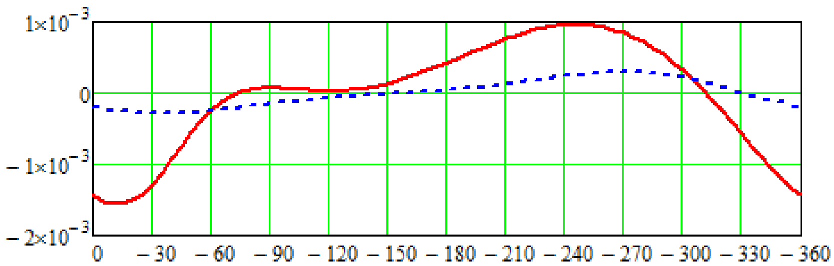
Fig. 1. Schemes of the investigated mechanisms: a - typical; b - proposed (new)

We will determine the values of these quantities for the mechanisms considered in [1]. The values of the velocity, acceleration, and jerk analogs of the vertical displacement of the working point P_{16} of the toothed rack of the proposed mechanism according to Figure 1 will be determined by differentiating expression (11) from [1] once, twice, and three times with respect to the angle φ_1. The values of the velocity, acceleration, and jerk analogs of the vertical displacement of the working point P_{13} of the toothed rack of the typical mechanism according to Figure 1 will be determined by differentiating the radius vector P_{13} (φ_1) once, twice, and three times with respect to the angle φ_1, which, in turn, can be determined using the method of vector coordinate transformation and the computational block of Mathcad according to [1].

The obtained values of the analogs of velocity, acceleration, and jerk of vertical displacements of the rack in the typical and proposed mechanisms of material movement are presented in the graphs in Figure 2.



a



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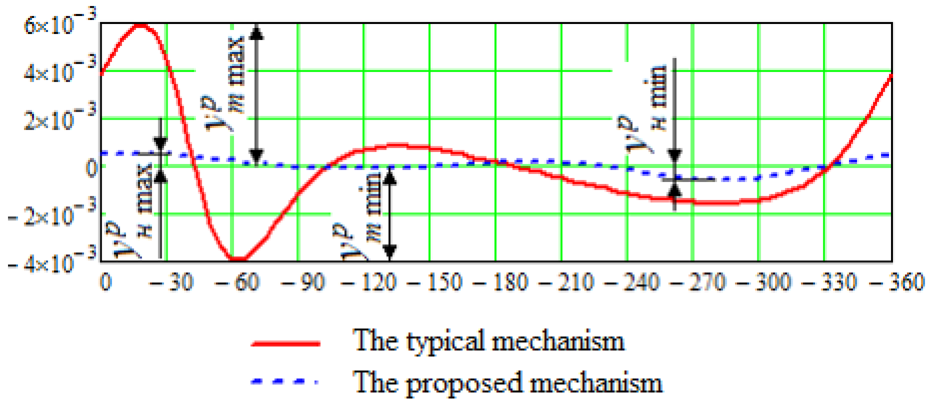

c

Fig. 2. Graphs of the values of kinematic characteristics of the mechanism: a - velocity analogs; b - acceleration analogs; c - jerk analogs

Hence, the maximum values of accelerations are derived from here.
– in the new mechanism

$$W_{н} := y^{в}_{н\max} - y^{в}_{н\min} = 4{,}43 \cdot 10^{-4} - \left(-2{,}20 \cdot 10^{-4}\right) = 6{,}63 \cdot 10^{-4} \text{ m};$$

– in the typical mechanism

$$W_{т} := y^{в}_{т\max} - y^{в}_{т\min} = 18{,}95 \cdot 10^{-4} - \left(-22{,}32 \cdot 10^{-4}\right) = 41{,}27 \cdot 10^{-4} \text{ m};$$

and jerks:
– in the new mechanism

$$P_{н} := y^{p}_{н\max} - y^{p}_{н\min} = 5{,}20 \cdot 10^{-4} - \left(-6{,}14 \cdot 10^{-4}\right) = 11{,}34 \cdot 10^{-4} \text{ m};$$

– in the typical mechanism

$$P_{т} := y^{p}_{т\max} - y^{p}_{т\min} = 59{,}67 \cdot 10^{-4} - \left(-39{,}54 \cdot 10^{-4}\right) = 99{,}21 \cdot 10^{-4} \text{m}.$$

The influence of the force interaction in the system of rack-and-pinion material presser pawl on the transportation quality has been investigated in the works [4, 7]. Significant negative impact on important transportation quality indicators such as material tightening and seating has been identified. This phenomenon is known as "paw bounce," which refers to its detachment from materials during transportation. This, in turn, depends not only on the machine speed but also on the dynamic characteristics of the material handling mechanism.

Since the analysis of mechanisms is comparative, to simplify calculations, we will use the methodology and input data from works [3].

Hence, the vertical displacement of the pressing pawl X_1 can be described by a non-uniform differential equation:

$$X_1 = X_a + X_m + X_1; \tag{1}$$

where:
- X_a is the displacement of the rack above the needle plate;
- X_m is the thickness of the uncompressed materials by the pawl, i.e., under the force F of the previous spring preload with stiffness K_1;
- X_1 is the deformation of materials under the action of the resulting force P;
- k_2 is the equivalent stiffness of materials and kinematic chains of the material handling mechanism.

The solution to the non-uniform differential equation (1) takes the following form:

$$P = A_1 \,cos(kt) + A_2 \,sin(kt) + \frac{B\,sin(\omega(t+t_0))}{k^2-\omega^2} + \frac{A_0}{k_2};$$

Where P is the resultant force acting on the pressing pawl.

$$A_0 = \frac{k_2}{m}\left(F + k_1(X_m + h\,sin(\omega t_0))\right);$$

$$A_1 = F - \frac{A_2}{k^2} - \frac{B\,sin(\omega t)}{k^2-\omega^2}; \qquad A_2 = \frac{hk_2^2\omega\,cos(\omega t_0)}{km(k^2-\omega^2)}$$

$$B = k_2 h\left(\frac{k_1}{m} - \omega^2\right); \qquad k = \frac{\sqrt{k_1+k_2}}{m};$$

Where:

ω is the angular velocity of the main shaft;

ωt_0 is the phase shift;

h is the vertical stroke of the feed dog.

From here, we obtain the equation for the vertical displacement of the presser foot as follows:

$$X_1 = A_1' \,cos(kt) + A_2' \,sin(kt) + B'\,sin\big(\omega(t+t_0)\big) + A_0'; \qquad (2)$$

where $A_1' = -\frac{A_1}{k_2}$; $A_2' = -\frac{A_2}{k_2}$; $B' = h - \frac{B}{k_2(k^2-\omega^2)}$;

$$A_0' = X_м - \frac{A_0}{k_2k^2} - h\,sin(\omega t_0);$$

The moment of detachment of the presser foot from the materials can be described by a homogeneous second-order differential equation, the solution of which, given the known deformation of the presser foot spring and the velocity of the foot at the moment of detachment, takes the form:

$$X_1 = X_0 \,cos(\omega_1 t) + \frac{\dot{X}_0}{\omega_1} sin(\omega_1 t).$$

Taking into account the initial conditions from equation (2):

$$\dot{X}_1 = -kA_1' \,sin(kt) + kA_2' \,cos(kt) + \omega B'\,cos\big(\omega(t+t_0)\big);$$

The value of X_1 is determined for the moment when $X_1 = 0$, or $P = 0$.

After the presser foot returns to the material, its movement will be described by a differential equation of forced oscillations, after which the process repeats.

The values of vertical strokes of the feed dog for typical h_t and new h_n mechanisms are determined in [1] ($h_m = 1{,}74mm$; $h_н = 0{,}50mm$).

The value of the angular velocity ω is determined from the technical specifications of a modern sewing machine ($n = 5000об/хв$;$\omega = 523{,}6c^{-1}$).

The rest of the input data will be taken from the works [3], where:

$F = 29H$; $k_1 = 1{,}03 \cdot 10^3 H/m$; $k_2 = 1{,}225 \cdot 10^5 H/m$; $t_0 = 0$; $m = 0{,}145$kg; $X_m = 0{,}75mm$; $X_a = 1{,}0mm$.

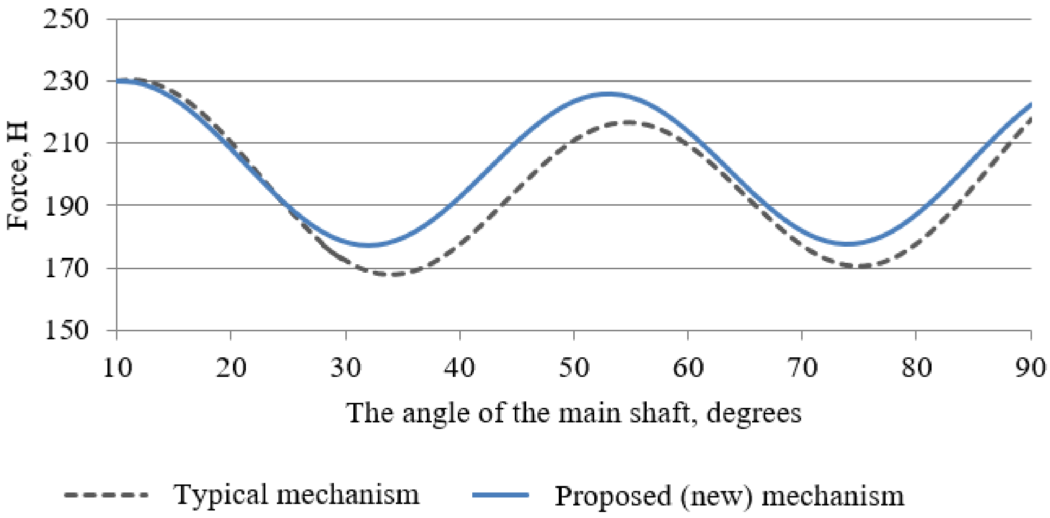

Fig. 3. Combined plots of the resultant force values acting on the foot of the typical and proposed (new) mechanisms

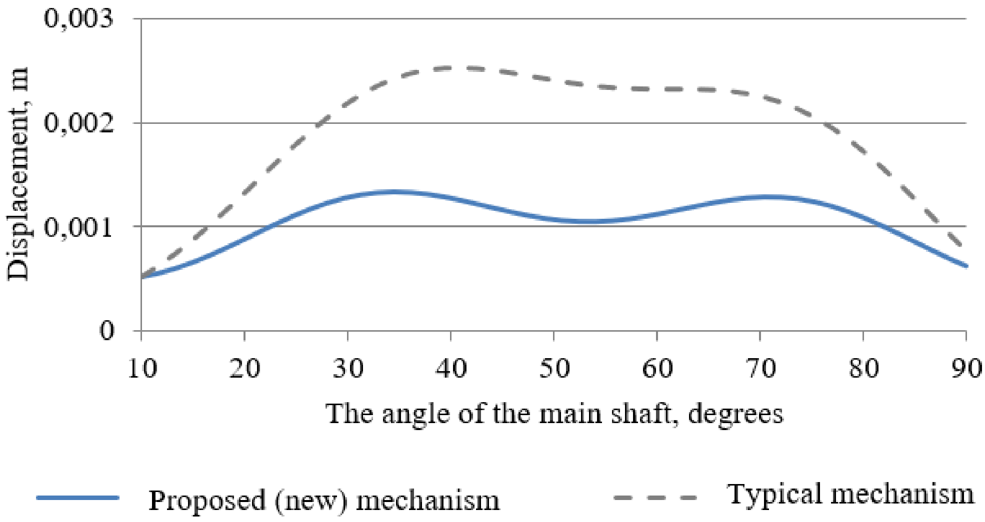

Fig. 4. Combined plots of vertical displacement values of the presser foot of the typical and proposed (new) mechanisms

Analyzing the results, it can be concluded that according to the metric parameters obtained in [1], the proposed new mechanism for material transport has lower indicators of presser foot force amplitude variation and smaller vertical displacement compared to the typical mechanism. This allows eliminating or at least reducing the occurrence of "paw bounce," material tightening, and seating, thereby improving stitch quality.

Conclusions. The obtained limit values of vertical components of position function, velocity, acceleration, and jerk of the working point of the new and typical mechanisms for material transport in sewing machines have determined the values of resultant force and vertical displacement of the feed dog of the new and proposed mechanisms. The influence of force interaction in the system of rack-material-presser foot on material transport quality has been investigated. Further research will focus on obtaining a rational design of multilink mechanisms for material transport using the obtained kinematic and dynamic models.

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