A physico-mechanical approach to analyzing nonlinear elasticity in sewing machine conical springs

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Abstract. This study presents an innovative approach to addressing vibration issues in sewing machines used in the light industry. The research focuses on the experimental analysis of a novel conical spring mechanism designed to enhance shock absorption in the kick mechanism of sewing machines, employing a physico-mechanical approach. This methodology integrates principles from physics and mechanics to provide a nuanced understanding of the spring's nonlinear elasticity and its impact on vibration damping. The study outlines the experimental determination of the oscillation characteristics of the proposed mechanism, offering insights into its effective reaction properties. Comprehensive results of compressive strength and spring elasticity calculations are presented, along with an analysis of dynamic forces using the electrostrain method. This research contributes to the advancement of sewing machine technology by addressing critical vibration issues, potentially leading to improved product quality and increased operational efficiency in the light industry sector. The physico-mechanical approach adopted provides a rigorous foundation for future improvements in sewing machine design and operation.

1 Introduction

The sewing machine, a cornerstone of the light industry, has undergone numerous improvements since its inception to enhance efficiency, precision, and reliability in the production of clothing, footwear, and knitwear. This paper focuses on an experimental analysis of a critical component in modern sewing machines: the conical spring of the kick mechanism, with particular emphasis on its nonlinear elasticity coefficient.

Sewing machines of the 1022 class feature a specialized thread pusher assembly, comprising a screw mounted on the stem, a bushing, and a shaft that passes through an adjustment screw hole [1]. This design aims to dampen vertical vibrations of the clamp shaft, resulting in smoother material movement during sewing, reduced thread breakage, and fewer dropped stitches. However, the existing design has limitations in fully addressing these issues, particularly when dealing with varying fabric thicknesses and structures [2].

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To overcome these challenges, this study proposes an enhancement to the clamping rod assembly and gas pushing mechanism by incorporating an additional conical spring. This modification is expected to significantly improve the machine's performance by providing more effective vibration damping and better adaptation to different sewing conditions.

The behavior of springs can be categorized as either linear or nonlinear. Linear springs follow Hooke's Law, exhibiting a direct proportional relationship between force and displacement. In contrast, nonlinear springs demonstrate a more complex force-displacement relationship, with varying stiffness throughout their range of motion. The conical spring in our study falls into the nonlinear category, necessitating a more sophisticated analysis of its elasticity coefficient.

This paper aims to present the design and working principle of the effective reaction mechanism in the modified sewing machine, determine the formula for calculating the nonlinear component of the uniformity coefficient of the conical spring in the kick mechanism, and analyze the connection graphs to recommend optimal parameters for the drive mechanism.

Our research employs a combination of theoretical analysis and experimental methods. We utilize advanced measurement techniques, including electrostrain methods, to accurately determine the forces acting on the reaction mechanism. This approach allows us to gain a comprehensive understanding of the spring's behavior under various operating conditions [3].

By focusing on the nonlinear aspects of the conical spring's elasticity, this study contributes to the broader field of sewing machine engineering. The insights gained from this research have the potential to significantly enhance the performance of sewing machines, leading to improved product quality, reduced material waste, and increased productivity in the light industry sector.

2 Materials and methods

The invention relates to light industrial equipment, that is, sewing machines used in the production of clothing, shoes and knitwear.

In sewing machines of the universal, the mechanism pressure tap has a trigger in the area of the trigger clip, it is attached by a screw and an adjustment screw to the rod that passes through the upper hole. With the help of screws, the projectile handle is attached to the rod. The upper part of the sturgeon is dressed in a braid, the lower part of which is stretched on the handle of the braid, the upper part is attached to the adjusting screw [4].

The importance of the mechanisms of pushing and pulling of the sewing machine is great in order to create many rows in the sewing machines. The drive mechanisms used in existing sewing machines have a number of disadvantages. In particular, due to the impact force of the toothed rack, there will be insufficient thrust in the drive mechanism due to unbalanced gases. It does not compress the gasses evenly. As a result, the gas pushing steps change, there are cases of thread breaks during the delivery of the yarn [5].

This is especially evident when sewing multi-layer fabrics with different physico-mechanical characteristics. Because multi-layer fabrics with different characteristics are deformed and changed due to the cylindrical spring when the tire is pressed. As a result, the vertical oscillations of the axle also change, causing the gas thrust to change. Therefore, when an additional conical spring is placed, the overall buckling coefficient changes in a non-linear manner and adapts to the ma deformation. As a result, the alignment of the reaction step is ensured.

One of the main parameters in this process is the force of friction between the fabric being sewn. It will be possible to push the fabric in the same step only if the friction force is sufficient. Therefore, it is important to determine the friction force between the fabric and the fabric when using the recommended friction mechanism. At the same time, theoretically determining the linear stiffness coefficient of the additional conical spring and setting the recommended values is considered one of the main issues.

The disadvantage of this design is considered inadequate damping of trigger and sturgeon vibrations that occur when changing the thickness and structure of sewing materials, the impact strength of the rail, as well as inconsistency of rotating elements on the sewing machine.

2.1 Determining the tension of the conical spring of the kick mechanism

Based on the calculation scheme in Figure 1, the weight forces of the rod, stern, and springs are balanced by the inertia forces of the springs in their static state and the inertia forces of the deformed fabric [6]:

$$G_T + G_{ps} + G_{pq} + G_{ct} = P_{St} + P_к + P_м \qquad (1)$$

where, G_T, G_{St} reaction and sturgeon weight; G_{PS}, G_{PQ} -weight of cylindrical and conical springs; P_M -the specified tensile strength of the fabrics being sewn; Elasticity of PS, P_K - cylindrical and springs, i.e. restoring forces [5].

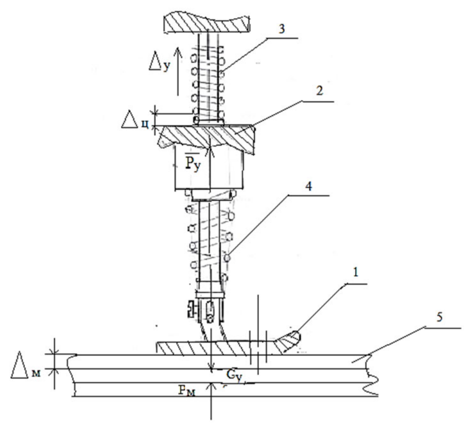

Fig. 1. Calculation scheme of the proposed reaction mechanism with fabric: 1-kick, 2-rod, 3-cylindrical spring, 4-conical spring, 5-fabric.

The forces of inertia of the springs, respectively:

$$P_{St} = C_{St}\cdot\Delta_{St};\; P_{Ks} = C_{к1}\cdot\Delta_к + C_{к2}\cdot\Delta_к^3;\quad P_к = C_м\cdot\Delta_м;\quad \frac{C_{м1}\cdot C_{м2}}{C_{м1}\cdot C_{м2}}\cdot\Delta_м; \qquad (2)$$

where, C_{St}- is the stiffness coefficient of the cylindrical spring; C_{K1}, C_{K2} are linear and non-linear adders of the stiffness coefficient of a conical spring. Δ_{St}, $\Delta_к$-springs corresponding deformation values; C_M-the listed resistance coefficient of the gasses being constructed; Δ_M-fabric deformation value; C_{M1}, C_{M2}-elasticity coefficients of woven fabrics

Putting the obtained (2) into (1), and given the values of the coefficient of inertia of the cylindrical spring and the linear component of the coefficient of inertia of the conical spring, the formula for calculating the values of its nonlinear additive can be obtained:

$$C_{к2} = \left\lfloor g(m_т + m_{St} + m_к + m_{St}) - C_{St}\mathit{\Delta}_{St} - C_{к1}\cdot\mathit{\Delta}_к\cdot\frac{C_{м1}\cdot C_{м2}}{C_{м1}\cdot C_{м2}}\cdot\mathit{\Delta}_м\right\rfloor \qquad (3)$$

The obtained numerical solution of (3) was carried out at the following initial calculation values of the following parameters:

$C_{St}=(0,5\div1,5)\cdot10^3 N/m;$ $C_{P1}= (0.8\div2.0)\cdot\frac{10^2 N}{m}$

$m_m=(1,2\div1,5)\cdot10^{-1}kg;$ $m_{PSt}=(0,65\div0,85)\cdot10^{-1}kg;$

$$m_x=(0{,}8\div1{,}5)\cdot10^{-1}kg; \qquad m_{St}=(3{,}0\div3{,}2)\cdot10^{-1}kg;$$
$$m_x=(0{,}8\div1{,}1)\cdot10^{-1}kg; \qquad m_T=(0{,}8\div1{,}1)\cdot10^{-1}kg;$$
$$\Delta_{St}=0{,}8\div1{,}1)\cdot10^{-3}m; \qquad C_{m1}=C_{m2}=(2.6\div2.8)\cdot10^{-3}N/m;$$
$$\Delta_m=(0{,}4\div1{,}12.8)\cdot10^{-3}m \qquad (4)$$

3 Results and discussion

The quoted values of $\Delta_{St,}$ $\Delta_{K,}$ Δ_M are determined mainly based on the results obtained from the experiment [7].

The spring deformation values are changed by a special screw. It is known [8] that the higher the mass of the axle, rod and springs, the higher the pressure force of the axle on the gas. In this case, it is necessary to increase the elasticity of the springs. Therefore, as a result of the calculations, Figure 2 shows graphs of the dependence of the generalized values of the masses on the value of the non-linear additive of the stiffness coefficient of the conical spring. The analysis of the resulting connections showed that when the total mass of the suspension mechanism increased from 0.15 kg to 0.9 kg, the values of the nonlinear component of the elasticity coefficient of the conical spring were linear from $0{,}12\cdot10^3$N/m to $0{,}26\cdot10^3$N/m, taking into account $C_{K1}=0{,}8\cdot10^3$N/m increases in legitimacy. We can see that the values of SK2 increase from $0{,}58\cdot10^3$N/m to $0{,}14\cdot10^3$ N/m when $C_{K1}=2\cdot10^3$ N/m respectively. The main reason for this is that the deformation of the conical spring increases with the increase in mass. Therefore, it is desirable to make the coefficient of elasticity larger

Therefore, the recommended values of the generalized mass should be less than $(0{,}6\div0{,}75)$ N/m. It is recommended that $C_{K1}=(1{,}2\div1{,}5)\cdot10^3$ N/m.

Figure 3 shows the graphs of the dependence of the law of change of the non-linear component of the stiffness coefficient of the conical spring of the recommended reaction mechanism on the elasticity coefficient of the sewing fabric.

When the elasticity coefficients of the fabrics being sewn are the same, their given values are equal to 0.5 cm, and the values of C_{K2} should be maximized. At 0.2 kg the values of C_{K2} decrease to $0{,}216\cdot10^3$ N/m in a linear connection.

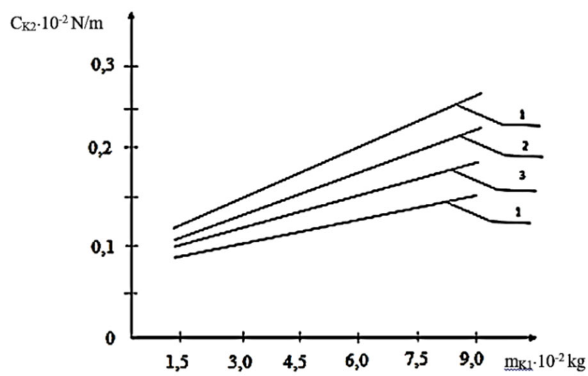

Fig. 2. Graphs of dependence of the law of change of the nonlinear component of the elasticity coefficient of the recommended drive mechanism conical spring on the generalized mass of the drive mechanism: $1-C_{K1}=0.8\cdot\frac{10^2\,N}{m}$; $2-C_{K2}=1.2\cdot\frac{10^{23}\,N}{m}$; $3-C_{K1}=1.6\cdot\frac{10^3\,N}{m}$; $4-C_{K1}=2.0\cdot\frac{10^3\,N}{m}$.

When the generalized mass increases to 0.8 kg, it can be seen that the values of C_{K2} decrease linearly from $0{,}272\cdot10^3$ N/m to $0{,}125\cdot10^3$ N/m. It is recommended that the straps of the fabrics being sewn are close to each other. In this case, it is recommended to take the non-linear component of the elasticity of the conical spring in the range of $(0{,}16\div0{,}21)\cdot10^3$ N/m.

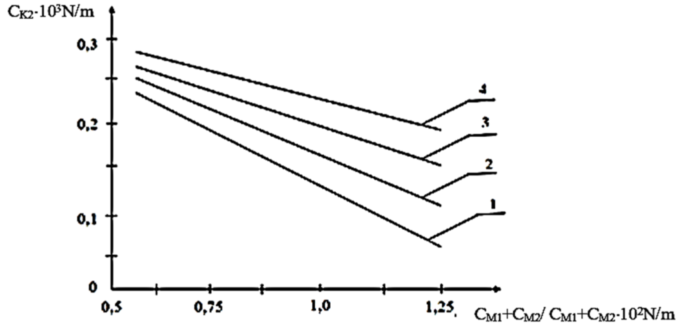

Fig. 3. The graphs of dependence of the given elasticity coefficient of sewing fabrics on the law of change of the nonlinear component of the elasticity coefficient of the recommended reaction mechanism of the conical spring: $1-\mathrm{M_{nel}}=0.2_{\mathrm{x2}}$; $2-\mathrm{M_{nel}}=0.4_{\mathrm{kg}}$; $3-\mathrm{M_{nel}}=0.6_{\mathrm{kg}}$; $4-\mathrm{M_{nel}}=0.8_{\mathrm{kg}}$.

In the mechanism for pushing the sewn material on a sewing machine, the rod is extended to a certain length due to the force of pressure on the material and the movement of the elastic trajectory of the rail.

In this case, it is important that there is sufficient frictional force between the reaction and the crosslinked material. Based on the Amontons-Coulomb law, the frictional force between flat points is determined by the following expression:

$$F_{fric.}=fN \tag{5}$$

where N is the total compressive force, ƒ is the coefficient of friction between the surfaces being stitched.

Between the spring and the material, the following forces mainly act in the directions of the total compressive force, the weight of the spring, springs and stern, the elastic recovery forces as a result of the deformation of the springs and the force of recovery of the spring. deformation of materials mainly under the action of the total pressure:

$$N=\mathrm{G_{tot.lo.}}-\mathrm{P_{TS}}-\mathrm{P_K}-\mathrm{P_{M;}} \tag{6}$$

Taking into account the above equation (5), we will compose an equation for determining the friction force:

$$\mathrm{F_{fric.}}=f\left[g(\mathrm{m_T}+\mathrm{m_{ts}}+\mathrm{m_K}+\mathrm{m_{st}})-\mathrm{C_{TS}}\Delta_{\mathrm{TS}}-\mathrm{C_{K1}}\Delta_{\mathrm{K^3}}-\frac{\mathrm{C_{M1}}\cdot\mathrm{C_{M2}}}{\mathrm{C_{M1}}+\mathrm{C_{M2}}}\right] \tag{7}$$

When calculating the calculated values of the friction force, the above calculated values of the parameters were taken into account and connection graphs were constructed.

Figure 4 shows the graphs of the dependence of the friction force between the sewing machine pusher and the pushed material on the unit force of the conical spring.

Based on the analysis of the obtained graphs, it should be noted that with an increase in the total specific force of the traction mechanism from 5.0 N to 30.0 N and a friction coefficient of 0.2, the friction values vary are from $0.52\cdot10^3$ N/m to $0.145\cdot10^3$ N/m a nonlinear increase was observed.

Therefore, with an increase in the strength of the unit, the friction force between the tire and the sewn material also increases. Accordingly, with a friction coefficient of 0.35, it can be determined that the Friction values increase from $0.11\cdot10^3$ N/m to $0.29\cdot10^3$ N/m with a nonlinear relationship. It is known that if the pressure force on the sewn material is too great, this will damage the material [9].

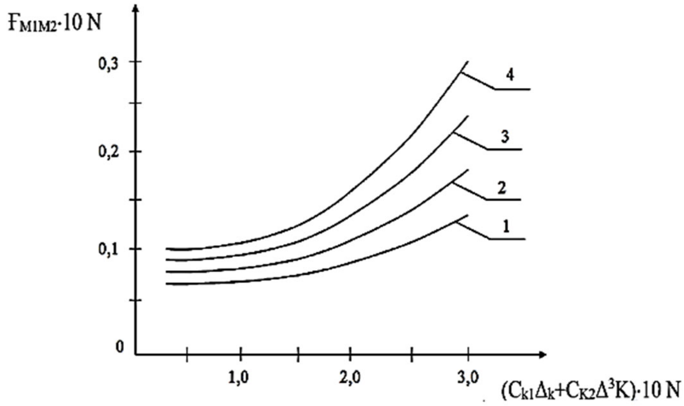

Fig. 4. Graphs of the dependence of the friction force between the pusher of the sewing machine and the pushed material on the unit force of the conical spring: 1*f*=0.2; 2-*f*-0.25; 3-*f*=0.3; 4-*f*=0.35.

4 Conclusion

An effective structural scheme of the sewing machine drive mechanism has been developed. The formula for calculating the non-linear component of the elasticity coefficient of the conical spring of the kick mechanism has been determined. Based on the analysis, the optimal values of the parameters were determined.

The formula for determining the uniformity of the conical spring adjusting the recommended drive mechanism of the sewing machine was obtained, the graphs of the relationship of the law of change of the nonlinear component of the uniformity coefficient to the generalized mass of the drive mechanism were constructed.

The graphs of the dependence of the specified material homogeneity coefficient of sewing materials are constructed. It is recommended to place pieces of the sewn material close to each other, plaster. In this case, it is recommended to take the nonlinear component of the stiffness of the conical spring in the range of $(0.16\div0.21)\cdot10^3$ N/m.

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