RESEARCH OF THE INFLUENCE OF THE TREATMENT PROCESS OF THREE-CONE PACKING ON CRITICAL SPEEDS OF BOBBIN HOLDER OF THE WINDING MACHINE

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Abstract: *The algorithm of critical speeds calculation of the winding mechanism with the account of three-cone packing was presented in the work. Computer simulation of the bobbin holder critical speeds of the winding mechanism in the process of packing is carried out. Dependences of change of critical speeds on the thickness of the packing and the angles of the generators inclination were obtained. Recommendations for designing new designs of winding mechanisms are given. The practical importance of the work is to determine the working speed of the equipment for rewinding threads, improving productivity, product quality. The use of the results obtained in the design and dynamic study accelerate the design process of rewinding equipment. The results are aimed at intensifying the rewinding and winding processes in the light industry.*

Keywords: *bobbin, critical winding speeds, bobbin holder, resonance, winding mechanism.*

1 INTRODUCTION

In today's realities, for the rapid pace of development of textile goods industrial production, there is a need to carry out on a large-scale research, design and practical work on the creation of new and improved equipment.

Textile processing plays a major role in the rewinding of yarns at the packaging level. Bobbin holders are intended for placement, alignment, retention of the thread carrier and transfer to it of rotation, which are applied on molding, reeling-exhausting, winding machines, rewinding machines, machines for receiving textured threads.

The rewinding process is one of the main stages of preparing the yarn, or yarn, for further processing. During rewinding, the quality of the thread obtained is monitored, different levels and densities of the packing length are developed, which requires increasing a number of requirements, especially with the introduction of new high-speed methods and mechanisms for producing the filaments. Therefore, a large number of light industry enterprises are equipped with cross-winding machines and automatic machines [1-3]. Along with rewinding machines, a similar design of the winding mechanism is used in winding machines [3]. Rewinders are very widely used in the weaving industry, in knitwear, ribbon. During operation of the winding mechanisms, there are a number of problems; the main is to limit the speed of rewinding, which leads to a decrease in equipment performance.

Increasing the speed of rewinding threads requires an increase in the spindle speed, which makes it necessary to calculate and analyze its critical speeds. Increasing the spindle speed is accompanied by an increase in the mechanism's vibration activity, which is important to take into account when upgrading the equipment and developing a new one [4], which also helps to reduce costs at the design stage. In this regard, there is a need to perform the simulation of winding processes on rewinding machines in order to analyze the critical spindle speeds. In [5, 6] the authors considered the dynamics of the movement of the thread and the winding drum, but did not pay attention to the oscillations of the winding mechanism. The conditions of thread movement are considered in detail. However, the critical speeds of the winding mechanism that affect the performance of the rewinding machine have not been determined.

Setting objectives. The purpose of the study is to develop an algorithm for calculating the critical and operating speeds of winding mechanisms of rewinding machines. Also, providing recommendations for improving the operating speed of equipment and the ability to use the results obtained in the design and dynamic study of rewinding equipment.

Objects and methods of research. The object of the study is the process of rewinding the bobbin thread. The subject of the study is the critical speed of the winding mechanisms. The known methods of analysis of natural frequencies of oscillations of spindles are applied in the work. The semi-rigid spindle method is based on the assumption that only the bobbin holder shaft is resilient, and the bobbin holder itself is considered to be absolutely rigid.

2 THEORETICAL SUBSTANTIATION

When designing high-speed winding mechanisms for winding textile threads on a bobbin, the values of the oscillation frequency and critical speed parameters that limit the range of working speeds of the rotors of the mechanisms are required.

One of the technical solutions is the use of a flexible shaft and the use of elastic supports in rewinding machines [4], which provides the necessary position of the range of operating speeds of equipment relative to critical speeds.

When calculating the critical velocities of bobbin holders, which have non-cylindrical elements in their composition, leads to significant errors in the calculation of the inertial parameters of the moving masses [4].

For practical calculations of the critical speeds of the winding mechanisms of textile machines, the method of "Semi-rigid spindle" is most widely used, which makes it possible to obtain two critical speeds of the winding rotor with an error not exceeding 10% [4, 7].

To determine the inertial parameters of the mandrel of the bobbin holder, it is divided into a number of simple elements *Mi* (cylindrical and conical shape). Thereby, the bobbin holder of the winding mechanism is formed by two conical elements (the bobbin locking mechanism, a conical thread carrier and a three-conical packing).

To simplify the calculation process and uniquely designate geometric parameters, all elements are considered conical. The appearance of the conical element and the designation of its main dimensions are shown in Figure 1.

The element on the plane is determined by the coordinates of the beginning and end of the element from the front support of the bobbin holder, *hci* - the coordinate of the position of the center of mass of the i-th element; *ri, rvi, Ri, Rvi* - the radii of a conic and i-th element.

In order to determine the effect of packing mass in the process of its accumulation on the critical velocity values, it is necessary to determine the mass-inertial parameters of the packing as a function of the thickness of the packing body.

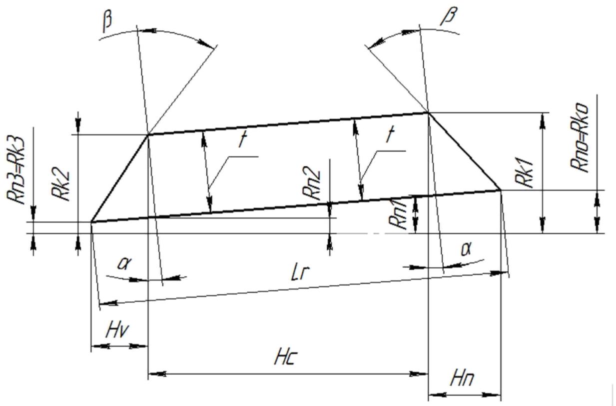

Figure 1 Geometric parameters of the packing section: *Rno, Rn1, Rn2, Rn3* - the inner radii of cones; *Rko, Rk1, Rk2, Rk3* - the outer radii of the cones; α - the angle of the cone of packing; β - the winding angle; t - is the thickness of the winding body; Lr - length of layout; *Hv, Hc, Hn* - the lengths of the upper, middle and lower sections of the packing respectively.

The relationship between the geometric dimensions of the package and the thickness of the winding body is determined by the ratios:

- length of packing areas [m]:

$$H_n = t \cdot (tg\alpha + tg\beta) \cdot \cos\alpha$$
$$H_v = t \cdot (tg\beta - tg\alpha) \cdot \cos\alpha \qquad (1)$$
$$H_c = Lr \cdot \cos\alpha - H_v - H_n$$

- packing cones radii [m]:

$$R_{n1} = R_{n0} - H_n \cdot tg\alpha$$
$$R_{k1} = R_{n1} + \frac{t}{\cos\alpha}$$
$$R_{n3} = R_{n0} - Lr \cdot \sin\alpha$$
$$R_{k3} = R_{n3} \qquad (2)$$
$$R_{k2} = R_{n3} + \frac{H_v}{tg(\beta - \alpha)}$$
$$R_{n2} = R_{k2} - \frac{t}{\cos\alpha}$$

- distance from the support to the items received [m]:

$$H_1 = H_0 + H_n$$
$$H_2 = H_1 + H_c \qquad (3)$$
$$H_3 = H_2 + H_v$$

Taking into account the parameters of the elements and dependencies (2, 3), the inertial parameters of the bobbin holder and the packing are determined from [8, 9]:

- is the volume of the i-th element of the bobbin holder Vi [m^3]:

$$V_i = \frac{\pi}{3}\cdot(X_{ki} - X_{ni})\cdot\begin{bmatrix}\left[(R_i)^2 - (R_{vi})^2\right] + \\ + (R_i \cdot r_i - R_{vi}\cdot r_{vi}) + \left[(r_i)^2 - (r_{vi})^2\right]\end{bmatrix} \quad (4)$$

- mass of the bobbin holder Mo [kg]:

$$M_o = \sum_i V_i \cdot \rho_i \quad (5)$$

where ρi - the density of the material of the element.

- the coordinate of the position of the center of mass of the i-th element of the bobbin holder hci support [m]:

$$h_{ci} = \frac{\pi}{12}\cdot\frac{(X_{ki} - X_{ni})^2}{V_i}\cdot\begin{bmatrix}3\left[(R_i)^2 - (R_{vi})^2\right] + \\ + 2(R_i \cdot r_i - R_{vi}\cdot r_{vi}) + \\ + \left[(r_i)^2 - (r_{vi})^2\right]\end{bmatrix} \quad (6)$$

- the coordinate of the position of the center of mass of the i-th element relative to the Xci support [m]:

$$X_{ci} = X_{ki} - h_{ci} \quad (7)$$

- polar moment of inertia of the coil holder Co [kg.m^2]:

$$C_o = \sum_i \frac{\pi}{10}\cdot M_i \cdot\frac{(X_{ki} - X_{ni})}{V_i}\cdot\begin{bmatrix}R_i\cdot(R_i + r_i)\times \\ \times\left[(R_i)^2 + (r_i)^2\right] + \\ + \left[(r_i)^4 - (r_{vi})^4\right] - \\ - R_{vi}\cdot(R_{vi} + r_{vi})\times \\ \times\left[(R_{vi})^2 + (r_{vi})^2\right]\end{bmatrix} \quad (8)$$

where - Mi is the mass of the i-th element of the bobbin holder.

- moment of inertia of the element of the bobbin holder Ac [kg.m^2]:

$$A_c = \frac{1}{2}\cdot C_o + \sum_i M_i \cdot\begin{bmatrix}\frac{\pi}{30}\cdot\frac{(X_{ki} - X_{ni})^3}{V_i}\times \\ \times\begin{bmatrix}6\left[(R_i)^2 - (R_{vi})^2\right] + \\ + 3(R_i \cdot r_i - R_{vi}\cdot r_{vi}) + \\ + \left[(r_i)^2 - (r_{vi})^2\right]\end{bmatrix} - \\ - (h_{ci})^2 \\ \end{bmatrix} \quad (9)$$

- coordinate position of the mass center of the bobbin holder Hcm [m]:

$$H_{cm} = \frac{\sum_i M_i \cdot X_{ci}}{M_o} \quad (10)$$

- the equatorial moment of inertia of the bobbin holder Ao [kg.m^2]:

$$A_o = A_c + \sum_i M_i \cdot (H_{cm} - h_{ci})^2 \quad (11)$$

Impact coefficients are determined similarly [2, 4, 10]:

$$\delta_{11} = \frac{l_1 \cdot H_{cm}^2}{3E\cdot I_1} + \frac{a^2\cdot(l_5 + 3l_3) + l_3^2\cdot(l_3 + 3a)}{3E\cdot I_2}$$

$$\delta_{12} = \frac{l_1 \cdot H_{cm}}{3E\cdot I_1} + \frac{2a\cdot(l_5 + 3l_3) + 3l_3^2}{6E\cdot I_2} \quad (12)$$

$$\delta_{22} = \frac{l_1}{3E\cdot I_1} + \frac{l_5 + 3l_3}{3E\cdot I_2}$$

where l_1 - the length between the supports [m]; Hcm – the length from the front support to the center of mass [m]; $l3$ - the distance from the front support to the rear cone [m]; $l5$ - the distance between the front and rear cones [m]; E - modulus of elasticity (for Steel 45 E = 2 × 1011 N/m^2); a - the distance between the rear cone of the bobbin holder and its center of mass.

$$a = H_{cm} - l_3 \quad (13)$$

The mathematical model of free oscillations of the bobbin holder with supports has the following form [4, 7, 11, 12]:

$$\begin{cases} M\ddot{\eta} + m_{1\eta}\eta - m_{2\eta}\alpha = 0, \\ M\ddot{\zeta} + m_{1\zeta}\zeta - m_{2\zeta}\beta = 0, \\ A\ddot{\alpha} + C\dot{\beta}\cdot\omega - m_{2\eta}\eta + m_{3\eta}\alpha = 0, \\ A\ddot{\beta} - C\omega\cdot\dot{\alpha} - m_{2\zeta}\zeta + m_{3\zeta}\beta = 0. \end{cases} \quad (14)$$

where - M, A, C- inertial parameters of the bobbin holder; $\varphi, \eta, \zeta, \alpha, \beta$ - generalized coordinates [4]; $m_{1\eta}$, $m_{2\eta}$, $m_{3\eta}$, $m_{1\zeta}$, $m_{2\zeta}$, $m_{3\zeta}$ - coefficients of rigidity of the mechanical system in the horizontal and vertical directions.

3 THE SOLVING OF THE PROBLEM

The critical velocities based on the expressions given in [4] are determined from the problem on the natural vibrational frequencies with the matrix:

$$(M - iC)\bar{x} = \lambda K\bar{x} \quad (15)$$

where $\lambda = 1/\omega^2$, M - the matrix of inertial coefficients; C - the matrix of gyroscopic coefficients; K - the stiffness matrix.

Finding the values of the self-oscillations leads to the solution of the standard problem:

$$A\bar{y} = \lambda\bar{y} \quad (16)$$

Matrix of inertial coefficients:

$$M = diag(M_0, M_0, A_0, A_0) \quad (17)$$

The stiffness and gyroscopic coefficient matrices have the following form:

$$K = \begin{vmatrix} m_{1x} & 0 & -m_{2x} & 0 \\ 0 & m_{1y} & 0 & -m_{2y} \\ -m_{2x} & 0_1 & m_{3x} & 0 \\ 0 & -m_{2y} & 0 & m_{3y} \end{vmatrix}$$

$$C = \begin{vmatrix} 0000 \\ 0000 \\ 000C \\ 00C0 \end{vmatrix} \qquad (18)$$

Substituting the input parameters and taking [13] into the program, the values of the critical velocities are given, which are given in Table 1.

Table 1 The values of the critical velocities

Marking		Critical speed values [rad/s]
During the start of the winding process	ω1 [s $^{-1}$]	683
	ω2 [s $^{-1}$]	7064
During the winding process	ω1 [s $^{-1}$]	334
	ω2 [s $^{-1}$]	5116

The value of the reduction of the first critical velocity in the packing process ranges from 683 rad/s to 334 rad/s. The value of the reduction of the second critical speed in the packing process is from 7064 rad/s to 5116 rad/s and is of no practical importance. The area of the working range of the winding speed of the filament must be up to the first critical speed, which ensures the receipt of quality packaging, uninterrupted operation of the winding mechanism.

The upper limit of the first operating angular velocity of the bobbin holder ω_p is defined by the following expression [10]:

$$\omega_p = 0.7 \cdot \omega_1$$

$$\omega_p = 0.7 \cdot 683 = 478\ s^{-1} \qquad (19)$$

The maximum speed of the rewinding speed of the thread V [m/s]:

$$V = \omega_1 \cdot Rnc \qquad (20)$$

where - Rnc is the average radius of conical packing [m] (for the machine BP-340 $Rnc = 0.031$ m).

$V = 478 \cdot 0.031 = 14.8$ *m/s.*

The results of modeling the dependence of the first critical velocity on the thickness of the winding body are presented graphically in Figure 2. Figure 3 shows the dependence of the first critical speed on the thickness of the winding body at different winding angles.

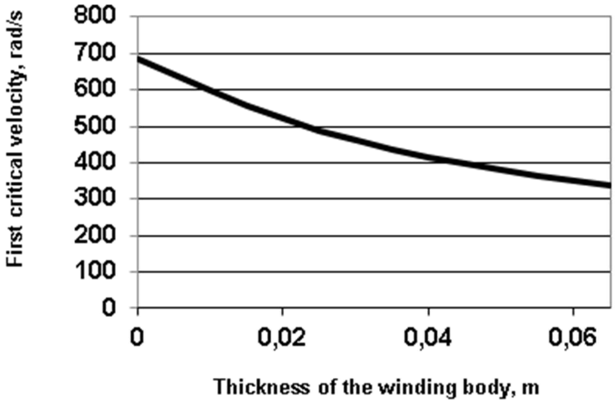

Figure 2 Dependence of the first critical velocity on the thickness of the winding body

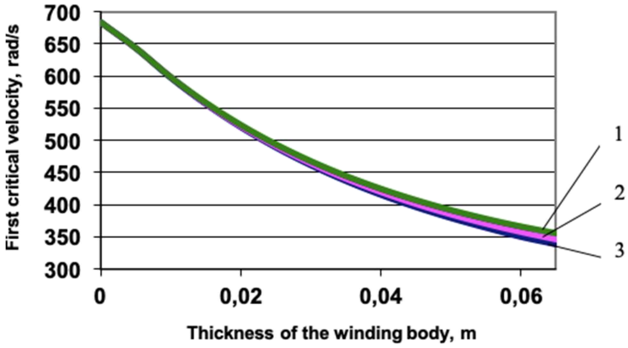

Figure 3 Dependence of the first critical velocity on the thickness of the winding body at different winding angles, 1 - 45°; 2 - 40°; 3 - 35°

The maximum speed of rewinding of threads for nylon fibers, achieved at the production, is 10.6 m/s [14].

The calculation shows that the working area of the bobbin holder is limited to the top angular speed of 478 rad/s. According to Figure 3, the value of the critical velocity changes with the change in the winding angle. This is due primarily to the change in the mass-inertia parameters of the packing and the design of the bobbin holder in general.

In order to facilitate the transition from the critical region to the working area of the speed of the bobbin holder, it is confirmed the expediency of using elastic supports of fastening of the spindle of the bobbin holder, which allows to increase the value of critical speeds, as well as to facilitate the transition through the critical speeds of rotation [10]. It is advisable to use an elastic shaft when designing winding mechanisms.

4 CONCLUSIONS

The method of calculation of the critical speeds of the winding mechanism with three-conical packing is presented in the work, the critical speeds of the process of winding the thread on the example of the BP-340 machine are determined. The analysis of the obtained results showed the possibility of increasing the operating speed of the equipment by 28%. The above calculation method allows to obtain the necessary results of critical velocity values by varying the materials of individual parts at the design stage, which facilitates the design stages of typical equipment.

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