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Determination of the critical rotation speed of the saw cylinder of a linting machine

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Abstract. The critical rotation speed of the saw cylinder of a linting machine is examined in the article in the form of a differential equation of the bent shaft. As a result, it was determined that at an increase in the distributed load from the seed roller from 0 to 42 kg/m, the critical rotation speed decreases from 335.784 to 277.761 rad/s (by 18.0%). With a known load of the seed roller m_l = 34.246 kg/m, at an increase in the bending stiffness of the saw blade shaft EJ_x from 100,000 to 1,000,000 $N·m^2$, the critical rotation speed decreases from 287.285 to 90.847 rad/s (by 65.8%). It was established that the rotation speed of the saw cylinder of a linting machine is in the first subcritical zone ($\omega_p \leq 0.75 \cdot \omega_{кр}$ – a stiff shaft) 76.44 rad/s≤ (251.84-208.32) rad/s.

1 Introduction

In a linter machine, the parts of the working chamber (mainly, its main unit - the saw cylinder) are under significant force pressure from external loads [1, 2].

To determine the critical speed of the saw cylinder, the methods of A.N. Krylov, A.I. Makarov, I.Ya. Korityssky, M.Ya. Kushul, Rayleigh; methods of successive approximations; method of initial parameters in matrix form, etc. were used. In [3 - 5], it was shown that the determination of critical speed is reduced to solving the problem of determining the eigenfrequencies of oscillations.

In [6], the finite element method (FEM) was used to reduce analytical calculations when determining the critical rotation speed of the saw cylinder of saw gins.

Determination of the critical speeds of the saw cylinder of a linting machine allows for the assessment of the danger of the operating speed approaching the critical one.

2 Materials and methods

Since we have proposed a new design of inter-saw spacers [7], then for $\omega_p=\omega_{cr}$ the shaft deflections and the load on the bearings can increase indefinitely, although this does not happen due to the limited deflections of pinching the shaft in the bearings, the presence of

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friction forces and external loads. When designing high-speed shafts, it is necessary to account for the danger of their operating speeds approaching critical ones, therefore, for shaft speeds below the first critical one, the following ratio is recommended: $\omega_p \le (0{,}75\text{-}0{,}8)\cdot\omega_{cr}$. In the interval between the first and second critical speeds the ratio is $1{,}4\cdot\omega_{1cr} \le \omega_p \le 0{,}8\cdot\omega_{2cr}$. When working in the first subcritical speed zone, the shafts are called stiff, and when working in the zone after the first critical speed, they are called flexible [8].

The goal is to determine the critical rotation speed of the saw cylinder of a linting machine ω_{cr} (D=320 mm is the diameter of the saw disks, d=61.8 mm is the diameter of the saw shaft, considering the load from the seed roller (an ideal incompressible fluid, Figure 1).

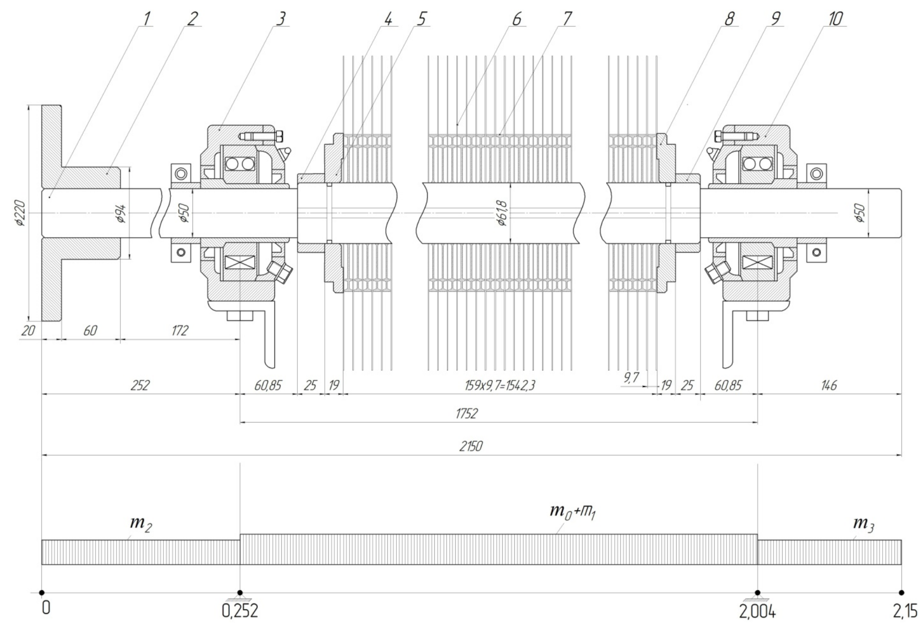

Fig. 1. Assembly drawing and diagram of loads acting on the saw cylinder of the linting machine: 1 – Shaft, 2 – Half coupling; 3, 10 – Bearing housing; 4, 9 – Nuts; 5, 8 – Washers; 6 – Saw disks, 7 – Spacers.

The mass of the seed roller per unit length of the saw cylinder of the linting machine m_1, the mass of the unit length of the saw cylinder m_0, (shaft, spacers, and saw cylinders) bending stiffness of the shaft EJ_x. Coriolis forces of inertia of seeds are ignored due to their smallness.

Uniformly distributed loads are:

m_1=91.021 kg/m; m_0=34.246 kg/m; m_2=47.174 kg/m; m_3=15.413 kg/m.

In the state deviated from the rectilinear equilibrium position, each unit of length of the saw cylinder of the linting machine is affected by the inertial force caused by the rotation of the saw cylinder with the seed roller, equal to $(m_0+m_1)\cdot\omega^2\cdot y$, and the centrifugal inertial force from the rotating seed roller caused by the curvature saw cylinder $m_1\cdot v^2/\rho = -\, m_1\cdot v^2\cdot y''$ (Figure 2) (the minus sign is determined by the curvature sign).

Let us present the differential equation of the curved axis of the saw cylinder shaft in the following form:

$$EJ_x\cdot y^{IV} = (m_0+m_1)\cdot\omega^2\cdot y - m_1\cdot v^2\cdot y'' \tag{1}$$

or

$$y^{IV} + k_1^2\cdot y'' - k_2^4\cdot y = 0.$$

where

$k_1^2 = m_1 \cdot v^2/(EJ_x)$, $k_2^4 = (m_0+m_1)\cdot\omega^2/(EJ_x)$.

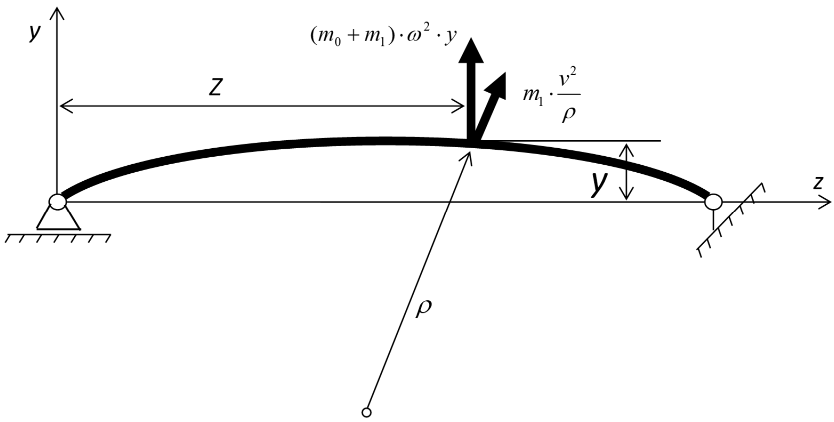

Fig. 2. Design diagram of the saw cylinder of a linting machine.

The characteristic equation for Eq. (1) has the following form:

$$\lambda^4 + k_1^2\cdot\lambda^2 - k_2^4 = 0, \tag{2}$$

hence

$$\lambda_{1,2} = \pm i\cdot\sqrt{(k_1^2 + \sqrt{k_1^4 + 4\cdot k_2^4})/2}; \tag{3}$$

$$\lambda_{3,4} = \pm\sqrt{(\sqrt{k_1^4 + 4\cdot k_2^4} - k_1^2)/2}. \tag{4}$$

We obtain the solution to Eq. (1) in the followinf form:

$$y = C_1\cdot sin(\lambda_1\cdot z) + C_2\cdot cos(\lambda_2\cdot z) + C_3\cdot sh(\lambda_3\cdot z) + C_4\cdot ch(\lambda_4\cdot z). \tag{5}$$

To determine the integration constants C_1, C_2, C_3, C_4 , we have the following conditions:
for $z=0$ $y=0$ and $y''=0$;
for $z=l$ $y=0$ and $y''=0$.

To determine the critical rotation speed ω_{cr} of the saw cylinder, we obtain the following equation:

$$sin(\lambda_1\cdot l)\cdot sh(\lambda_3\cdot l) = 0. \tag{6}$$

The left-hand side of equation (6) is zero in the following cases:

- $\lambda_3=0$, i.e. for $\omega=0$; $(\lambda_1\cdot l) = k\cdot\pi$.

For $k=1$, i.e. $(\lambda_1\cdot l) = \pi$, we obtain the value of the critical rotation speed:

$$\omega_{кр} = \sqrt{\frac{\pi^4 EJ_x}{l^4(m_o + m_1)} - \frac{\pi^2 m v^2}{l^2(m_o + m_1)}} \tag{7}$$

3 Results and discussion

Considering the values of l=1.752 m; (m_0+m_1)=125.267 kg/m; (EJ_x) = 992657.998 N·m^2 and substituting into (7), we determine the pattern of variations in the critical speed ω_{cr} of the saw cylinder of the linting machine depending on the mass of the seed roller m_1 and the bending stiffness of the shaft of the saw cylinder of a linting machine EJ_x (Figure 4).

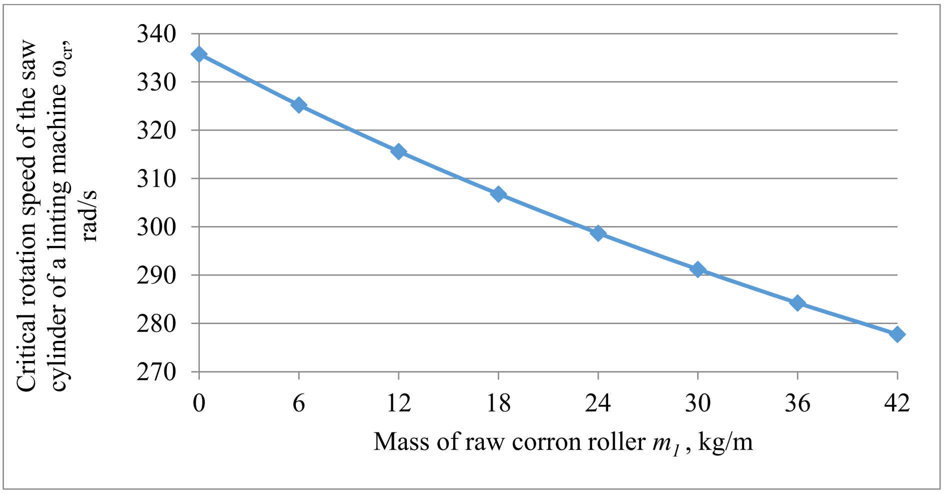

Fig. 3. Variation in the critical speed of the saw cylinder of a linting machine ω_{cr} depending on the mass of the seed roller m_{1}.

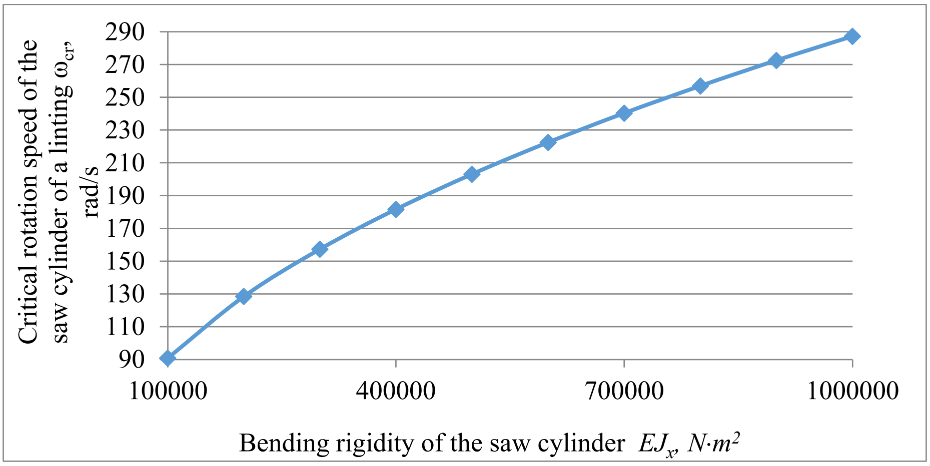

Fig. 4. Variation in the critical speed of the saw cylinder of a linting machine ω_{cr} depending on the bending stiffness of the saw blade EJ_x.

4 Conclusion

Analysis of equation (7) and Fig. 3 showed that at an increase in the mass of the seed roller per unit length of the saw cylinder of a linting machine from 0 to 42 kg/m, the critical rotation speed decreases from 335.784 to 277.761 rad/s (by 18.0%).

Analysis of equation (7) and Fig. 4 showed that at m_1 = 34.246 kg/m, at an increase in the bending stiffness of the saw cylinder shaft EJ_x from 100,000 to 1,000,000 N·m^2, the critical rotation speed decreases from 287.285 to 90.847 rad/s (by 65.8%).

Considering the load from the seed roller, the rotation speed of the 160-saw cylinder of the linting machine is in the first subcritical zone ($\omega_p \leq 0.75 \cdot \omega_{1cr}$ – a stiff shaft) 76.44 rad/s ≤ (251.84-208.32) rad/s.

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