Vessel ellipticity and eccentricity effect on automatic balancing accuracy

Evgeny N. Pashkov[1], **Nikita V. Martyushev, Igor A. Masson**
Tomsk Polytechnic University, 30, Lenina av., Tomsk, 634050, Russia

E-mail: epashkov@tpu.ru, martjushev@tpu.ru, massoni@sibmail.com

Abstract. The article investigates rotor spinning with a liquid layer on the chamber wall during a visco-elastic shaft operation within the framework of two-dimensional model. The outcomes of the mathematical analysis and trial runs on the stated subject-matter are provided. The article considers the influence of external friction forces and external torque on rotor spinning with the liquid auto- balancing device, located around vertical axis. As a result of the study, the dependencies of shaft bending, system disbalance, torque at a preset shaft angular velocity on the ratio of the reduced mass and rotor mass and external friction forces have been specified. In addition, the dependence, allowing calculation of the angular velocity, when the shaft "sticking" is possible in case of insufficient engine power, has been obtained.

1. Introduction

This article investigates the rotor spinning with a liquid layer, being on the chamber wall, at a visco-elastic shaft operation within the framework of two-dimensional model. It is assumed that the border of the independent liquid layer represents the circle with its centre on the rotation axis, and the liquid itself is spinning along with the rotor as a solid body.

2. Materials and Methods

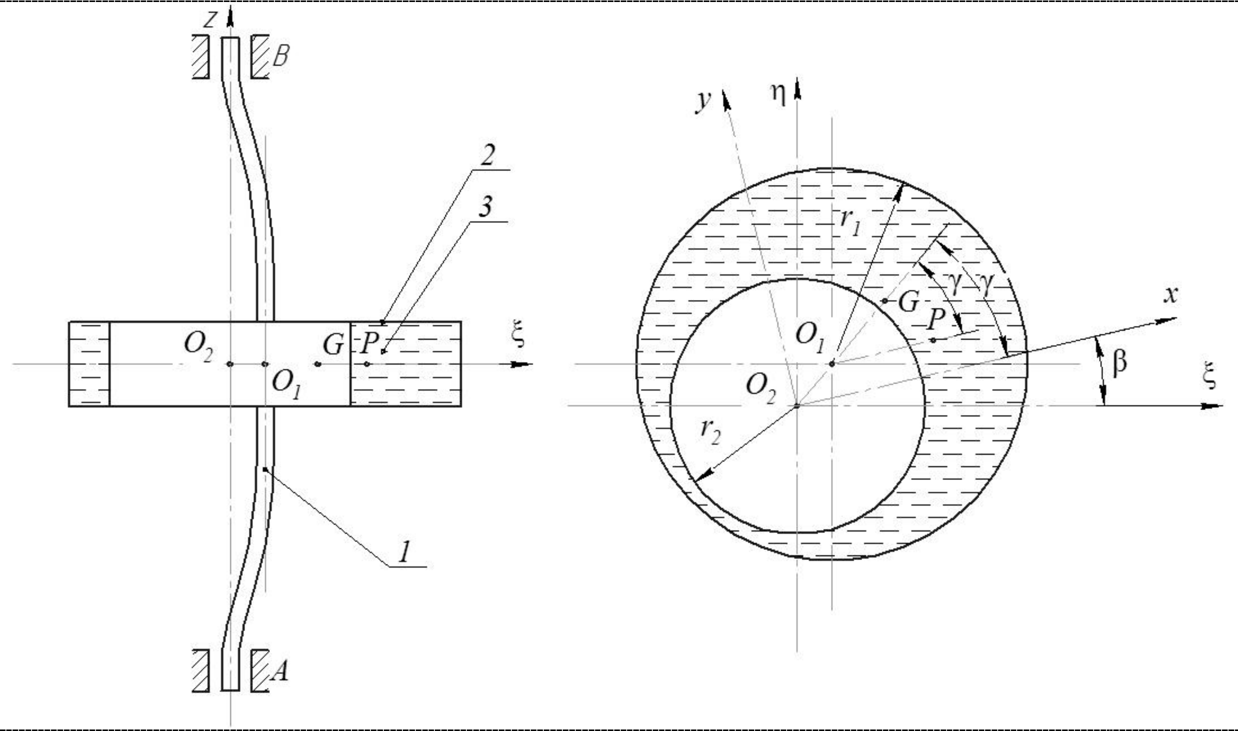
In the previous works [1, 2] a steady motion of the out-of-balance rotor with liquid at presence of external resistance was discussed. It appears from these works that at a stationary motion the liquid, placed in a correction chamber, spins along with the rotor as a solid body. But this article considers the influence of external friction forces and external torque on the rotor spinning with liquid auto-balancing device around the vertical axis.

3. Results

We specify the torque M, applied to the shaft from the side of the engine, from the equilibrium equation of all the torques relatively AB axis (see figure 1, 2).

$$M = O_2O_1 \cdot \chi V_{O_1} = \chi a^2 \omega = \chi\omega(x^2 + y^2) \qquad (1)$$

[1] To whom any correspondence should be addressed.



a b

Figure 1. a – Rotor mounting diagram; b – Section of the rotor with a liquid

Complementing the calculations, carried out in [3-5], with equation 1, we can calculate the shaft bending $a = \sqrt{x^2 + y^2}$; system disbalance $d = (m_1 + m_2) \cdot r_c$; torque M in the following way:

$$a = \frac{ez}{\sqrt{D(\mu_1)}}; \quad d = \frac{m_1 e\sqrt{1+nz}}{\sqrt{D(\mu_1)}}; \quad M = \frac{e^2 z^2 c\sqrt{nz}}{D(\mu_1)};$$

$$D(\mu_1) = (1 - \mu_1 z)^2 + nz. \tag{2}$$

Here $\mu_1 = m / m_1$ is the ratio of the system reduced mass to the rotor mass.

To compare the motion of the rotor with liquid (ABD) and without it, let us consider the following ratios:

$$\frac{a}{a_1} = \frac{d}{d_1} = \sqrt{\frac{D(1)}{D(\mu_1)}}; \qquad \frac{M}{M_1} = \frac{D(1)}{D(\mu_1)}, \tag{3}$$

where a_1, d_1, M_1 are the shaft bending, disbalance, torque correspondingly, obtained from (2), when μ_1=1, during rotor motion without balancing liquid.

Phase-shift angle of motion γ is specified by the formula

$$tg\gamma = y/x = -\frac{\chi\omega}{c - m\omega^2} = -\frac{\sqrt{nz}}{1-\mu_1 z} \quad (4)$$

In case of liquid absence, that is, when μ_1=1, this equation coincides with the similar equation in [6]. The ratio of shaft bendings a/a_1, when n =0, coincides with the corresponding value, obtained for spinning without friction forces in [7].

From formulas (1–4) it follows that when $\omega\to\infty$ ($z\to\infty$), $a\to m_1e/m$, that is, the shaft bending becomes less than out-of-balance condition e, as $m_1/(m_1+rm_2)<1$; $r_c\to 0$, $\gamma\to\pi$, $x\to -m_1e/m$, $y\to 0$; the coordinates of rotor mass centres and the liquid layer obtain the following values: $x_p=rm_2e/m$, $y_p=0$ и $x_G=-rm_1e/m$, $y_G=0$; $d\to 0$; $M\to\infty$. Thus, in case of large ω values, the centre of system masses tends to take a position on rotation axis *AB,* and the system aligning occurs [8, 9].

Since $D(1) < D(\mu_1)$ when $z > 2/(1+\mu_1)$, according to (2), liquid ABD lessens the bending and system disbalance in comparison with the rotor without liqu id, having rotating frequencies, which are higher than $\omega = \sqrt{2/(1+\mu_1)\omega_0^2}$.

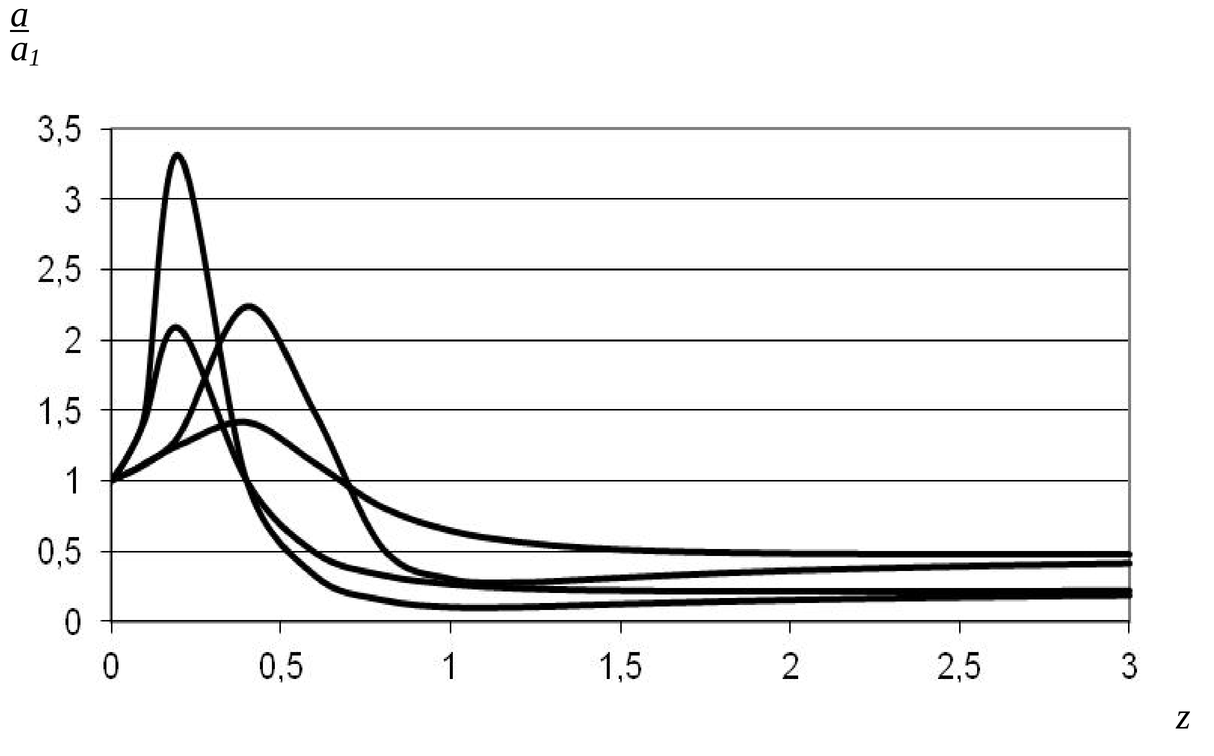


Figure 2. Dependence of the shaft bending on the angular velocity, when μ_1 and n have different values: 1 – μ_1=2, n=0.1; 2 – μ_1=2, n=0.7; 3 – μ_1=4, n=0.1; 4 – μ_1=4, n=0.7

Figure 2 represents the ratio of the rotor shaft bending with operating ABD to the bending without ABD, calculated for μ_1=2; 4 and n=0.1; 0.7. The figure shows that at the same μ value and at different n values the coincidence of the system shaft bendings occurs at the same z value. With the increase of μ parameter the critical rotating frequency decreases, and the extreme bending value decreases with the increase of n. The same curves describe the change in the ratios of disbalance and torque radicals.

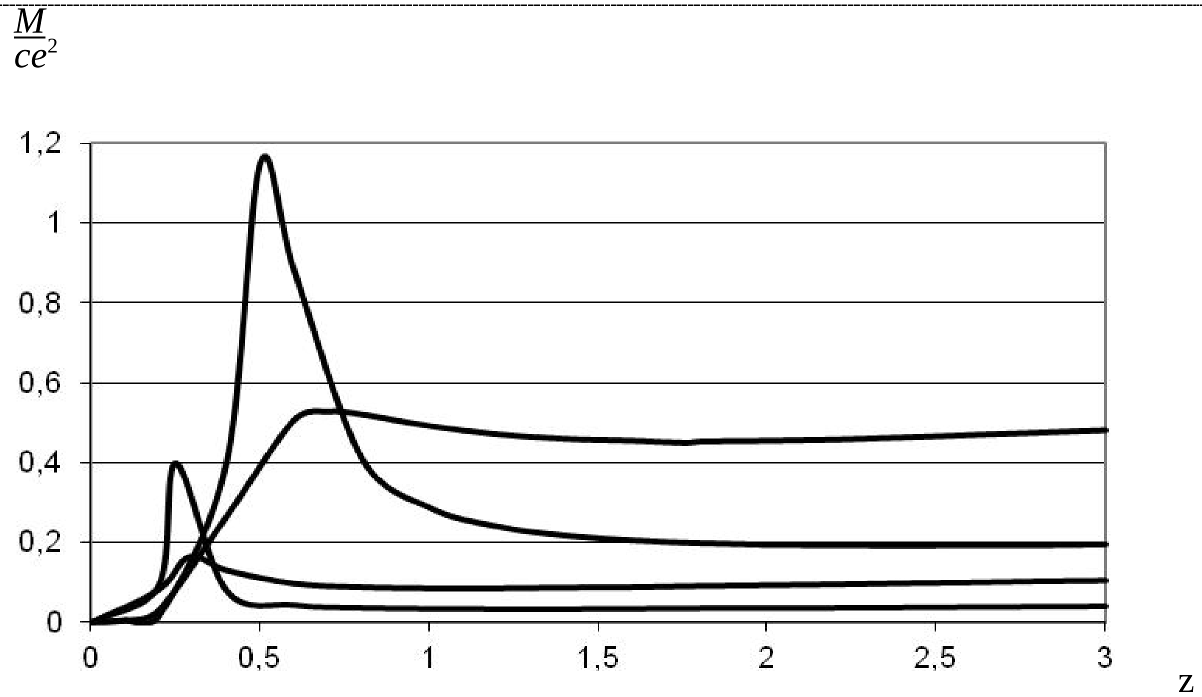


Figure 3. Dependence of the torque on the angular velocity at different μ_1 and n values: 1 – μ_1=2, n=0.1; 2 – μ_1=2, n=0.7; 3 – μ_1=4, n=0.1; 4 – μ_1=4, n=0.7

From (2) it follows that maximum shaft bending $a^{cr} = 2e/\sqrt{4\mu_1 n - n^2}$ occurs at critical angular velocity $z^{cr} = 2/(2\mu_1 - n)$. If liquid is absent from the correction chamber, $z_1^{cr} = 2/(2-n)$ and $a_1^{cr} = 2e/\sqrt{4n - n^2}$. Comparing these values, we can conclude: the liquid ABD decreases critical speed and maximum rotor deflection from the rotation axis. The alteration of the torque depending on the angular velocity is shown in figure 3. The calculations have shown that, when $\mu_1 > 2n$, these curves have two extreme rotating frequencies $z_{1,2} = (6\mu_1 - 3n \pm \sqrt{(6\mu_1 - 3n)^2 - 20\mu_1^2})/(2\mu_1^2)$. The first one (with a negative sign) corresponds to a maximum torque value, the second one corresponds to a minimum torque value. Hence, in case of low engine power when transferring through frequency z_1, shaft "sticking" is possible at this rotating frequency [10].

4. Conclusions

The dependencies of the shaft bending, system disbalance, torque at a preset angular shaft velocity on the ratio of the reduced mass and rotor mass and external friction forces have been established.

The equation for rotor rotating frequency, depending solely on the ratio of the system masses and rotor mass, above which the specified characteristics of motion of the system with ABD become less than for the rotor without liquid, has been obtained.

The dependence, which allows calculating the angular velocity, at which shaft "sticking" is possible in case of insufficient engine power, has been obtained. The results obtained should be taken into consideration when designing and applying liquid ABD for oscillation suppression of out-of-balance rotors, having vertical rotating axes.

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6. References
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