An investigation into autobalancing devices with multi-reservoir system

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Abstract. Behaviour of a liquid-type automatic balancing device is modeled in this paper. To perform mathematical research the authors use a rotor model which contains a ring functioning as a reservoir coupled to a rigid shaft being rotatable in bearings. An autobalancer with several reservoirs is used for the mathematical investigation. The article provides the layout of forces acting in a multi-reservoir balancing system. Data on the effect of various factors on balancing accuracy as well as the main calculation features of a multi-reservoir autobalancer are presented. The obtained modeling results indicate that autobalancing efficiency is enhanced by increasing the number of reservoirs. An increase in the number of reservoirs causes a decrease in a critical rotor speed.

1. Introduction
Known autobalancing devices are quite effective in reducing the mode change of rotor unbalance. However, this performance is achieved by using a heavy liquid (mercury) as a correction weight (mass). When designing machines and devices, engineers aim to avoid the use of highly toxic substances. At the same time, available nontoxic liquids are characterized by a density of no more than 2 g/cm^3. Therefore, using them instead of mercury as a correction weight in liquid-type autobalancers results in the reduced efficiency of automatic rotor balancing [1, 2]. It is due to relatively low efficiency of liquid-type autobalancers caused by a low density of such liquids, that the factors affecting the balancing accuracy have been understudied. At the Department of Theoretical and Applied Mechanics of the Tomsk Polytechnic University a device has been designed [3], which allows a multiple increase in the efficiency of the automatic rotor balancing by using liquid autobalancing devices. Hence, there appears the necessity to investigate various factors that affect the accuracy of balancing.

2. Materials and Methods
As can be seen in Fig. 1, only a part of the liquid of the reservoir's inner surface and the cylindrical surface touching the reservoir's surface and having an axis coincident with the rotor axis is involved in the balancing process in a liquid-type autobalancing device. The weight of this liquid satisfies the

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boundary value under the condition of its sufficiency, i.e. at a specified shaft deflection value the free surface of a liquid touches the inner surface of a reservoir.
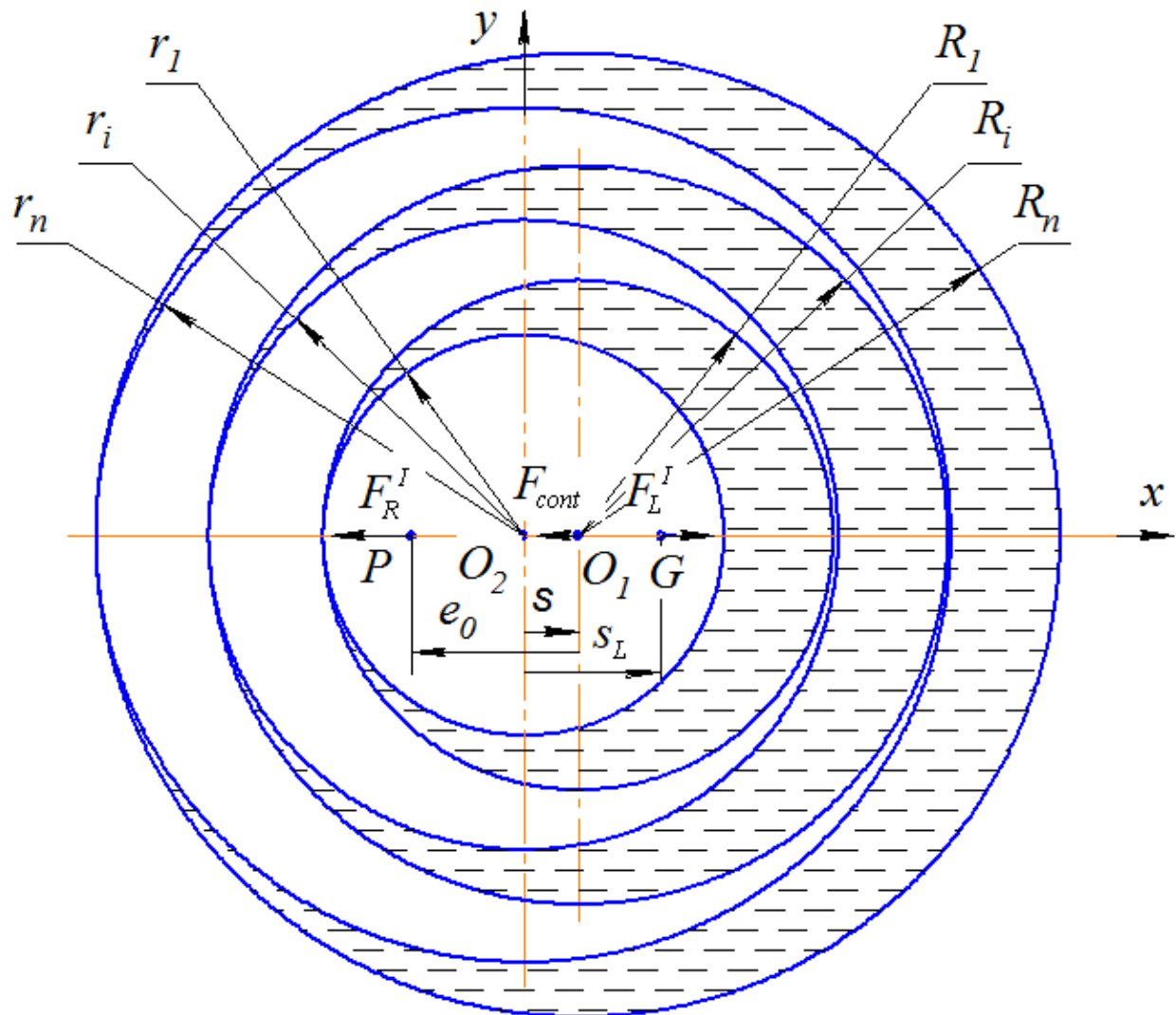

Figure 1. Diagram of forces in a multi-reservoir system**.**

The other part of the liquid is not involved in the balancing process. Based on this fact, an automatic balancing device with several concentric reservoirs, the axes of the internal cylindrical surfaces of which coincide with the rotor axis, has been proposed. This device will be further called a multi-reservoir device [5, 6]. The multi-reservoir autobalancing device operates like a liquid-type autobalancer with a single reservoir. Let us analyze its performance.

3. Results
On the assumption that the rotor has static unbalance (Fig. 1), i.e. the rotor's mass center (point P) is displaced with respect to the rotor axis (point O_1 in projection) by the value of e_0. As the rotor rotates

at a constant speed ω that exceeds the critical value, the deflection of the rotor shaft occurs in such a way that the following equation of the forces acting on the system is satisfied:

$$\sum \overline{F} = \overline{F}_{cont} + \overline{F}_R^I + \overline{F}_1^I + ... + \overline{F}_i^I + ... + \overline{F}_n^I = 0$$

or in projections onto the x-axis:

$$-F_{cont} - F_R^I + F_1^I + ... + F_i^I + ... + F_n^I = 0, \tag{1}$$

where: $F_i^I = m_i \omega^2 s_i$ is the fluid inertia force in the i-reservoir applied to its mass centre;

$m_i = \rho \pi h (R_i^2 - r_i^2)$ is the fluid mass in the i-reservoir according to the condition of its sufficiency;

$s_i = s \dfrac{R_i^2}{(R_i^2 - r_i^2)}$ is the distance from the rotor's rotation axis to the fluid's mass centre for the i-reservoir;

R_i, r_i are the radius of the reservoir's inner surface and the radius of the fluid's free surface for the i-reservoir;

n – is the number of reservoirs.

The condition of the liquid's sufficiency in a multi-reservoir system differs from a similar condition in liquid autobalancing devices with a single reservoir. In a multi-reservoir device, the condition of the liquid's sufficiency is satisfied if the free surface of a liquid in the i-reservoir does not intersect with the reservoir's inner cylindrical surfaces formed by the cylindrical partitions [7-9]. Therefore, the condition of the liquid's sufficiency in a multi-reservoir device is as follows:

$$R_i - r_i \geq s \text{ ; } r_i - (R_{i+1} + \delta) \geq s, \tag{2}$$

where δ is the thickness of the cylindrical partition's wall.

Taking account of the condition of the liquid's sufficiency (2), we define the rotor's vibration amplitude when balancing it with the use of a multi-reservoir device:

$$s = \frac{e_0 m \omega^2}{(m + \rho \pi h \sum_{i=1}^{n} R_i^2) \omega^2 - c}. \tag{3}$$

It is seen that in contrast to single-reservoir liquid autobalancers, in multi-reservoir devices the amplitude of rotor vibrations decreases with an increase in the number of reservoirs and in the radii of their internal surfaces. The vibration amplitude does not depend on the mass of the liquid in the chamber if the condition of its sufficiency is satisfied (2).

Using the expression (3) for a multi-reservoir autobalancing device, we can obtain the expressions for calculating the critical rotor speed and automatic balancing efficiency:

$$\omega_k = \sqrt{\frac{c}{m + k \rho \pi h \sum_{i=1}^{n} R_i^2}}; \tag{4}$$

$$E_e = \frac{m + \rho \pi h \sum_{i=1}^{n} R_i^2}{m} = 1 + \frac{\rho \pi h \sum_{i=1}^{n} R_i^2}{m}. \tag{5}$$

4. Conclusions

The obtained results indicate that automatic balancing efficiency is enhanced with an increase in the number of reservoirs. An increase in the number of reservoirs causes a decrease in the critical speed of a rotor.

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6. References

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