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STATIONARY ROTATION OF THE UNBALANCED ROTOR WITH THE LIQUID AUTOBALANCING DEVICE UNDER ACTION OF EXTERNAL FRICTION FORCES

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Influence of external friction forces on rotation of the rotor with the liquid autobalancing device is considered. The liquid in the balancing chamber at stationary movement rotates together with the rotor as solids. Analytical expressions for deflection of the shaft, unbalance of the system and the necessary rotating moment from the engine providing rotation with set speed are received.

To eliminate an unbalance of rotating bodies one uses a liquid balancing devices (LBD) [1]. At designing of such LBDs it is necessary to know influence of a liquid on rotation of the body. Research of rotation of balanced rotor at its partial filling with the liquid is considered in works [2, 3]. The bend fluctuations of the shaft with an unbalanced disk on it are investigated in [4, 5]. Influence of the liquid in the rotating rotor on automatic balancing of mechanical system not taking into account resistance forces is shown in [6, 7]. The steady movement of the unbalanced rotor with a liquid in presence of external friction is considered below.

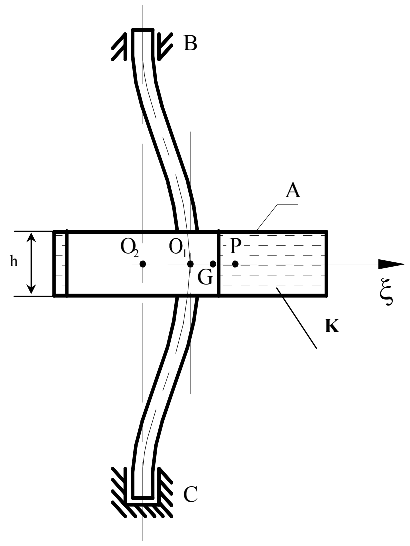

Fig. 1. *Diagram of fastening of the rotor*

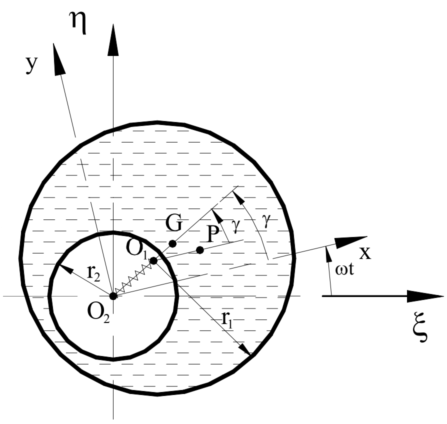

Fig. 2. *Section of the rotor with a liquid*

Let`s the rotor *A* (fig. 1) with the balancing chamber *To*, filled in part with a liquid, is symmetrically fastened on a flexible vertical shaft, passing through the geometrical center O_1. The center of rotor masses (point *P*) is displaced from O_1 on distance $O_1P=e$. At rotation of the rotor the shaft is displaced on length $O_2O_1=a$, and the incompressible homogeneous liquid, with density ρ, flows in the side with deflection of the shaft. In case of the steady movement the liquid in the rotating rotor occupies a cylindrical layer with height *h* which free surface is the circle of radius r_2 with the center being on the rotation axis *BC* (point O_2 on fig. 2), and rotates with angular speed of the rotor ω=const [1]. Therefore, the mass center of the liquid layer is on the line of centers O_2O_1 in point *G*, and movement of the rotor is flat.

Let's enter into planes of movement of points O_1, *G*, *P* two systems of coordinates (Fig. 2) with the common origin in point O_2 on line *BC*: the motionless system $O_2\xi\eta$ and the mobile one O_2xy, which axis *x* is parallel to piece O_1P. Angular speeds of rotation of the rotor and the system O_2xy, are identical, hence, the rotor in the mobile system of coordinates is motionless. We shall consider coordinates in the mobile system of point O_1 – *x*, *y* as generalized coordinates.

From the shaft side the rotor is under action of elastic force $\overline{F}_c=-c\overline{O_2O_1}$ and the external friction force applied to point O_1, which are proportional to absolute speed $\overline{V}_{O_1}$ of this point, $\overline{F}_\chi=-\chi\overline{V}_{O_1}$, where *c* and χ are factors of elasticity and external friction. According to D`Alambere principle, being fair for any mechanical system, we have the equation of balance of the main vectors of external forces and inertial forces:

$$-c\overline{O_2O_1}-\chi\overline{V}_{O_1}-m_1\overline{a}_P^e-m_2\overline{a}_G^e=0. \quad (1)$$

Here m_1 and m_2 are masses of the rotor and the liquid, $\overline{a}_P^e$ and $\overline{a}_G^e$ – are transferring accelerations of points *P* and *G* accordingly. Coordinates of these points are defined by expressions

$$x_P=x+e, \quad y_P=y, \quad x_G=rx, \quad y_G=ry, \quad (2)$$

Where $r=r_1^2/(r_1^2-r_2^2)$; r_1 – is radius of the rotor.

Projecting (1) on an axis *x*, *at* and using (2) for calculation $\overline{V}_{O_1}$, $\overline{a}_P^e$ and $\overline{a}_G^e$, we obtain the equations of stationary movement of system:

$$\begin{aligned} cx-\chi\omega y-m\omega^2x&=m_1e\omega^2; \\ cy+\chi\omega x-m\omega^2y&=0. \end{aligned} \quad (3)$$

Here $m=m_1+rm_2$ is the reduced mass of system, $rm_2=\rho\pi_1^2h$ is the fictitious mass of the liquid filling all balancing chamber of the rotor [1].

From the equation of balance of the moments of all forces in relation to the axis BC, we determine the rotating moment M applied to the shaft from the engine

$$M = O_2O_1 \cdot \chi V_{O_1} = \chi a^2\omega = \chi\omega(x^2+y^2). \qquad (4)$$

The solution of the equations (3) is

$$x = \frac{m_1e\omega^2(c-m\omega^2)}{(c-m\omega^2)^2+\chi^2\omega^2};\; y = -\frac{m_1e\chi\omega^3}{(c-m\omega^2)^2+\chi^2\omega^2}. \qquad (5)$$

By formulas (2–5) one calculates deflection of the shaft $a=\sqrt{x^2+y^2}$; unbalance of the system $d=(m_1+m_2)r_c$, where $r_c=\sqrt{(x_pm_1+x_Gm_2)^2+(y_pm_1+y_Gm_2)^2}/(m_1+m_2)$ is deviation of the mass center of the rotor with LBD from axis BC; and rotating moment M

$$a = \frac{ez}{\sqrt{D(\mu)}};\; d = \frac{m_1e\sqrt{1+nz}}{\sqrt{D(\mu)}};\; M = \frac{e^2z^2c\sqrt{nz}}{D(\mu)};$$

$$D(\mu) = (1-\mu z)^2 + nz. \qquad (6)$$

Here $z=m_1\omega^2/c$, $n=\chi^2/(cm_1)$ is dimensionless factor of resistance, $\mu=m/m_1$ is – the relation of the reduced system mass to of the rotor mass.

For comparison of movement of the rotor with liquid LBD and without it we shall consider the following relations:

$$\frac{a}{a_1} = \frac{d}{d_1} = \sqrt{\frac{D(1)}{D(\mu)}};\qquad \frac{M}{M_1} = \frac{D(1)}{D(\mu)}, \qquad (7)$$

where a_1, d_1, M_1 are a deflection of the shaft, unbalance, the rotating moment at movement of the rotor without the balancing liquid, obtained from (6) at $\mu=1$, accordingly.

The angle of the movement phase shift γ is defined by the formula

$$\mathrm{tg}\gamma = y/x = -\frac{\chi\omega}{c-m\omega^2} = -\frac{\sqrt{nz}}{1-\mu z}, \qquad (8)$$

This expression at absence of a liquid, i. e. at $\mu=1$, coincides with the similar formula in [3]. The relation of deflections of a shaft a/a_1, at $n=0$ coincides with the corresponding value obtained for rotation without friction forces in [5].

From formulas (5–8) it follows, that at $\omega\to\infty$ ($z\to\infty$), $a\to m_1e/m$, i. e. the shaft deflection becomes less than unbalances e, since $m_1/(m_1+rm_2)<1$; $r_c\to 0$, $\gamma\to\pi$, $x\to -m_1e/m$, $y\to 0$; coordinates of the mass centers of the rotor and the layer liquid accept 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, at large ω the mass center of system aspires to occupy position on an rotation axis BC with self-centering of the system.

As $D(1)<D\mu)$ at $z>2/(1+\mu)$, according to (7) liquid LBD reduces a deflection, unbalance of the system in comparison with the rotor without a liquid on rotation frequencies being higher than $2/(1+\mu)$.

Relation of the deflection of the rotor shaft with working LBD to the deflection without it, calculated for $\mu=2$; 4 and $n=0{,}1$; 0,7 is shown on the fig. 3. From figure it is visible, that at the same value μ and various n coincide of deflections of the system shaft and the rotor without liquid occurs at the same value z. With increase of parameter μ critical frequency of rotation decreases, and the extreme value of the deflection decreases with growth of n. The same curves describe change of relations of unbalance and radicals of the rotating moments.

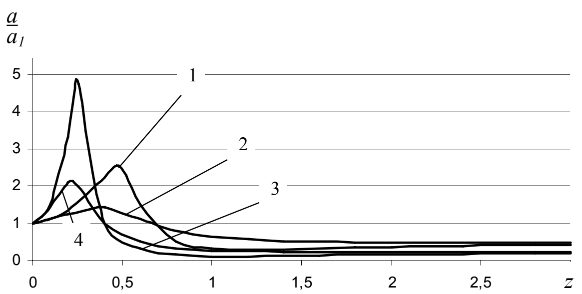

Fig. 3. *Dependence of a shaft deflection a/a_1 on angular speed z at various values of μ and n: 1) μ=2, n=0,1; 2) μ=2, n=0,7; 3) μ=4, n=0,1; 4) μ=4, n=0,7*

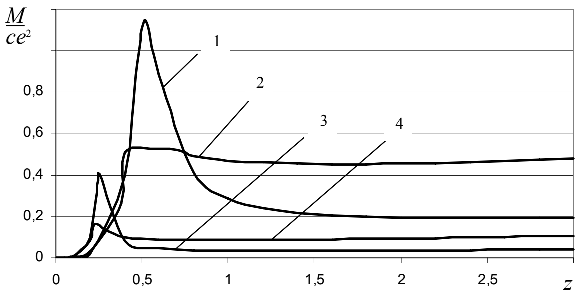

Fig. 4. *Dependence of the rotating moment on angular speed at various values μ and n: 1) μ=2, n=0,1; 2) μ=2, n=0,7; 3) μ=4, n=0,1; 4) μ=4, n=0,7*

From (6) it follows, that the maximal deflection of the shaft $a^{кр}=2e/\sqrt{4\mu n-n^2}$ occurs at critical angular speed $z^{кр}=2/(2\mu-n)$. At absence of a liquid in the balancing chamber $z_1^{кр}=2/(2-n)$ and $a_1^{кр}=2e/\sqrt{4n-n^2}$. Comparing these values, we conclude: liquid LBD reduces critical speed and the maximal deviation of the rotor from an rotation axis. Change of the rotating moment with angular speed is shown on the fig. 4. Calculations have shown, that these curves at $\mu>2n$ have two extreme frequencies of rotation $z_{1,2}=(6\mu-3n\pm\sqrt{(6\mu-3n)^2-20\mu^2})/(2\mu^2)$. The first (a sign a minus) corresponds to the maximal value of the moment, the second to minimal. Therefore, in case of low power of an engine, at transition through frequency z_1 [8], the situation is possible when energy is insufficient for overcoming a resonance.

Conclusions

Dependences of a deflection of the shaft, un balance of the system, the rotating moment at the set angular speed of the shaft on relation of the reduced mass to the rotor mass and external friction forces are established. The frequency of rotation being dependent only on the relation of masses is obtained, above which the specified characteristics of movement of system with LBD become less than for the rotor without a liquid. Angular speed at which the rotor cannot overcome critical frequency, for low power of the engine is calculated. The obtained results should be taken into account at designing and use of liquid LBDs for clearing fluctuations of unbalanced rotors with a vertical axis of rotation.

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THE AMPLIFIER OF UNIPOLAR PULSES OF THE SHORT RANGE RADAR SYSTEM

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The amplifier of videopulses intended for work as a source of a pulse feed of the Hannah diodes 3A763A-M of the short range radar system is described. Characteristics of the amplifier are: coefficient of amplification 16 dB; the maximal amplitude of output pulses – 6 V; the maximal current in a pulse – 2,5 A.

At the present velocities of moving objects, for example, automobiles, is measured with wide using of the short range radar systems, based on the Doppler effect. Generators of the SHF oscillations of the named systems are made more often on the Hannah diodes working in the continuous mode. Abilities of such systems of a short range radar location can be expanded by converting the generators in the pulse operating mode. In this case it becomes possible to measure not only the velocity of objects, but and distance to them.

According to the nominal data [2] to excite the Hannah diodes 3A763A-M it is required the generators of videopulses with positive polarity amplitude 5...6 V at the output current 1,5...2 A. The standard generators of videopulse work as a rule for standard loading 50 Ohm and have a output voltage 1 V.

The circuit diagram of the amplifier allowing to raise the output parameters of the standard generator of pulse signals up to required values is shown on Fig. 1.

The amplifier contains the input resistive divider of voltage, two cascades of amplification, the stable current generator, the control output.

The resistive divider of voltage staying on the amplifier input and made on the resistors R1-R3, ensures coordination of the amplifier with output resistance of the generator and stabilization of general negative feedback depth, covering the amplifier.

In both cascades of the amplifier made on transistors VT2 and VT4, it is applied active collector thermostabilization of rest currents [3]. The transistor rest currents themselves were chosen from the undistorted amplification of videopulses with pulse ratio changing from 10 up to ∞. For transistor VT2 the rest current is equal 70 mA, for VT4 – 300 mA that is found by selection of nominal of the resistors R5 and R12.

During start of the generator on the Hannah diode its resistance changes. To reduce influence of changing loading resistance the amplifier characteristics its output cascade is made by the circuit with the general collector, and the amplifier is covered with the general negative feedback consisting of elements R7, C8. As result the output resistance instant frequency of generation of the amplifier equal 0,4...0,6 Ohm is realized.

It is known, that change temperature of Hannah diode crystal results to change of the instant generation frequency [4]. To reduce the named factor the stable current generator on the transistor VT5, providing heating of the diode during the periods between arrival of start pulses is mounted in the amplifier. The stable current generator has limits of regulation 0,1...0,5 A.

The control output (fig. 1) is foreseen in the amplifier, which allows to register amplitude of pulses given on the Hannah diode. Diode VD1 is mounted for protection of the amplifier transistors against breakdown at