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For an incompressible lubricant in the bearing sliding surfaces of the spherical segments with the adjusted surfaces

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Abstract. A mechanism consisting of a deformable surface and a gear unit with a curve is considered. An incompressible viscous liquid is applied to the surface. The gear unit rotates or moves along the surface. Under the influence of the load, the gear unit can deform the surface. Such a mechanism can be considered as a sliding bearing. Using the tensor analysis apparatus, it is proved that in all cases a thin layer of incompressible lubricant is formed. The results of the following studies are presented: The effect of the lubricant with harmonic oscillations of the gear unit is normal to the surface. With the harmonic oscillations of the gear unit, the velocity distribution of the liquid in a thin liquid layer depends only on the dimensionless amplitude of the oscillations. The incompressible fluid flows out beyond the edges of the gear unit when the thickness of the layer (the movement of the tooth to the surface) decreases between it and the surface and flows from outside with the increasing thickness (removing the tooth from the surface). The appearance of the bearing capacity of such a mechanism is associated with the forces of friction and inertia inside the fluid.

1 Statement of the problem

An important contribution to the development of the hydrodynamic lubrication theory was made by A. Sommerfeld, N. E. Zhukovsky, S. A. Chaplygin, S. Duffing, A. Cameron, M. V. Korovchinsky, N.. Slezkin Targ S. M., I. Y. Turner, A. L. Pozniak. A number of studies have examined the effect of forces of inertia of liquid on the characteristics of the hydrodynamic layer. The method of averaging inertia forces according to the thickness proposed by Keskinen N.. and Targum S. M., applied research Palackoho A. T., Burguete A. G., Andreichenko K. P., Bourgin Patrick, John Tichy.

One of the main hypotheses of the hydrodynamic lubrication theory is a negligible change in the properties of the fluid and the lubrication pressure on the thickness of the oil layer. In the bulk of the plain bearings in the bearing layer of the lubricant takes place laminar flow. Over the past 70 years, a wide class of works has been published, in which

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theoretical issues of bearing dynamics of various designs used in mechanical engineering and instrument-making have been developed. In these works, the use of viscous liquids and gases as a lubricant was considered. In addition to the known methods of creating excessive pressure in the lubrication layer of the supports slide, known as the effects of the wedge and the external forcing of the lubricant in the theory of gas lubrication is a principle of increase in pressure due to vibrations of the with high frequency of solid wall. The appearance of the bearing capacity of the support, in which as a lubricant is used incompressible viscous liquid and takes into account the slow oscillations of the walls studied very little.

2 Analysis of recent achievements and publications that have begun to address this issue

The General research questions of the vibrations of the surfaces in sliding bearings in our country was engaged in Dimentberg, D. M., V. V. Bolotin, V. L. Biderman, V. A. Svetlitsky, J. G. Panovko, A. N. Filippov, D. V. Gronin, S. V. Arinichev, A. G., Zablotsky N. D., Burkov S. M., Burgwitz. Self-oscillations caused by the presence of grease in the bearings were investigated by many authors. The first work in this direction belonged to A. Stodola (1925), who considered the movement of the shaft on the lubrication layer, the Subsequent work on the sliding supports can be divided into two groups. The first is the work in which the surfaces are considered taking into account the lubrication layer, which allows more accurate account the characteristics of the stiffness and damping of the lubricant layer for the bearing of finite length and arbitrary shape. The second includes works in which between two identical bearings on a flexible shaft in the middle one disk is planted. By virtue of symmetry, the problem is similar to the first, but it is necessary to take into account the additional forces caused by the elasticity of the surfaces, where one bearing is an elastic linear support, and the second bearing is a sliding bearing.
In the works of the first group, the study of the dynamics of the shaft in the sliding bearing was studied by direct integration of the equations of motion. In the works of the second group in the equations of motion of the disk laid in addition to the characteristics of lubrication, and the elastic parameters of the surface.
The diversity of structures and the continuous growth of speeds in mechanical engineering and instrument-making led to the further development of the hydrodynamic lubrication theory and the account of non-stationary processes in the lubricant layer.

3 Equations and mathematics

The axisymmetric problem of fluid motion between segments of spheres of large radius, oscillating in the direction of normal, is considered (Fig. 1). The direction of the x and y coordinates is shown in the figure.
In a thin layer approximation, the equations of motion can be written as

$$\frac{\partial(x,u)}{\partial x}+x\frac{\partial w}{\partial z}=0,\quad \frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+w\frac{\partial u}{\partial z}+\frac{1}{\rho}\frac{\partial p}{\partial x}=\nu\frac{\partial u^2}{\partial z^2},\quad \frac{\partial p}{\partial z}=0. \qquad (1)$$

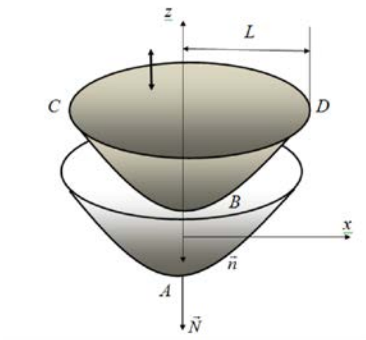

Fig. 1. Support in the form of segments of spheres of large radius of finite diameter at compression of a liquid layer.

The thickness of the layer is formed between the segments of the spheres.

Assumptions:

- the smallness of the gap compared to the size of the surfaces,
- not very high surface oscillation speed, which allows to neglect inertial terms in this equation of motion,
- taking into account the smallness of the gap, the Gaussian curvature and the average curvature differ little in magnitude.

Table of symbols:

L - half the distance CD,

H - half the distance between surfaces.

z – coordinate in the transverse direction; *u* – the longitudinal velocity of the fluid; *w* – transverse velocity of the liquid; *t* – time; *p* – the pressure in the liquid layer; ξ, η – dimensionless coordinates in the longitudinal and transverse directions; τ – dimensionless time; $\overline{u}$, $\overline{w}$ – dimensionless longitudinal and transverse velocity values; $\overline{p}$ – dimensionless pressure in the liquid layer; t_* и H_* – typical values of the time interval and the gap; a_0 – the dimensionless amplitude of the surface; ν – the kinematic viscosity of the fluid; c_* – the parameter is time-dependent, viscosity and clearance.

If these conditions are satisfied and the last of the equations (1) can be considered fair, then the beginning of the reference z does not matter and does not matter, fluctuate both surfaces or only one of them, only the law of the change of the gap in time is important.

Denoting half the distance between the surfaces , the boundary conditions written in the form $u = 0$ at $x = 0$; $p = p_a = const$ $x = L$;

$$w = 0 \text{ at } z = 0; \; u = 0, \; \frac{\partial u}{\partial z}{=}0, \; w{=}\frac{\partial H}{\partial t}{=}0 \text{ at } z = H(t) \tag{2}$$

and the initial in the form $u = w = 0$, $H = H_0(t)$, at $t = 0$.

Equations (1) have a self-similar solution such that the transverse component of the velocity does not depend on the longitudinal coordinate, that is $w = w(z, t)$. In this case, due to the first of the equations (1), the longitudinal velocity component is proportional to *x*. This flow can be realized away from the edges of the plates, where the boundary effects can be neglected.

Let's go to dimensionless variables by formulas

$$\xi = x / L, \quad \eta = z / H, \quad \tau = t / t_*, \quad \overline{w} = wt_* / H_*, \quad \overline{u} = \frac{ut_*}{\xi L}. \tag{3}$$

where t_* и H_* – characteristic values of the time interval and the gap. When periodic oscillation is natural in this as take the period of oscillation and the average value *H*. We also denote

$$\bar{H} = H / H_*,\ \bar{p} = p / p_a,\ p_* = \frac{p_a t_*^2}{\rho L^2},\ c_* = \frac{t_* \nu}{H_*^2},\ H_\tau^{'} = \frac{\partial H}{\partial \tau}.$$

Then, instead of (3) we get the equation

$$\bar{H}\bar{u} + \frac{\partial \bar{w}}{\partial \eta} = 0,\ \ \frac{\partial \bar{u}}{\partial \tau} + \frac{\bar{w} - H_\tau^{'}\eta}{\bar{H}}\frac{\partial \bar{u}}{\partial \eta} + \bar{u}^2 + \frac{p_*}{\xi}\frac{\partial \bar{p}}{\partial \xi} = \frac{c_*}{\bar{H}^2}\frac{\partial \bar{u}^2}{\partial \eta^2}. \tag{4}$$

with boundary conditions

$$\bar{p} = 1 \text{ at } \xi = 1;\ \bar{w} = 0,\ \frac{\partial \bar{u}}{\partial \eta} = 0 \text{ at } \eta = 0;\ \bar{u} = 0,\ \bar{w} = \bar{H}_\tau^{'} \text{ at } \eta = 1 \tag{5}$$

and initial conditions $\bar{u} = \bar{w} = 0, \bar{H} = H_0 / H_*$, at $\tau = 0$.

When you recorded the initial conditions should be $\left.\frac{\partial \bar{H}}{\partial \tau}\right|_{\tau=0} = 0$, so the harmonic oscillations of the gap should be set as $\bar{H} = 1 + a_0 \cos(2\pi\tau)$, where a_0 – dimensionless oscillation amplitude $0 \le a_0 < 1$.

Denoting the last component in the right part of the second equation (4) $P_\xi = \frac{p_*}{\xi}\frac{\partial \bar{p}}{\partial \xi}$, note that it depends only on time and can be determined from the solution of the system of equations (4) given $\bar{H}(\tau)$. Thus, in case of harmonic oscillations of the gap, the velocity distribution in it depends only on two parameters: c_* and a_0, and the third parameter *p* does not affect the velocity distribution and is important only in determining the dimensional pressure by dimensionless value P_ξ, and also in determining the force acting on the plate.
Equations (4) are similar to boundary layer equations and differ only in that P_ξ unknown and is determined from the additional (compared to the boundary layer) boundary condition for $\bar{w}$. The equations were approximated by a known second-order scheme and solved by a matrix run with non-linearity iterations.
Result of calculation. Some results of calculations of the problem $a_0 = 0{,}5$ and different values c_* presented in Fig. 2, where by curves, the velocity distribution is shown $\bar{u}(\eta)$ at time τ = 1.00, 1.17, 1.34, 1.51, 1.68 соответственно. The change in time is also shown $\bar{H}_\xi(\tau)$.
Figure 3 presents the results of the calculations of the $a_0 = 0{,}5$ and different values c_* for the axisymmetric problem between plane plates, where curves, the velocity distribution is shown $\bar{u}(\eta)$ at time τ = 1.00, 1.17, 1.34, 1.51, 1.68, 1.85 respectively. The change in time is also shown $\bar{H}_\xi(\tau)$ и $P_\xi(\tau)$.

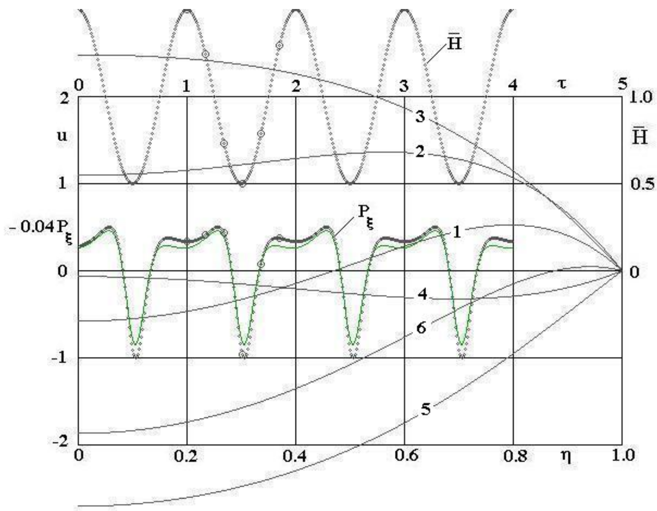

Fig. 2. The distribution of the dimensionless fluid velocity $\overline{u}$, the dimensionless clearance $\overline{H}_{\xi}(\tau)$ from the coordinates in the transverse direction η at different points in time τ for problem with segments of spheres.

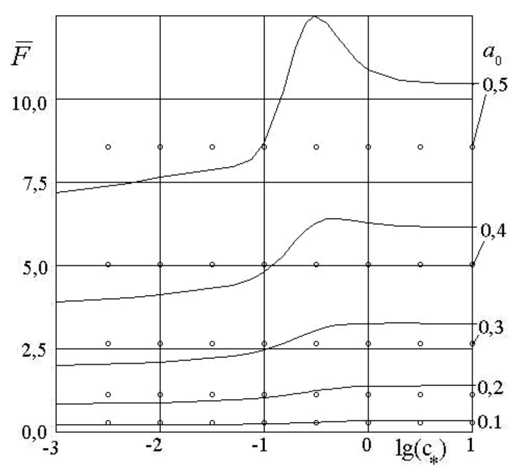

Fig. 3. The dependence of the dimensionless load carrying capacity $\overline{F}$ on the parameters c_* for a problem with sphere segments with a_0 =0,5.

4 Output

Thus, the effect of the oscillating surface for incompressible fluid is found, similar to the effect with the vibrating surface for the gas layer. A support consisting of two disks of finite diameter and an incompressible liquid between them, or two segments of spheres of large radius, can carry a load, similar to a vibroopor, where gas is used as a lubricant. The physical picture of a support with an incompressible fluid is slightly different from the processes in the support, where the lubricant is used as a gas. In contrast to the supports with gas lubrication, incompressible liquid flows over the edges of the support for reducing the gap between the plates and flows from the outside if you increase the gap. The appearance of the bearing capacity of the support is associated with the friction and inertia forces inside the liquid, rather than compressibility, as in the case of gas lubrication..

References

1. N. Ah. Slezkin, *Dynamics of viscous incompressible fluid*, Moscow: GOS. ed. technical and theoretical literature (1955)
2. O.G Zavyalov, Study of dynamics of rolling of ball making contact with the surface, considering unsteady layer of viscous fluid, International magazine Nauka i studia (Poland), № **42** (110), pp. 99-111 (2013)