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ON EXPERIMENTAL DETERMINATION OF THE OPERATING PARAMETERS OF THE FLUID FRICTION SLIDING BEARINGS

The article deals with existing methods and devices for experimental determination of the operating parameters of fluid friction sliding bearings (FFSB), such as the lubricating layer thickness, the pressure in it and the temperature, i. e. the parameters, which determine safety and bearing capacity of the FFSB.

The methods and devices for experimental determination of these parameters at the same time in nearly every point of the FFSB circumference were offered.

Keywords: lubricating layer, thickness, pressure, temperature.

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ДО ПИТАННЯ ЕКСПЕРИМЕНТАЛЬНОГО ВИЗНАЧЕННЯ РОБОЧИХ ПАРАМЕТРІВ ПІДШИПНИКІВ РІДИННОГО ТЕРТЯ КОВЗАННЯ

У статті розглянуто існуючі способи та пристрої для експериментального визначення робочих параметрів підшипників рідинного тертя ковзання (ПРТ): товщини мастильного шару, тиску, розвиваємого в ньому і температури, параметрів, які визначають надійність і несучу здатність ПРТ. Запропоновані способи і пристрої для експериментального визначення цих трьох параметрів одночасно практично в кожній точці по колу ПРТ.

Ключові слова: мастильний шар, товщина, тиск, температура.

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К ВОПРОСУ ЭКСПЕРИМЕНТАЛЬНОГО ОПРЕДЕЛЕНИЯ РАБОЧИХ ПАРАМЕТРОВ ПОДШИПНИКОВ ЖИДКОСТНОГО ТРЕНИЯ СКОЛЬЖЕНИЯ

В статье рассмотрены существующие способы и устройства для экспериментального определения рабочих параметров подшипников скольжения жидкостного трения (ПЖТ): толщины смазочного слоя, давления, развиваемого, в нем и температуры, параметров, которые определяют надежность и несущую способность ПЖТ. Предложены способы и устройства для экспериментального определения этих трех параметров одновременно, практически в каждой точке по окружности ПЖТ.

Ключевые слова: смазочный стой, толщина, давление, температура.

Relevance of the study

The tendency of improvement of the calculation of fluid friction sliding bearings (FFSB) based on advanced study of the physical processes occurring in the sliding bearings is a topical issue in the development of the hydrodynamic theory of lubrication. The theory provides partial solutions to the most pressing problems such as non-isothermal lubricant flow, determination the extent of lubrication bearing layer and so on.

The purpose and objectives of the article

The question of determination of bearing capacity of sliding bearings still remains vital. It cannot be effectively resolved without determining heat flow in a bearing, and determining on that basis lubricant layer temperatures not only in the loaded but unloaded zones, without experimental determination of the lubricating layer thickness and pressure therein synchronized with the temperature of the lubricating layer on a sliding bearing circumference.

Substantiated explanation of the basic material and received results

For the first time fairly significant results on determination of the lubricant layer thickness were obtained by D. S. Kodnir [1], F. P. Snehovskyi [2]. The authors used a capacitive method distinguished by velocity, low thermal variation sensitivity, sensor simplicity and, most importantly, capability to register the occurrence of the contacting lubricated surfaces, since in the moment of contact the capacitance stops being a physical amount by which the thickness of the lubricating layer is measured. The essence of the capacitive method is that it is used for measuring of the capacitance C between the sensor installed in the shaft and insulated from it and bearing liner.

$$C = \frac{\varepsilon_0 \varepsilon S}{h} , \qquad (1)$$

where ε_0 - is an electric constant

ε - is a relative dielectric constant of the medium (in this case the lubricant);

h - is a distance between the sensor and the liner (in this case the lubricant layer thickness);

S - is an area of the reciprocal interception of the sensor's and liner's faces.

i. e., the product $\varepsilon_0 \varepsilon S$ (2)

can be considered a constant, although it should be noticed that the dielectric constant of lubrication and sensor face area vary with temperature and pressure changes, but these changes are small and can be disregarded. A significant flaw of the capacitance method, in the form in which it was used, was that the oscillogram of the changes of the layer thickness around FFSB resulting from the experiment didn't reflect real-time layer thickness and required additional decoding for the calibration curves. Calibration curves were constructed on special calibrators and were nonlinear. Naturally, all this caused a significant measurement inaccuracy.

The next important parameter of FFSB is pressure that developed in the lubricating layer. It was first measured by Tower in 1883 by means of connecting a manometer to the radial drilling in the bearing bush. Later on this method has been improved by the installation of various sensors in the bearing bush. Qualitatively new results were obtained by F.P. Snehovskyi [3], who has developed and widely introduced a method for measuring the hydrodynamic pressure in the lubricating layer of the rubbing surfaces. The method lay in calking of the pressure sensor flush with the moving sliding support and connecting it through the current collector with recording equipment. Now all researchers apply this method. But frankly speaking, the choice of sensors is limited due to their large size, their low inertia and resolution.

The earliest experimental work, the purpose of which was the study of the lubricating layer temperature were the papers by Lasche and Freudenberg, who used expansion thermometers put in the special holes in bearing liners. This method of examination of the lubricating layer temperature with use of more advanced sensors is widely used nowadays. The distinctive feature is that the sensors measure not the temperature of the lubricating layer, but the temperature of the surface liner layer contacting with the lubricating layer. The main cause of inaccuracy in the temperature measurement is a large temperature gradient in the radial direction of the liner - up to 4000 degrees per centimeter.

A method of measuring the lubricating layer thickness and device for that [4] were offered for more accurate and full examination of the thickness and form of the lubricating layer forming in FFSB. These allow to receive the oscillogram reflecting real-time changes in the thickness of the lubricating layer around the circumference of FFSB, to exclude effortful operations of decoding of the oscillogram on nonlinear calibration curves. The constant A in the formula (2) must be divisible by a value proportional to the capacitance C for the output of the device to match the lubricating layer thickness. Digital methods are not fully acceptable here due to necessity of analog-digital transformation of the signal proportional to the capacitance C and application of discrecity into the final result. The solution is simplified here by the use of analog methods such as taking the logarithms, substructing the logarithms and anti-logarithmation. A block diagram of such a device is shown in Fig.1.

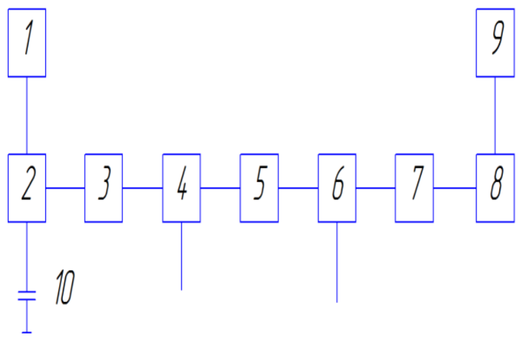

Fig. 1. Block diagram of the device for measuring the thickness of a lubricating layer

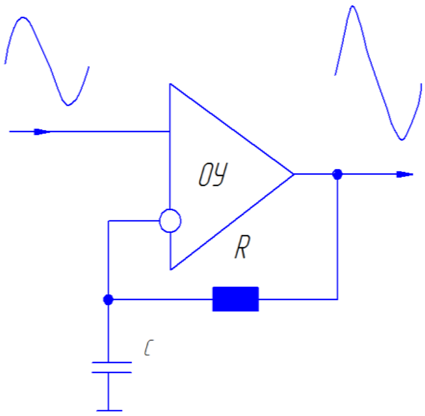

Fig. 2. Capacitance meter

where 1 - frequency-stabilized quartz oscillator,
2- linear capacitance meter,
3 - amplitude detector,
4 - subtraction circuit compensating stray capacitances,
5 - logarithm-taking amplifier, that gives a signal proportional to the logarithm of the capacitance measured, 6 - subtraction circuit of the capacitance logarithm and of the constant logarithm,
7 - anti-logarithm-taking amplifier,
8 - normalizing amplifier,
9 - current source providing a current proportional to the voltage for connection to a loop oscillograph.

To avoid nonlinear dependencies in the sensor capacitance measurement a method capacitive-ohmic divider was employed, wherein the magnitude of the measured capacitance and its change is determined by the voltage drop on the active arm of the capacitive-ohmic divider generated by current, value of which is determined by reactive conductivity of the measured capacitance - Fig. 2.

Analysis of the sensors and devices used to measure the distribution of hydrodynamic pressure in FFSB allows us to formulate a number of requirements they must meet. First of all, the sensor must not introduce any distortion into the lubricant layer, i.e. not change its value as a result of deformation, avoid lubricant overflow from holes of any kind; it has to be of a high velocity, to be sensitive to both low and high pressures, which allows to determine not only the length of the hydrodynamic pressure zone, but also possible discontinuous pressure changes.

Of particular interest is the measurement of pressure and lubricating layer thickness at each point on the circumference of FFSB at the same time. To do this, the sensor must combine the functions of a pressure sensor and a the lubricating layer thickness sensor.

A new type of a pressure sensor was offered - a magnetoelastic one, based on effect of magnetic conductivity of ferromagnetic bodies depending on occurring mechanical stress caused by outer mechanical forces, in our case by pressure in the lubricating layer. Such sensor works without an outer power source. When the sensor is being pressed, its magnetization, i.e. the magnetic flow in it, changes and the electromotive force *e* turns in the sensor winding:

$$e = w d\Phi/dt \,, \qquad (3),$$

where: - *w*- the number of turns of the winding,

-*Φ* – magnetic flux interconnected to the turns of the windings. Since the emf *e* is proportional to the derivative from the magnetic flux *Φ* (pressure) so if we integrate the emf *e* we may get an originally applied pressure diagram:

$$Uout = \frac{1}{RC}\int_0^t e\,dt, \qquad (4),$$

where R and C are the resistance and capacitance of the integrating device. If the magnetization of the sensor material and, correspondingly, the magnetic flux are linearly dependent on the pressure, we find:

$$Uout = \frac{1}{RC}\int_0^t w\frac{d\Phi}{dt}dt = \frac{w}{RC}d\Phi, \qquad (5),$$

and since the differential of the independent variable Φ is equal to its delta, we find:

$$Uout = \frac{w}{RC}\Delta\Phi \,, \qquad (6)$$

Hence, the magnetoelastic transducer by integration of its output signal provides the FFSB pressure measurment. If the rod of the pressure sensor is isolated electrically from the shaft and connected to the lubricating layer thickness meter, we'll find a device with one gage sensor for both these parameters of FFSB lubricating layer at the same time - Fig. 3. On the Fig. 3: 1 - the rod made of ferromagnetic material, 2 - the pressure sensor winding, 3 - the insulating spacer, 4 - the holder, 5 - the pressure sensor connectors, 6 - the thickness sensor connectors, 7 - the shaft.

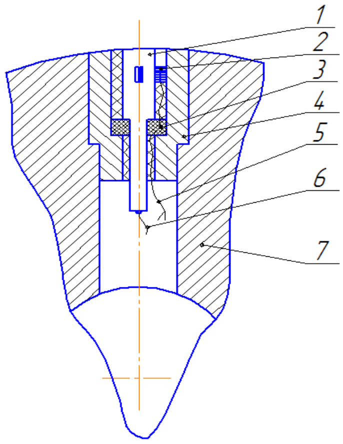

Fig. 3. Sensor for simultaneously measuring the thickness of a lubricating layer and pressure developing in it

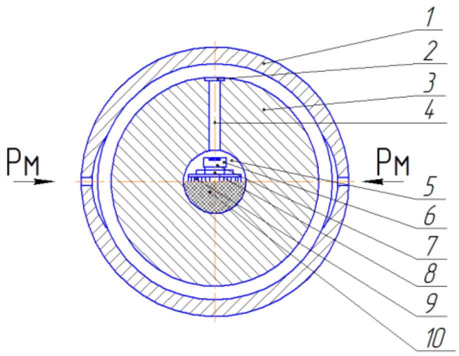

Fig. 4. Meter temperature of the lubricating layer

Analysis of the infrared (IR) temperature measurement methods has shown that they can be successfully used by direct measurement of the lubricating layer temperature of the FFSB around the circumference. The scientists have developed a device [6] using c IR receiver set on the shaft and connected with the shaft surface through a radial passage (Fig. 4). The radial channel on the surface of the shaft is shielded by window made of pure silicon which transmits infrared radiation from the lubricating layer in diapazone from 0 to 300 degrees. During each turn of the shaft the IR-receiver as if scans the lubricating layer temperature on a circumference of FFSB in a loaded zone, in the first lubricating passage, in an unloaded area and in the second lubricating passage. On the Fig. 4: 1- the bearing liner, 2- the shielding window, 3- the shaft, 4- the radial passage, 5- the center passage, 6- the IR-receiver, 7- the receiving element, 8- the board, 9- the spacer, 10 – the bar.

The results of the research including the use of proposed temperature measurer and combined pressure and layer thickness sensor are shown in the figures (in the copies of the oscillograms taken with a loop oscillograph). On the figures 5, 6, 7: the first upper curve: the alteration of the lubricating temperature on the circumference of the lubricating layer; the second curve: the alteration of the lubricating layer thickness; the third: the alteration of the pressure in the lubricating layer; the fourth: the course of the applied thickness load (and zero line for the lubricating layer thickness at the same time). The first two figures are for the bearings with liners made of current-conducting material - babbitt, the third is for bearings made of non-conducting material - polycaprolactan.

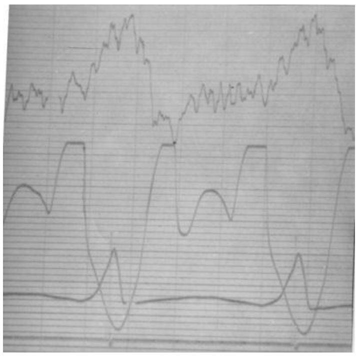

Fig. 5. Waveforms of the three parameters of the lubricating layer obtained by using the loopback oscilloscope

Fig. 6. Waveforms of the three parameters of the lubricating layer obtained by using the loopback oscilloscope

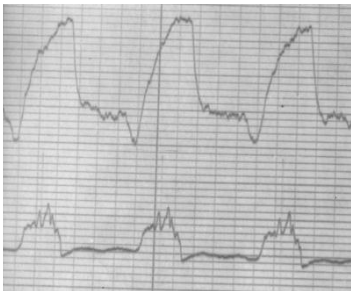

Fig. 7. Waveforms of the three parameters of the lubricating layer obtained by using the loopback oscilloscope

Conclusions and prospects for further researches

The methods and devices offered in the research allow us to examine the operating parameters of the fluid friction sliding bearings in the real time, such as the lubricating layer thickness, the pressure in it and the temperature on the sliding bearing circumference, which allows determining its bearing capacity.

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