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UDC 620.192, 621.432

MODELING OF LOCAL DAMAGE TO BEARINGS DUE TO ENGINE LUBRICATION SYSTEM FAILURE

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Annotation.

The analysis of the condition of the crankshaft bearings of automobile internal combustion engines in the event of oil supply breakage and cessation of them was carried out. It is noted that this failure is one of the common causes of damage to rubbing pairs in an operation. In such cases, the different groups of bearings are often damaged, which cannot be explained within the framework of existing models of lubrication of plain bearings.

The purpose of the work is to develop a mathematical model of oil supply for connecting rod bearings in emergency mode, which would take into account the characteristic features of the bearing design. Depending on the nature of the damage, this helps to determine and explain the causes of bearing damage if it occurs in various modes when operating conditions are broken.

Keywords: crankshaft bearings, lubrication, operating, damage, failure, modeling.

Introduction.

As is known, main and connecting rod bearings in internal combustion engines have different structural oil supply devices [1, 2]. Thus, the main bearings are lubricated with engine oil supplied to them from the engine sump by an oil pump under pressure from the main oil line in the cylinder block. At the same time, oil is supplied to the connecting rod bearings from the main bearings through radial-axial oil channels made in the crankshaft.

Damage to engine bearings is always or almost always local in nature, when some groups of bearings are damaged and others are not, and vice versa [3, 4]. The reason lies in differences in the lubrication conditions of different bearings, as well as in engine operating modes, especially after a failure in the lubrication system.

In the process of investigating the causes of malfunctions in the engine lubrication system, the following main and most common types of damage to crankshaft bearings are usually identified [5, 6]. In accordance with manufacturers' data [7, 8], they can be divided into 3 main types:

1) most or all connecting rod bearings are damaged (Fig. 1),

2) most or all main bearings are damaged (Fig. 2),

3) both the main and connecting rod bearings are damaged (Fig. 3).

Despite these obvious features of bearing damage, practice shows that some specialists, when determining the cause of such failures, do not take into account the observed difference in the degree of damage to the main and conrod bearings. As a result, reports and conclusions indicate causes of lubrication failure that directly contradict the existing signs.

For a more accurate evaluation of all factors affecting the supply of oil to the connecting rod bearings in emergency mode after a failure in the engine oil system, it is necessary to clarify the oil supply diagram from the crankshaft main journal to the conrod journal. To do this, consider a diagram that is as close as possible to the actual design of crankshafts of modern automobile internal combustion engines (Fig. 4).

Purpose of the work can be formulated as determination of the change in pressure in the lubrication hole in front of the conrod bearing after failure of oil supply to the main oil channel (in front of the main bearing). To solve this, it is necessary to find the mass of the oil column in the lubrication hole and the coordination of its center of mass.

This will allow us to calculate not only the pressure in the area of the lubrication hole on the conrod bearing, but also the change in this pressure over time.

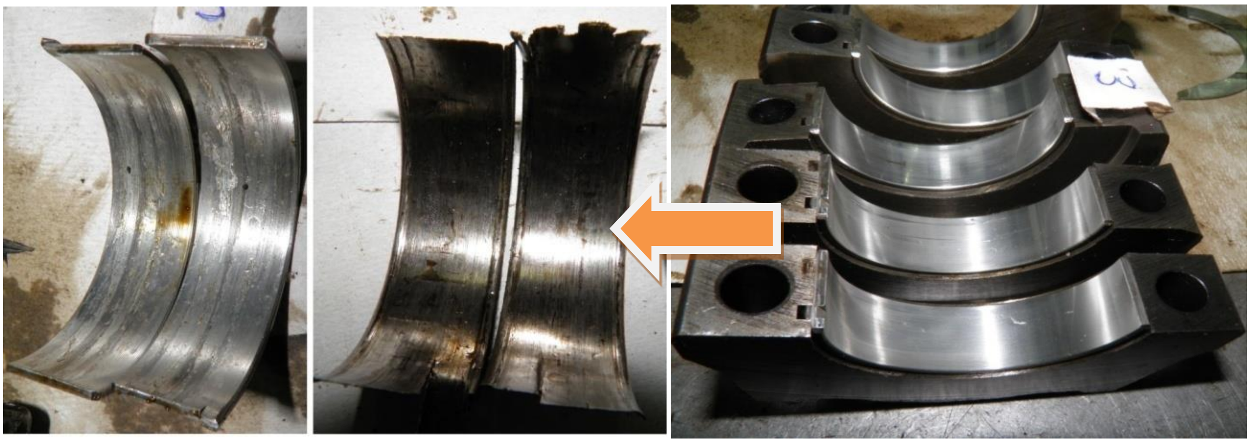

Fig. 1. Damage to the connecting rod bearings (left) in the absence of noticeable damage to the main bearings (right)

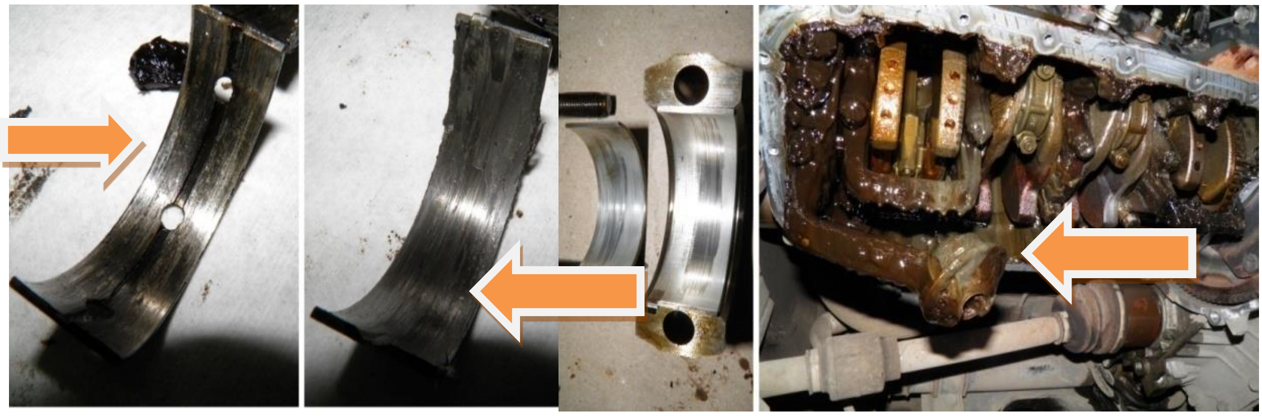

Fig. 2. Damage to the main bearings through scuffing, melting, jamming in the cylinder block (left). It was accompanied by relatively minor damage to the conrod bearings (center)

Fig. 3. Damage to all bearings, both main (left) and connecting rod ones (center and right)

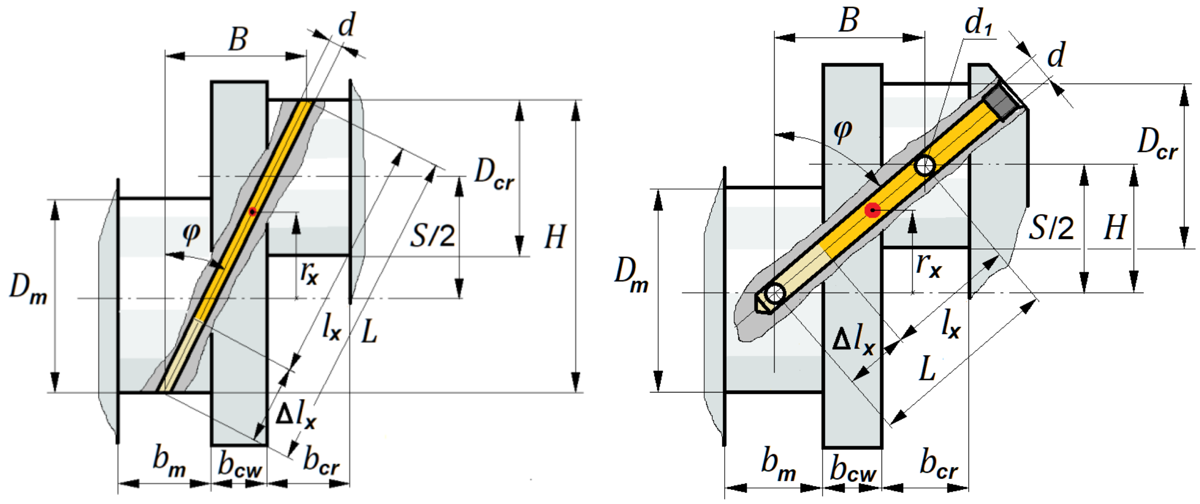

Fig. 4. Calculation diagram of oil supply from the main journal to the conrod journal of the modern (left) and previous years of production (right) engines

Materials and methods. The oil mass in the hole does not remain constant over time, since oil, after the supply to the main bearing is stopped, continues to flow out of the oil hole into the connecting rod bearing. The change in oil mass per unit time will be exactly equal to its mass flow through the conrod bearing, since after failure nothing enters the lubrication hole:

$$\frac{dm_x}{d\tau} = -G_{cr}. \quad (1)$$

where the sign "minus" indicates a decrease in the oil mass as it flows out of the hole.

In accordance with the change in mass, the length of the oil column in the hole also changes over time, since these quantities are proportional. Then from (1) it follows that:

$$\frac{dl_x}{d\tau} = \frac{4}{\pi \rho d^2} G_{cr}. \quad (2)$$

If we set the cross-sectional area that determines the oil flow rate in the bearing f_{cr}, the flow coefficient μ, and the pressure drop in the conrod bearing Δp_{cr}, then the oil flow rate G_{cr}, included in equation (2) can be calculated using the formula

$$G_{cr} = 2\mu f_{cr} \sqrt{2\rho \Delta p_{cr}}, \quad (3)$$

where f_{cr} is the cross-sectional area that determines the oil flow in the bearing,

μ is the flow coefficient, Δp_{cr} is the pressure drop in the conrod bearing.

To a first approximation, without taking into account the eccentricity of the shaft, the area is determined by half of the diametrical working clearance in the bearing (which is usually close to δ_{cr} = 0,05 mm and is further assumed unchanged in the process under consideration). That is $f_{cr} = \frac{1}{2}\pi d\delta_{cr}$. The flow coefficient through this hole depends on the coefficient of hydraulic resistance ξ of the section $\mu = \frac{1}{\sqrt{1+\xi}}$, taking ξ according to [9] in the range of 1.5-2.5. However, taking into account the fact that in a real crankshaft the channel is inclined, the centrifugal force on the column at an angle φ (Fig. 4) can be written as:

$$p_{cr} = \frac{\pi^2}{900}\rho r_x n^2 l_x cos\varphi. \quad (4)$$

where $v = \pi R n/30$ is a peripheral velocity of the liquid column, n is the rotation speed, rpm.

From equation (4), the pressure from centrifugal forces is directly proportional to the radius of the center of mass of the column and its height (length). Substituting the expression (3) into equation (2) and taking into account equation (4) for pressure, we obtain an equation for changing the length of the oil column in the lubrication hole in the form:

$$\frac{dl_x}{d\tau} = -\frac{4\delta_{cr}}{d\sqrt{\rho(1+\xi)}}\sqrt{2(p_{cr-}p_k)}. \quad (5)$$

Equation (5) is a 1st order differential equation resolved with respect to the derivative, which describes the process of changing (decreasing) the length of the oil column in the lubrication hole due to the oil flow from the hole under the action of centrifugal force applied to the column. The solution to equation (5) is found by specifying the time step $\Delta\tau$ and the initial conditions, which, obviously, is the length of the column at the initial time, equal to the length of the channel, i.e. at $\tau = 0$ $l_x = L$.

Results and discussion. The calculation results are presented in Table 1, as well as in Fig. 5, where it is clearly seen that the lubrication of the crankpins of the crankshaft actually disappears after a failure of the engine lubrication system with a certain delay. In this case, the duration of the delay depends both on the design and size of the lubrication channel, and on the crankshaft speed.

Table 1

The engine lubrication system operation in various modes after failure

Operating mode, rpm	1000	2000	3000	4000	5000	6000
Operating time before damage to conrod bearings begins, s						
Modern engines (Fig. 6)	6	3	2	-	-	-
Engines of previous years (Fig. 7)	14	7,5	4,5	3,5	3	2,5
Maximum oil supply pressure for conrod bearings from centrifugal forces, MPa						
Modern engines (Fig. 6)	0,107	0,126	0,160	-	-	-
Engines of previous years (Fig. 7)	0,103	0,111	0,125	0,145	0,170	0,20

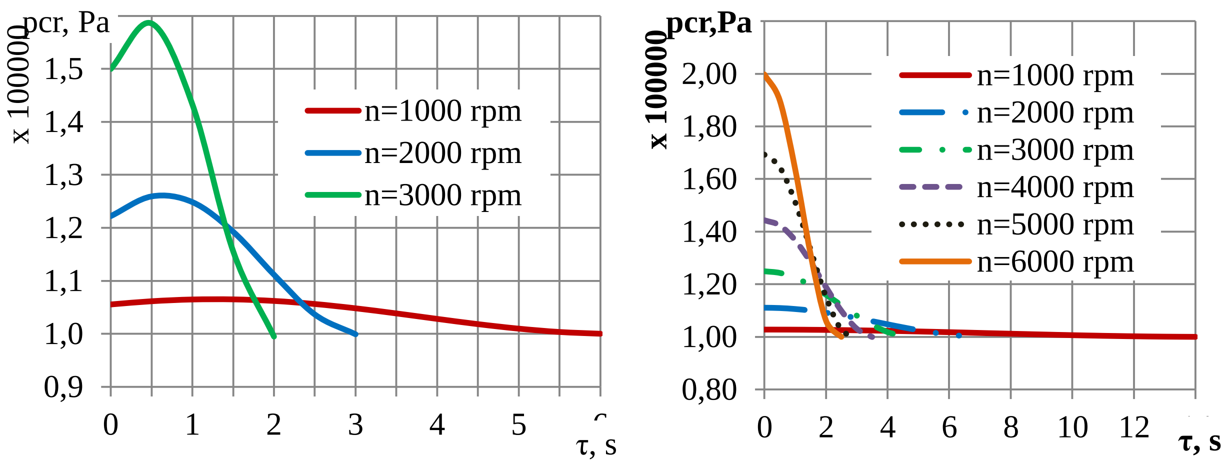

Fig. 5. Change in oil pressure in the crankshaft lubrication hole of modern (left) and older (right) design over time after an oil supply failure, depending on the engine operating mode

Noteworthy is the fact that modes close to the idle mode (1000 rpm) provide the maximum duration of lubrication of connecting rod bearings at low supply pressure.

The calculations performed show that in the event of an emergency interruption of the oil supply to the main bearings, the connecting rod bearings are not immediately left without lubrication. For some time, the oil pressure in them is ensured by the action of centrifugal forces acting on the oil column in the lubrication hole. In this case, the amount of pressure created by centrifugal forces may still be quite sufficient for normal operation of the bearing (albeit under small loads and for a very limited time, until the oil is completely squeezed out of the lubrication hole into the connecting rod bearing).

Then, if we assume that at engine low loads and speeds the conrod bearing remains operational as long as there is oil supply, then Fig. 6 shows the maximum time from the moment of failure to stopping the engine, provided there is no damage to the conrod bearings.

Conclusions. Based on these features of the operation of conrod bearings, the results obtained confirm that it is the presence of centrifugal forces that explains the significant differences in damage to the main and conrod bearings observed in the practice of studying the failure causes. In particular, we are talking about those cases when jamming of the crankshaft in the main bearings is not accompanied by any damage to the conrod ones. This makes it possible to explain some facts known from expert research, including when an oil supply failure is accompanied by the activation of an insufficient oil pressure alarm. If such a failure occurs at high speeds, serious damage to all crankshaft bearings is natural, especially on engines of modern designs. On the contrary, at low speeds the driver has time to react to a failure and stop the engine in a timely manner, and in this case the connecting rod bearings may not be damaged.

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