A method of quality control of plain bearings by their thermophysical properties

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Abstract. The article proposes a method for controlling the quality of plain bearings materials in internal combustion engines that affect the failure of such important and expensive parts as a crankshaft and a cylinder block. Quality control of materials, which have been used for plain bearings manufacture, during repair action of construction machinery and equipment, as well as reduction of cost and duration of technical control operations implementation are among the issues of the day for repair service organizations. In this paper a thermal method of plain bearings materials quality assessment in internal combustion engines is suggested. This method is remarkable for its comparative simplicity; it does not require destruction of the material and application of expensive equipment. A thermal calculation of the compared plain bearings has been improved and carried out, taking into account the obtained thermophysical parameters, the minimum clearances for the coupling “crankpin - liner” for the studied samples of foreign production, which can be used in manufacture as guidelines, have been defined. The calculation of the specific heat, the coefficients of thermal conductivity and linear expansion of plain bearings permits to select the right kind of lubricant, the required clearances, and thus prevent accidental breakdowns after major repairs of internal combustion engines.

1. Introduction

Oil and gas machinery and equipment for construction and repair of oil and gas pipelines equipped with internal combustion engines (ICE) are widely used in industry.

In modern machinery designs, there is a tendency for the development of a non-repairable components strategy or their one-time usage, including such parts, as a crankshaft, a cylinder block, an oil pump body, etc. The repair strategy of domestic enterprises has reduced volumes associated with restoration operations and is mainly engaged in dismantling and assembly operations [1]. However, this stage of repair also necessitates compliance with assembly rules, which include input control of technical parameters of parts.

In the practice of production service repair organizations often try to reduce the cost of repair by using parts analogues [2]. In particular, the replacement of original plain bearings with non-original ones is no exception.

At best, quality control in production practice is carried out by geometrical parameters: liner thickness, tolerance on the measured nip magnitude, nominal diameter and others, but the structure, chemical composition of the material is not controlled [3 - 13]. This is due to the high cost of carrying out these types of analysis, as well as additional loss of time and labor expenditures. In the practice of production service repair organizations often try to reduce the cost of repair by using parts analogues [2]. In particular, the replacement of original plain bearings with non-original ones is no exception.
It is also worth noting that for independent monitoring of such parameters as the minimum admissible and maximum operating clearances in the coupling “shaft neck – bearing liner” of foreign ICE, dealers do not always provide such information, which greatly complicates the search for the cause of tear and crank of the liners.

2. Statement of the problem
At present, one of the urgent issues of ensuring the specified coupling resource “plain bearing - engine crankshaft of ICE” is the use of original parts or analogues that meet the technical requirements established by the manufacturer. The policy of import substitution of products in the Russian Federation, including machine parts, implies mandatory compliance with a given level of quality, which must be confirmed by technical control at different stages of the product life, otherwise there will be an increase in the number of failures and losses during the operation of oil and gas machinery and equipment. Manufacturing plants of machine parts use constructive methods of increasing reliability by using different materials in order to increase durability, endurance of products, and reduce costs.

To solve the problem connected with improving the control quality of plain bearings, it is necessary to control not only the geometrical dimensions, but also the thermophysical parameters. Thereto we propose a method which does not require the use of sophisticated technological equipment, the destruction of the product material, but at the same time identifies differences in materials at the control stage. The solution to this problem is especially important when replacing bearings of foreign manufacture with domestic analogues and justifying the required clearances in the couplings.

The analysis of existing works devoted to the problems of plain bearing failures indicates that cranking, tear of the bearing liners are about 41% of the total number of this part faults.

According to the available sources and researches of the authors, the causes of bearing liners cranking and tear are such factors as use of off-grade engine oil, violation of maintenance regulations, premature failing of the oil and air filters, the oil pump, the failure of the feed and lubrication systems nozzles, etc.

A large number of studies have been devoted to the determination of such parameters as the coefficients of thermal conductivity, thermal diffusivity, and specific heat. To determine these parameters, various means and technologies of measurement are used.

Certain methods and means are used for input quality control of plain bearings. However, they are based on measuring linear parameters at normal temperature (at 20°C).

Separate studies on measuring of the bearing liner thickness are given in the work. At the same time, the test technology itself is not described. Therefore, the authors of this article have proposed a pilot plant, described below. Using this pilot plant, the thermophysical parameters of the liners under study were determined.

It is also necessary to indicate that information on the thermophysical parameters of foreign-made plain bearings is not available currently. The main condition dictated by domestic and foreign manufacturers is the need to use only original parts.

In connection with the mentioned above, it is necessary to look for ways to reduce the cost of technical control of plain bearings quality to verify compliance with the technical regulations of the manufacturing plants.

The solution to this problem will contribute to the implementation of technical control of bearings quality on a larger scale. Determination of the specific heat, thermal conductivity of the plain bearings will make it possible, using the existing procedure, to determine the probability of their failure at the input control stage, and therefore make a more correct decision when choosing parts for quality repairs. This, in turn, will lead to a decrease in the number of premature sudden failures and costs connected with the acquisition of expensive non-recoverable parts (crankshaft, cylinder block), outages of technological machinery and equipment.

3. Methodology
The purpose of plain bearing is to ensure sliding at starting, maintain the required oil film thickness and fatigue strength under various loads, prevent the occurrence of wear products, heat removal to the connecting rod body, the cylinder block, and keep the required clearance at existing thermal loads [6-8].

One of the common types of post-repair failure of plain bearings in the crankshaft of an internal combustion engine is their cranking; tear caused by, among other reasons, the use of analogues that do not correspond to the thermophysical characteristics of original products [7]. To test the quality of plain bearings, the authors proposed a method based on a comparison of the thermophysical properties of the original bearing and its substitute [14]. The tests were carried out on Cummins (USA) original bearings and their replacement manufactured by Mahle (Germany) [1]. General view of the plant for checking plain bearings thickness change depending on temperature and duration of warming is shown in figure 1.

![General view of the plant](image)

Figure 1. General view of the plant for checking plain bearings thickness change depending on temperature and duration of warming.

The data obtained were used in table 1 in the calculation of operation modes of the coupling “crankshaft neck - liner”. The existing thermal method for calculating the sliding bearings implies taking into account the thermal conductivity coefficient, but today there are no experimental data on the nature of changes in engine oil temperatures at the bearing inlet and outlet. Therefore, it was proposed to use the existing method, but taking into account the difference in the coefficients of thermal conductivity of the original and non-original liners [14]. A different coefficient of linear expansion of the studied samples depending on their heating temperature was also taken into account.

Studies have shown that a non-original liner has the linear expansion coefficient by 1.27 times higher than an original one [14].

The calculation and measurement of the parameters of the KT TA-19 internal combustion engine for thermal calculation of sliding bearings have been carried out (table 2).

Table 1. Initial data and results of the experiment.

| Parameters                                      | Cummins Plain Bearing (USA) | Mahle Plain Bearing (Germany) |
|------------------------------------------------|-----------------------------|-------------------------------|
| Heater temperature, °C                        | 260                         | 260                           |
| Sample temperature at the beginning of the experiment, °C | 40                          | 40                            |
Table 2. Technical parameters of the ICE KT TA-19 for the thermal calculation of sliding bearings.

| Parameters for calculation | Average radial load on a gudgeon, kN | The diameter of the crankpin shaft, mm | Gudgeon length (liner width), mm | Nominal crankshaft rotation speed, rpm |
|---------------------------|-------------------------------------|--------------------------------------|----------------------------------|---------------------------------------|
| Value                     | 70.5                                | 101.56                               | 55                               | 2100                                  |

To determine the required minimum clearances, the heat balance between the amount of heat generated by friction and the amount of heat removed due to the circulation of engine oil and through the walls of the bearing and the shaft into the environment is calculated, and the reliability coefficient of hydrodynamic friction is taken into account.

The difference of bearing liners in the coefficient of thermal conductivity by 11% with a clearance of 70 μm increases the temperature of the thermal balance of a non-original liner by 2 °C, i.e. up to 94 °C, which is valid.

Calculated studies were also carried out on the minimum allowable clearance in the coupling under study, provided that the reliability coefficient of hydrodynamic friction is not lower than 1.5. At that the critical thickness of oil film was adopted 4 microns. The value of the minimum allowable gap for both liners was 61 microns for the original liner and 62 microns for the non-original one. According to the Cummins engine repair manual, the minimum clearance was calculated on the basis of the manufacturing plant’s normative tolerances on a liner thickness, diameters of a lower connecting rod head and a crankpin, which amounted to 45 microns. Figure 2 shows the dependence of the reliability coefficient of hydrodynamic friction on the size of the clearance in the “shaft neck -original connecting rod liner” coupling.
As it has been shown by calculations, with the recommended G-Profi MSI Plus Gazpromneft engine oil, according to API SAE 15W40 classification with a viscosity of 14.58 mm$^2$/sec at 100 °C to ensure a given coefficient of hydrodynamic friction, the minimum recommended clearance for an original liner should be increased by 26%, with respect to the calculated one, based on tolerances.

Thus, the application of the manufacturing plant’s regulatory guidelines for the minimum clearance size in the coupling “shaft neck - liner” can lead to their tear, especially if a non-original production liner is used.

The ultimate operational clearance was also determined for the coupling under study, which amounted to 0.138 mm.

4. Results and discussion

The mentioned studies are aimed at elimination of emergency failures of the coupling “liner – crankshaft” caused by the use of substandard liners, because if the materials of a liner are not properly selected, an excessive increase in the liner thickness may occur, as well as changes in the physical-mechanical and thermophysical properties of engine oil. This affects the reduction of a clearance size, the thickness of the oil film, which leads to the direct contact of the crankshaft neck surface with the liner surface and as a result causes the process of scuffing, seizure.

When a clearance size and viscosity of engine oil are reduced, this significantly increases the probability of liners cranking, tears formation.

Steelbabbit liners should be exploited up to 100 °C [2]. The obtained temperatures of the oil film of 92–94 °C, at which thermal equilibrium is reached, correspond to this condition. ICE operation with non-original liners is characterized by a higher temperature of the oil film.

This proves once again that the original liners are more adapted to the hard operating conditions.

Similar experiments were carried out for crankshaft bearing liners, released in 2016 and 2018 for the engine manufactured by Mercedes-Benz, model 6 R 1300/OM 471, used for drilling equipment as well. A significant difference between the liners in the thermal conductivity coefficient (up to 40%) was obtained. On the liner produced in 2018 tarnish colors were formed, which was not observed on the liner of 2016 year. Thus, in the considered case, the clearances in the coupling “crankshaft neck - liner”, regulated by the manufacturing plant, require adjustment. Below there are graphical dependencies of changes in the amount of heat generated by friction and the amount of heat removed by circulating of engine oil and through the walls of the bearing and the shaft into the environment, on the average temperature of the oil film for the above-mentioned liners with a clearance of 61 μm (figure 3).
Figure 3. Determination of the oil film temperature, corresponding to the thermal balance of Mersedes-Benz plain bearings, manufactured 1 - in 2016, 2- in 2018

With the help of graphical dependences, the heat balance temperatures have been determined, which differ by 7.8 °C. The temperature of the liner with a lower thermal conductivity is close to the critical value. That is, such a liner under a slight change in viscosity of engine oil can lead to an emergency failure of the internal combustion engine. Thus, before installing main bearing liners in the process of engine overhaul, the control according to the above mentioned method is recommended.

There arises a need to establish a correlation between the obtained thermophysical parameters and the chemical composition of an antifriction layer, the temperature of engine oil and plain bearings during their operation.

5. Conclusion

Based on the results obtained, it can be concluded the following:

- a) in the course of technical control of plain bearings, in addition to the geometrical dimensions, it is necessary to control the thermophysical parameters;
- b) it is necessary to establish the relationship between the temperature at the inlet and at the outlet from the coupling “shaft neck - liner” zone, the nature of the change in the difference between these temperatures;
- c) an increase in the temperature of the oil film, which corresponds to the heat balance, varies linearly in accordance with a decrease in the coefficient of thermal conductivity;
- d) it is necessary to avoid the operation of liners in heavy mode, at increased temperature conditions, by increasing the minimum clearance in the coupling “shaft neck - liner”.

The quality of the material in the production of plain bearings should be determined by a generalized parameter, and at the same time its testing should not require large financial, time and labor costs. According to the authors, the proposed control method meets these criteria.

The advantage of the proposed express method is the implementation of the quality control of sliding bearings without the use of complex technological equipment. The use of relative values in this case is valid. If it is necessary to determine a more accurate reason for the difference in the thermophysical, physical-mechanical properties of the compared sliding bearings, higher-precision equipment should be used. The proposed method allows reducing the number of measurements with complex technological equipment, thereby significantly decreasing the cost and complexity of technical control. The authors are planning further improving the proposed plant, namely the use of
sensors that continuously record the temperature and thickness of the change of the monitored samples, the development of a program for the prompt calculation of thermophysical parameters. Thus, the introduction of the proposed method and the plant in repair production will reduce the likelihood of using bearings that do not meet the thermophysical parameters of the original products control, and therefore reduce the probability of their tear, cranking during the warranty period of the operating time, costs of conducting expensive analyzes of the chemical composition of materials, loss of time for their implementation, financial costs from failures and equipment outages during the construction and repair of oil and gas pipelines.

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