INVESTIGATION OF GEOMETRIC PARAMETERS OF CAMSHAFT SUPPORTS IN ENGINE CASING COMPONENTS

Andriy Novytskyi[1], Valentyna Melnyk[1], Oleksandr Bannyi[1], Valerii Bustruy[1], Oleksandr Mykhailiuk[2]
[1]National University of Life and Environmental Sciences of Ukraine, Ukraine;
[2]Private higher educational institution “European University”, Ukraine
novitskiyav@ukr.net, vim2607@gmail.com, alexsandrbannyi@gmail.com,
o.mykhailiuk@nubip.edu.ua

Abstract. Restoration of the functionality of automotive and tractor engines represents a complex technological challenge, necessitating an in-depth analysis of design and technological characteristics, as well as a comprehensive assessment of the technical condition of components submitted for repair. The study of the mentioned question involves the analysis of the conditions of operation of the parts of the specified group and characteristic defects. A clearly defined repair route and carefully selected rational restoration methods should be followed. The object of the study is blocks, block-carters of diesel engines, which are sent for repair. The subject of the study is the technical condition of engine housing parts, which changes in the process of performing the assigned functions, under the action and influence of a number of factors: structural, technological, operational. The primary method for studying the block-crankcase is instrumental analysis. It includes assessment and research of the state of geometric parameters, their change, suitability for effective and acceptable repair methods. It has been established that the weak points in the design of the SMD engine block-crankcase are the 2nd, 3rd, and 4th camshaft supports. Their technological, respectively, base surfaces perform the function of sliding bearings and undergo significant wear and tear before the first repair. The results of the measurements show that 23% of block crankcases are not suitable for reuse. To eliminate the specified design flaw, the function of the bearing should be performed by a replaceable sleeve, as in the 1st support. The designed fixture is suitable for use in both laboratory and production environments. The measurement accuracy is characterized by the ratio between the root mean square deviation of the measurement error and the tolerance of the size being controlled. The measurement error values are smaller than the metrologically permissible error values, for the diameters of the camshaft supports, respectively, they are 10 μm with a tolerance of 40 μm. The obtained measurement results and their analysis confirm the appropriate metrological accuracy of the device.

Keywords: defecting, repairability, control-measuring device, technical condition, crankcase.

Introduction

Ensuring the reliable operation of power equipment is becoming increasingly important, as the rate of its performance degradation significantly outpaces the renewal rate of the technical fleet in Ukraine’s agricultural enterprises [1]. To prevent parametric and catastrophic failures of such equipment, which may occur during field operations [2; 3], on roads, or under livestock farm conditions, it is essential to implement fault prediction [4]. In this context, determining the reliability indicators of machines and assessing the residual service life of their components play a crucial role in implementing measures to maintain their operational efficiency [7-9].

In mechanical engineering and equipment maintenance, complex-shaped casing components are of significant importance, being widely used in pumps and compressors, gearboxes, and internal combustion engines [7; 9; 10]. They comprise numerous planar and cylindrical surfaces that require high-precision machining, considering diametral and linear dimensions, shape, and mutual positioning. Given the critical role of the engine block and the significant costs associated with its restoration, an accurate assessment of its technical condition throughout engine operation is essential. This can be achieved through the implementation of modern digital technologies and expert systems, which enable the identification of wear patterns and determination of residual service life [5; 6].

To enhance the operational characteristics of engines and extend their service life, it is crucial to detect damage and defects in casing components, particularly in the ventilation channels of the cylinder head crankcase, which are made of aluminum alloy using the gravity casting method. Detection of defects, damage and analysis of possible causes of their occurrence is proposed to be carried out using the method of fishbone diagram analysis, which, according to the authors [11], increases production efficiency and helps maintain high operational characteristics of engines.

The manufacturing process of engine casing components, such as the right crankcase cover, aims to ensure high product quality and reduce the likelihood of defect formation during subsequent use. Several authors [12] have dedicated their research to modeling the aluminum alloy die-casting process using AnyCasting software. As a result, they identified optimal process parameters that ensure high-quality castings without apparent defects, fully meeting the requirements of the manufacturing process.

Due to the low efficiency of manual detection of defects, such as hydraulic channel disruption in the engine cylinder block, and the limited ability of traditional defect detection methods to generalize design features, the authors of scientific papers [13] proposed an improved model for detecting destruction of water channels in the cylinder block, which is based on a fast neural network RCNN and allows significantly increasing the accuracy of defect detection. To enhance the capability of detecting minor damage, a Feature Pyramid Network (FPN) has been applied. The improved network achieves a defect detection accuracy of over 80%.

The operation of the crankcase as part of the engine significantly affects the operating costs of mobile power equipment, since timely and accurate determination of its technical condition is crucial for ensuring the principles of operational reliability. At the same time, the available guidance materials and recommendations do not always contain a complete and sufficiently substantiated approach to repair, which necessitates the improvement of diagnostic and restoration methods.

The study aims to enhance the efficiency of monitoring and measuring the geometric parameters of casing components, using the engine block as an example, under repair production conditions. The primary focus is on deviations in shape, the positioning of key technological surfaces, and the geometric parameters of complex casing components. The analysis of existing fixtures and methods used in serial and mass production has revealed their insufficient adaptability to the needs of machine repair. In this regard, a detailed examination of the structural and technological features of this group of components is necessary to develop more effective approaches to their diagnostics and restoration.

The purpose of the research is to improve the quality of defect detection in internal combustion engines undergoing repair by developing specialized devices for monitoring and measuring deviations in the shape and location of the technological surfaces of block crankcases.

Materials and methods

Coaxiality tolerance of camshaft support holes TPC_c is within 50 µm, in accordance with the technical requirements for repair. Thus, the eccentricity deviation (ERC) must not exceed the specified values, i.e. $TPC_c \leq 40$ µm. The adopted values are justified by dimensional analysis of the “shaft journal – plain bearing” connections, which operate effectively with minimal functional clearance. Different permissible coaxiality values are due to varying initial clearances in the joints. According to the technical requirements, the average clearance in the camshaft-support connection is S_{avg} = 135 µm. The permissible measurement error values for the camshaft support diameters are as follows $[\Delta]_{cs}$ = 10 µm under a tolerance of ITD_{cs} = 40 µm.

The main indicator that allows the use of a particular measuring instrument is its total measurement error, which includes all components that depend on the design and metrological characteristics of the instrument, installation dimensions, basing, temperature effects, etc. The values of permissible errors in measuring linear dimensions up to 500 mm are standardized and set depending on the tolerance value assigned to the size. Determination of errors in measuring linear dimensions of the project is based on the results of a preliminary analysis of errors of measuring instruments (DSTU 2681-94, DSTU OIMLR 34:2014).

In recent decades, both traditional and modern methods for assessing the technical condition of components - such as optical, physical, and mechanical techniques - have been employed to ensure the reliability of machinery and equipment in agricultural production. These methods enable the diagnosis of machine conditions during scheduled maintenance [7; 11]. In this study, the reliability indicators of the internal combustion engine were evaluated based on the analysis of defects in the structural elements of the engine block, which had a positive impact on its performance.

Analysis of the obtained data shows that due to the high complexity of controlling the prepared surface, it is advisable to use flaw detection methods designed to examine local areas of the block-crankcase structure. In this study, such methods were used to detect defects in the block-crankcase of a tractor, which allowed to increase the efficiency of diagnostics.

The verification of coaxiality deviations of the camshaft's middle support holes relative to the outer supports was carried out using a specialized fixture developed by the Department of Machinery Reliability at NUBiP of Ukraine. The design of the fixture includes a housing in the form of a hollow tube, inside which four fixed and two clamping supports are positioned according to the locations of the engine block outer supports. The supports are evenly distributed around the perimeter at an angle of 120°. The fixed stops were ground in a single setup to the nominal size of the support holes (98 + 0.02 mm). Two indicator heads with a graduation of 0.01 mm are mounted in the housing on the same axis as the fixed stops, allowing for determination of coaxiality deviations.

Before measuring the bearings of the distribution shaft, the block was positioned vertically using a tilt stand (R776E). The fixture was sequentially installed through the first and subsequent bearing holes of the block, where it was automatically centered in the outer bearings by means of movable spring-loaded stops. After smoothly rotating the fixture, the indicator legs were positioned at the lower points of the second and third bearing holes of the block. The indicator readings were set to "zero" through the inspection windows, and the deviations of the middle bearings relative to the outer ones were determined based on the maximum deflection of the indicator needles during the gradual rotation of the fixture, following the measurement scheme (Fig. 1).

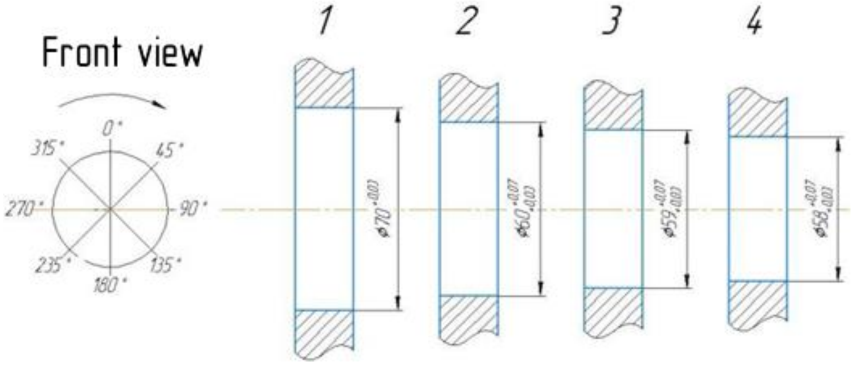

Fig. 1. **Measurement scheme of support hole diameters and deviations in coaxiality of the middle supports relative to the outer supports of the camshaft using the PVK-2 fixture**

The magnitude of misalignment deviations is largely influenced by deformations in the shape of the bearing holes. Therefore, measurements of their diameters are typically conducted according to a predefined scheme (Fig. 1), allowing for assessment of deviations from a cylindrical shape and determination of the misalignment error. An NI 50-160 dial bore gauge is used for these measurements.

Results and discussion

During the inspection of coaxiality deviations of the middle supports relative to the outer ones and obtaining their actual values, it is necessary to measure:

- the diameters of the holes 2, 3, 4 (dimensions according to the drawing

$$\varnothing 60^{+0,070}_{+0,030}, \ \varnothing 59^{+0,070}_{+0,030}, \varnothing 58^{+0,070}_{+0,030},$$

  in accordance) of the camshaft supports, according to the measurement scheme. In the presence of cylindricity deviations (EFZ), determine their values (ovality);
- coaxiality deviations EPC_{cs}, of the middle camshaft support holes relative to the outer ones, using the PVK-2 fixture.

In laboratory conditions, the method of installing devices, measurement schemes and techniques, and operating time for performing measurements are practiced.

Under production conditions, micrometric measurements of the specified parameters of 30-40 engine blocks undergoing their first overhaul are planned. The obtained measurement values must be mathematically processed and analyzed to assess the metrological accuracy of the fixture designs.

The accuracy of the camshaft bearing hole alignment plays a key role, as it affects the complexity of assembly and the engine's longevity after repair. Significant deviations can lead to partial or complete shaft jamming, while even minor errors alter the required clearances in plain bearings, noticeably reducing the service life of the connections.

To ensure high accuracy in inspecting the condition of the engine block during defect analysis, the use of specialized devices is advisable. One such device is the PVK-2 fixture (Fig. 2), which is used to check the coaxiality deviations of the middle support holes relative to the outer ones. Structurally, the device consists of a housing containing four fixed and two clamping stops, positioned in accordance with the outer supports of the block. The stops are positioned at an angle of 120° to each other. The fixed stops are ground in a single setup to the nominal size of the support holes (98 + 0.02 mm). In the same plane as the fixed stops, two indicator heads with a graduation of 0.01 mm are installed in the housing.

Before starting the measurements, the engine block was fixed in a vertical position using a tilting stand. The device was sequentially inserted through the upper and subsequent supports of the block, automatically centering itself in the outer supports due to the spring-loaded movable stops. After smoothly rotating the device, it was positioned so that the indicator legs were in the lower position in the area of the 2nd and 3rd main supports. Then, through the inspection windows, the indicator scales were set to zero, and the misalignment of the middle supports relative to the outer ones was determined based on the maximum readings of the indicator needles during device rotation.

A similar method is used to determine the runout of the camshaft bearing holes using the PKV-2 device, which consists of a housing with two built-in dial bore gauges with a graduation of 0.01 mm. The measuring movable surfaces of bore gauge 5 are positioned in the same plane as the fixed stops, which are ground to the final dimensions of the outer support holes. Measurements or inspections are recommended to be performed with the engine block in a vertical position. After installing the device into the block, the dial gauge indicators are set to zero.

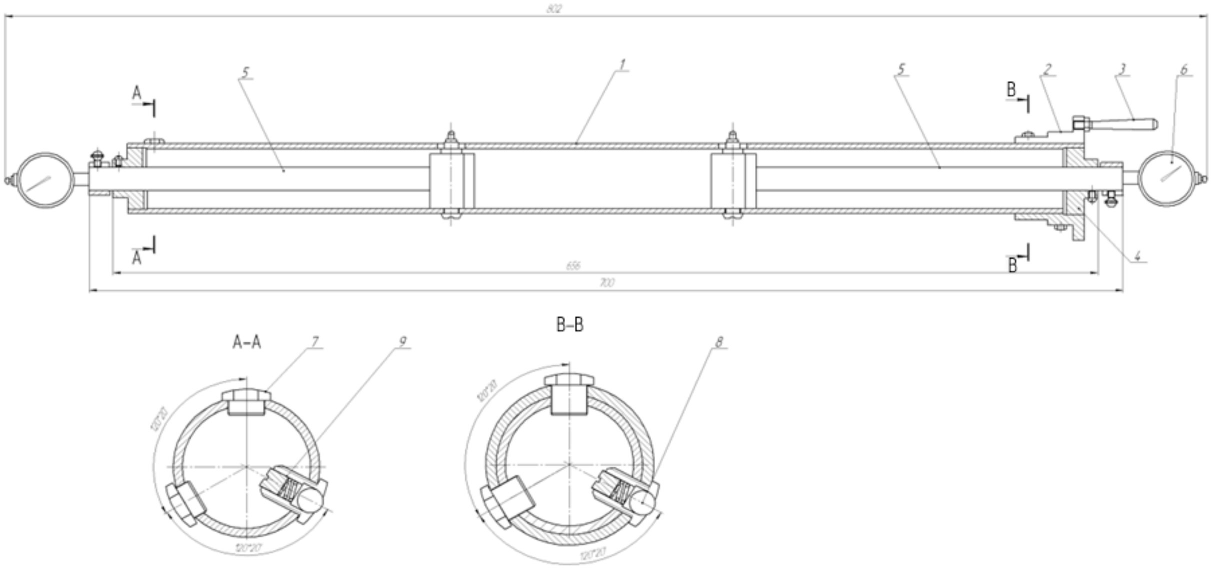

Fig. 2. **The PKV-2 device for checking the alignment of the camshaft middle bearing holes relative to the outer bearings consists of:** 1 – housing; 2 - flange; 3 – handle; 4 – pressing stop; 5 – collet; 6 – dial gauge head; 7 – pressing stop; 8 –ball; 9 – leg

According to the presented methodology and measurement scheme (Fig. 1), the deviations of the camshaft middle bearings relative to the outer bearings were measured. For this purpose, the maximum deviation of the dial gauge readings from the zero mark was recorded.

The geometric parameters of the cylinder blocks intended for reuse were measured under production conditions according to the established methodology. To obtain reliable statistical data, 25 visually suitable blocks were selected. Based on the measurement schemes, micrometric charts were created to record the measurement results, which served as the initial data for calculating the arithmetic mean and root mean square values, as shown in Figures 3 and 4.

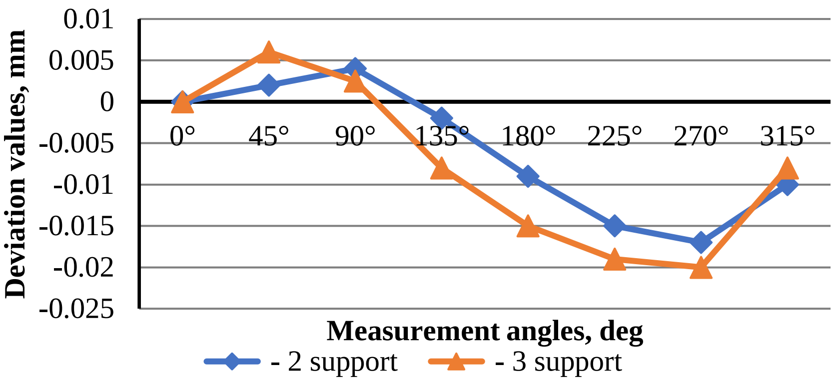

Fig. 3. **Average values of misalignment deviations of the middle camshaft supports relative to the extreme ones**

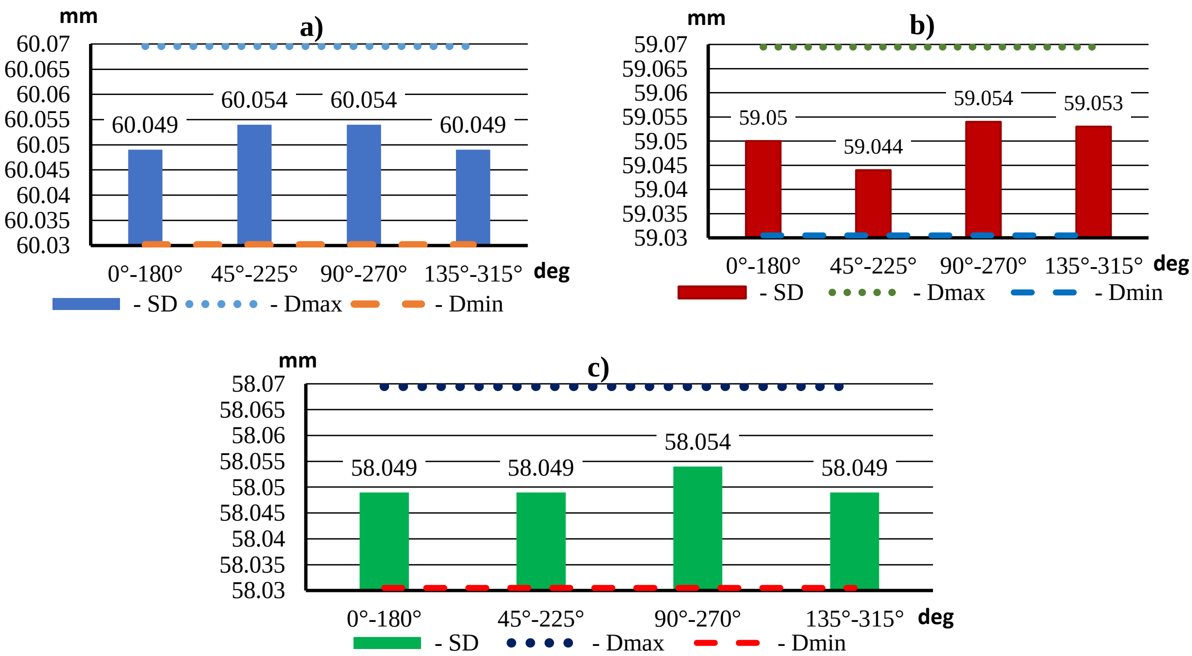

Fig. 4. **Root mean square values of the actual dimensions (mm) of the camshaft supports relative to the horizontal plane (deg):** a – 2*nd* support; b – 3*rd* support; c – 4*th* support

It should be noted that the weak point in the design of crankcases of this modification is the 2nd, 3rd, and 4th camshaft supports. Their technological, and consequently reference surfaces, function as plain bearings and experience significant wear before the first repair. The measurement results indicate that 23% of the blocks are unsuitable for reuse. To eliminate this design flaw, the bearing function should be performed by a replaceable bushing, similar to the one in the 1st support.

Analysis of the measurement results obtained using indicator devices in repair production conditions revealed that deviations from alignment or displacement of the middle camshaft supports relative to the extreme ones can range from -0.02 to +0.007 mm, which is beyond the diameter tolerance. The maximum value was recorded for the third camshaft bearing. The results obtained show that the largest deviations are found in the horizontal plane (2250-2700) with a simultaneous displacement to the lower part of the vertical plane. This direction of displacement may be due to the zones of maximum values of forces acting during the engine operation. Deviations within the range of -0.03 to + 0.07 are considered acceptable for determining the suitability of internal combustion engine crankcases for further operation.

The analysis of the effectiveness of experimental studies on the quality of defect detection in internal combustion engine components confirms that, in recent years, the majority of researchers have developed and implemented various defect detection methods using digital technologies [6, 8, 9]. However, most of these methods do not involve the use of instrumentation that would provide full control of technological processes of defect removal during the restoration of parts in machine repair conditions [7].

Some researchers employ digital diagnostics to model and enhance the functioning of cylinder block systems [8; 11; 15]. Studies and recommendations [11] focus on improving the quality of cylinder blocks and identifying critical areas for defect detection during manufacturing. However, as noted in the conference materials [7], these recommendations are not always suitable for assessing the technical condition of used cylinder blocks that require restoration [15]. Research [14] indicates that an accuracy of up to 88% in defect detection within the cooling system can be achieved using such methods.

Although the mentioned methods are effective for detecting defects on external surfaces, they do not allow for the assessment of the structural parameters of cylinder blocks, particularly the alignment of the main bearing bores.

The need for monitoring or measuring misalignment of the supports is justified by the fact that improper installation of the camshaft can lead to a reduction in operating clearances.

Conclusions

1. In our cases, the measurement error values are smaller than the metrologically permissible values for the camshaft support diameters – $[\Delta]_{cs}$ = 10 µm with a tolerance of ITD_{cs} = 40 µm.
2. The aim of this study was to address the issue of extending the service life of engines during their secondary use by preventing the assembly of cylinder blocks with deviations beyond the permissible accuracy norms for the shape of technological surfaces and geometric parameters.
3. This objective was achieved through the development of a fixture design and a methodology for its use, ensuring a reliable assessment of geometric parameters with a high level of efficiency in defectoscopy.
4. Processing of measurement results using indicator devices in production conditions showed that misalignment or displacement of the middle main bearings relative to the extreme ones can range from -0.02 to + 0.007 mm, exceeding the diameter tolerance. The largest deviations are observed in the horizontal plane (225° to 270°) with displacement towards the lower part of the vertical plane. This type of displacement is explained by the zone of maximum forces acting during engine operation.
5. Laboratory testing of the fixtures and metrological assessment of permissible measurement errors showed that deviations within the range of -0.03 to + 0.07 mm are acceptable for determining the suitability of engine blocks for further use.

Author contributions

Conceptualization, A. N., V. M., methodology, V. B., validation, A. N., V. M., O. B., V. B. and O. M., formal analysis, A. N. and V. M., data curation, O. B., writing – original draft preparation, O. B. and V. B., writing – review and editing, A. N. and V. M., visualization, O. B., project administration, A. N., funding acquisition, A. N., V. M., O. B., V. B. and O. M. All authors have read and agreed to the published version of the manuscript.

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