UDC 621.787.4
DOI: 10.15587/2706-5448.2026.359283

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IMPROVING THE EFFICIENCY OF FAULT-FINDING WORK DURING CAMSHAFT REPAIRS

The object of this research is the process of inspecting the camshafts of internal combustion engines in the context of vehicle repair production. As the inspection of a camshaft is a highly labor-intensive process due to the need to measure a large number of its components, there is a pressing need to improve the efficiency of inspection work.

An approach is proposed for inspecting components with multiple worn surfaces, which involves determining the wear on one surface and calculating the wear on another using a regression model that establishes a quantitative relationship between the wear on the surfaces. This allows for a significant reduction in the labor intensity of defect detection work without compromising the reliability of the technical condition assessment of the component. This approach has been implemented using the example of defect detection on the camshaft of a KamAZ lorry engine.

A hierarchical diagram of the camshaft structure as a system, where its individual elements are subsystems, is examined. It is noted that, among the surfaces of the camshaft, the cams and journal necks are subject to the most intense wear. A statistical model of camshaft wear has been constructed in the form of a linear regression equation, establishing a quantitative relationship between the wear of the journal necks and the cams.

The practical significance of the proposed approach lies in improving the efficiency of defect detection work by reducing the volume of measurements by a factor of 2.6, which reduces the labor intensity of defect detection by 40%. When inspecting a batch of 100 camshafts, this results in a saving of 3,200 measurements, or over 36 hours.

The results of this research have practical significance and are important for automotive repair enterprises engaged in the repair of internal combustion engine components.

Keywords: *distribution shaft, defect detection, wear measurement, statistical model, regression equation, quantitative correlation.*

Received: 18.02.2026
Received in revised form: 17.04.2026
Accepted: 27.04.2026
Published: 30.04.2026

How to cite

Shepelenko, I., Krasota, A., Krasota, M., Vasylenko, I., Solovuch, A. (2026). Improving the efficiency of fault-finding work during camshaft repairs. Technology Audit and Production Reserves, 2 (1 (88)), 25–31. https://doi.org/10.15587/2706-5448.2026.359283

1. Introduction

The wear of machine parts depends on numerous and varied causes that are not interrelated in any way and, taken together, are random [1].

Determining the extent of wear on parts in a repair production context is essential as one of the criteria for selecting restoration methods. The economic viability of the restoration methods used depends directly on the extent of wear on the surfaces, as this determines the duration of the restoration process, material and energy costs, and the labor required for repairing the parts [2].

To develop recommendations for improving the manufacturing or restoration technology of any component, such as camshafts, it is necessary to have an understanding of the characteristic wear patterns of the components, as well as the patterns of their distribution [3].

The problem of component restoration is complex in nature. To address it, a systematic approach may be employed, which involves a methodological framework for research based on viewing the object as a system. In this context, a component, as an object of research, can be represented as a set of elements linked by interaction, which consequently act as a single entity in relation to the surrounding environment [4].

A component, as an object of manufacture or renovation (restoration), also corresponds to the key concepts of a system [5]. Possessing integrity, it consists of interrelated parts; its functional and structural components depend on the type and complexity of the component's design and its purpose. Consequently, it is entirely appropriate to consider a part as a system; it can be divided into subsystems or simply into elements. The main elements of a part are the mating surfaces. The number of structural components depends on the type and complexity of the part's design and its purpose [6].

On the other hand, a component – as a product of the automotive repair industry representing a basic subsystem of a vehicle – is characterized by a multitude of parameters that determine its final condition [7].

The findings of this research [8] also confirm that each component can be regarded as a system, and its structural elements are subsystems. Therefore, determining the technical condition of a component, its characteristic defects and wear requires the use of a systematic approach based on viewing objects as systems [9].

From the perspective of a systems approach, one can also consider one of the most heavily loaded and rapidly wearing components of the gas distribution mechanism in modern automotive and tractor internal combustion engines (ICE) – the camshaft.

Among the working surfaces of camshafts, the cams and journal necks are subject to the most severe wear. During engine repairs, camshafts are encountered with wear limited to the journal necks, wear limited to the cams, or shafts exhibiting both types of damage [10].

The choice of technology for repairing the main defects of the camshaft – the cams and journal necks – depends largely on the extent of their wear. The nature of the wear on the components is determined

ISSN-L 2664-9969; E-ISSN 2706-5448

by the processes occurring on their surfaces. Data on the patterns of surface wear of parts provide the necessary information for the correct design and selection of methods for the restoration and strengthening of parts. However, existing sources on the repair of internal combustion engine parts have not provided comprehensive information regarding the wear condition of cams and camshaft journals.

It is known [11], however, that statistical methods are appropriate for investigating component wear. A highly reliable method for determining the numerical characteristics of component wear is micrometer measurement [12].

Although wear is, in most cases, random in nature, the research [8], using the example of a hydraulic pump gear, established a certain correlation between the wear of individual working surfaces of the component.

It should be noted that in some cases, measuring part wear and inspecting for defects is highly labor-intensive due to the large number of components. For example, a single camshaft has 16 cams, each of which must be measured in two cross-sections. In addition, five bearing journals must be measured, with four measurements required for each, in two planes and two cross-sections. Consequently, there is an urgent need to improve the efficiency of measuring camshaft defects.

A critical analysis of the cited scientific researches has revealed the following.

The paper [1], which emphasizes the importance of predicting and assessing wear processes in internal combustion engine components, lacks methods for quantitatively evaluating the relationship between the wear of individual surfaces within a single component.

The authors of [11] performed a statistical analysis of the wear parameters of freight wagon brake blocks. However, this work is limited to a one-dimensional analysis without establishing regression relationships between the wear of different surfaces of the component.

A similar shortcoming is found in the work [10], which is devoted to the design of a manufacturing process for the restoration of camshafts in marine engines. The issue of quantitatively assessing the relationship between the wear of cams and journals is not addressed in the work, which significantly reduces its scientific value.

The importance of ensuring tribological measurements is emphasized in [12]. The authors propose a tribotester for measuring component wear. However, the proposed approach is geared towards laboratory research and is not suitable for mass inspection of components in automotive repair production settings.

Due to the complexity of application, the use of thermodynamic methods for monitoring and evaluating wear processes in automotive repair production appears impractical [3].

Thus, the data presented allow the following generalizations to be made.

In the research considered, the wear of individual surfaces within a single component is examined independently, without establishing a quantitative relationship between them.

There are no researches on the development of a wear model for the component, nor on approaches to reducing the labor intensity of defect detection work during the repair of camshafts.

The proposed theoretical and laboratory methods for assessing the wear of individual components are not suited to the conditions of the automotive repair industry and are unsuitable for mass defect detection.

Conducting specialized research to identify the main patterns of wear on cams and camshaft journals will provide an objective picture of the processes occurring during the component's operation. Furthermore, the development of a statistical wear model will provide a mathematical representation of the component, the characteristics of which determine the type, degree and interrelationship of wear corresponding to real operating conditions.

The data presented justify the relevance of conducting research and enable the formulation of the research objective and the aim of research.

The object of this research is the process of inspecting camshafts in internal combustion engines within the context of automotive repair production.

The aim of this research is to establish a quantitative relationship between the wear of the cams and the camshaft journal bearings:

To achieve this aim, the following objectives were addressed in the research:

1. To construct a hierarchical diagram of the camshaft structure.
2. To conduct a statistical analysis of the wear data for the cams and journals of the camshaft.
3. To derive a statistical model of camshaft wear in the form of a regression equation, which will allow the amount of wear on one surface to be determined with a predetermined probability based on the known value of the wear on another element.

2. Material and Methods

The procedure for constructing a statistical model of camshaft wear was as follows:

1. Collection of preliminary data on the wear of cams and camshaft journals by means of micrometer measurement.
2. Calculation of the minimum required sample size.
3. Determination of the numerical characteristics of the random sample.
4. Checking the collected information for outliers.
5. Selecting a theoretical distribution law and determining its parameters.
6. Creating a mathematical model of the worn component in the form of a system of regression equations describing the relationship between cam and camshaft journal wear.

Preliminary data was collected at vehicle repair workshops in Kropyvnytskyi by measuring the working surfaces of the camshaft on a KamAZ lorry engine – specifically the cams and journals – using a micrometer.

To determine the height wear of the cams, a MK-50-1 micrometer (DSTU GOST 6507:2009) with a graduation of 0.01 mm was used. To measure the wear on the camshaft journals, an MK-75-1 micrometer (Intertool, China) compliant with DSTU GOST 6507:2009 was used.

The wear on the camshaft components – cams and journals – was determined by direct measurement of their dimensions

$$I = I_{meas} - I_{nom}, \quad (1)$$

where I_{meas} – the measured dimension of the element, in mm; I_{nom} – the nominal dimension of the element, in mm.

The cam wear was measured along its height, as this component is subjected to the highest loads and therefore experiences the greatest wear. The cylindrical part of the cam that comes into contact with the tappet when the valve is closed is, accordingly, subjected to the least load and will therefore wear the least.

For a detailed research of wear, each cam and neck was measured according to the diagrams shown in Fig. 1.

In accordance with the diagram shown (Fig. 1, *a*), the degree of wear is determined for each cam by taking measurements in two cross-sections, I and II. The wear of the camshaft journals is measured in two cross-sections, I and II, and in two mutually perpendicular planes, A–A and B–B (Fig. 1, *b*).

The choice of the micrometer method for measuring wear is due to its sufficient accuracy (graduation of 0.01 mm) at the maximum wear limits of 1.6 mm for the cam and 0.12 mm for the support journals, which meets the requirements of the technical documentation for the repair of KamAZ engines. Unlike other measurement methods (profiling, etc.), this method does not require specialized equipment, can be carried out directly at the defect detection station, ensures the shortest measurement time and lowest cost, and can be used in mass repair production conditions.

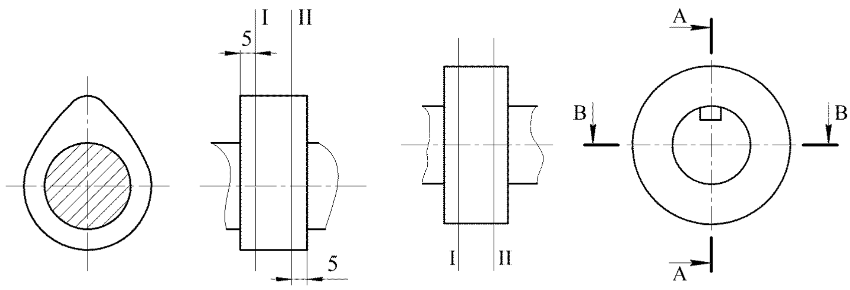

Fig. 1. Schematic diagram for measuring wear on the working surfaces of camshafts: *a* – cams; *b* – journals

The experimental data obtained were analyzed using methods of mathematical statistics in accordance with the procedure described in [8].

As the number of measurements increases, the accuracy of experimental researches improves; however, on the other hand, the cost of conducting experimental researches also rises. Therefore, in such cases, a sampling method is employed. The calculated sample statistical parameters allow the parameters of the population to be estimated with a certain confidence level.

Therefore, the number of measurements was calculated using the formula

$$n=\frac{t^2_{\alpha,n}\cdot S^2_{a_i}}{\varepsilon^2\cdot\bar{a}^2}, \qquad (2)$$

where ε – the relative measurement error, $\varepsilon = 0.1$; S_{a_i} – the standard deviation; $\bar{a}$ – the mean wear value, mm; t_a – the Student's *t*-value

The minimum required number of observations was determined after receiving the results for 16 camshafts ($N = 16$), based on data regarding the wear condition of the cam surfaces.

With a confidence level of $\alpha = 0.95$ and degrees of freedom $f = N - 1 = 16 - 1 = 15$, let's obtain a Student's *t*-value of $t_\alpha = 2.131$. A preliminary analysis of cam wear yielded a mean value $\bar{Z} = 1.171$ and a standard deviation $S_z = 0.385$.

For the entire series of observations, the wear interval of the individual components of the camshaft was determined as follows

$$\bar{Z}-t_\alpha\cdot S_{\bar{\bar{Z}}}\le\bar{Z}\le\bar{Z}+t_\alpha\cdot S_{\bar{Z}}. \qquad (3)$$

The absolute error is equal to

$$\Delta_{\bar{Z}}=t_\alpha\cdot S_{\bar{a}}. \qquad (4)$$

The relative error is

$$\varepsilon_{\bar{Z}}=\frac{\Delta Z}{\bar{Z}}100\%. \qquad (5)$$

Thus, the number of minimum measurements is

$$n=\frac{2.131^2\cdot 0.385^2}{0.1^2\cdot 1.171}=49.09. \qquad (6)$$

A minimum sample size of 50 shafts was selected for measurement.

Statistical analysis of the data on wear of the cams and camshaft journals was carried out using the STATISTICA 12 software package (StatSoft, USA) [13].

Regression analysis was used to determine the relationship between wear on the cam surfaces and the journal surfaces. The quality and adequacy of the model were verified using the coefficient of determination and Fisher's criterion.

The use of statistical analysis of experimental data is due to the stochastic nature of component wear, which depends on a number of random factors. Unlike deterministic relationships, which are unable to adequately describe the distribution of wear, the use of statistical analysis allows, with a given confidence level, the numerical characteristics of the wear distribution to be obtained and the correlation relationships between individual wear patterns of the component to be established. The STATISTICA 12 software package (StatSoft, USA) was selected as the tool for statistical processing and regression analysis, ensuring the reproducibility of calculations.

3. Results and Discussion

3.1. A schematic representation of the camshaft

Taking into account the fundamental principles of the systems approach, the following hierarchical structure of the camshaft in a tractor engine is proposed (Fig. 2, 3).

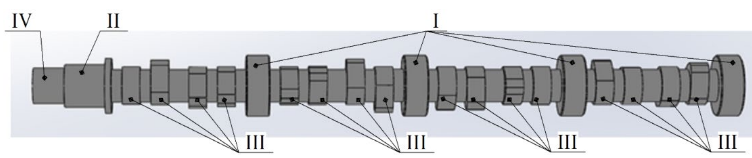

Fig. 2. Structure of the camshaft: I–IV – functional parts of the component

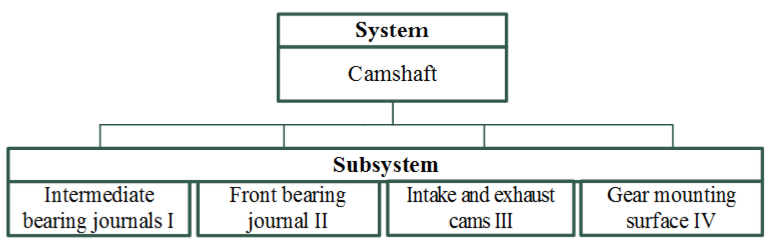

Fig. 3. Hierarchical diagram of the distribution shaft structure

Among the surfaces of the camshaft, the cams and journal bearings are subject to the most severe wear. It is therefore these components of the subsystem that require further in-depth investigation.

3.2. Statistical analysis of camshaft cam and journal wear data

The initial processing of the experimental wear data was carried out separately for each component (cam and journal) in accordance with the measurement procedure (Fig. 1).

After obtaining the results of the initial processing of the experimental data for the cams of a specific batch, they were checked for 'outliers'. Consequently, 18 values were removed from the overall series of cam wear data.

The results of the re-analysis of the experimental data showed that within individual cams in cross-sections I and II, a uniform distribution pattern is observed. To confirm or refute this hypothesis, the

 ISSN-L 2664-9969; E-ISSN 2706-5448

randomness of the discrepancy between the two sample variances was determined.

An analysis of the sample variances showed that the difference between them, with a confidence level of $\alpha = 0.95$, can be considered random, which allows to combine these samples in sections I and II.

The results of recalculating the point estimates of the random variable for the combined sample of cams are given in Table 1.

Table 1

Point characteristics of the random variable representing cam wear

Parameter name	Value
Number of valid measurements, *N*	782
Percentage of valid values, %	97.7
Mean, mm	1.132
Median	1.16
Frequency mode	10
Minimum	0.51
Maximum	1.78
Variance	0.124
Standard deviation	0.352
Coefficient of variation, %	31.09
Skewness	–0.133
Kurtosis	–1.05

The next stage of the research involved determining the theoretical distribution law and reconciling it with experimental data on cam wear.

To establish the theoretical distribution law, it is possible to focus on the coefficient of variation *V*. When the coefficient of variation is $V < 33\%$, the population is considered homogeneous and the mean value is considered typical. This is a necessary condition for the use of parametric methods and the assumption of a normal distribution. If the coefficient of variation takes a value of $V < 33\%$, the population is heterogeneous, indicating that the distribution is asymmetric. In such cases, the normal distribution is usually rejected, and another distribution law (e. g. Weibull) is adopted.

Given that the coefficient of variation is 31.09% (Table 1), it is possible to assume that the distribution of cam wear values on the camshaft follows a normal distribution. These assumptions can also be confirmed by the closeness of the measures of central tendency: the mean (*Mean* = 1.13) and the median (*Median* = 1.16) are quite close in value.

Therefore, based on the set of characteristics, cam wear follows a normal distribution. The application of Pearson's χ^2 goodness-of-fit test confirmed the validity of the chosen theoretical distribution.

The data obtained allowed to calculate the differential and integral functions and plot their cam wear curves (Fig. 4).

For a sample size of $n = 50$ and a confidence level of $\alpha = 0.95$, let's find the Student's *t*-value $t_a = 2.131$. Thus, with a confidence level of $\alpha = 0.95$, the wear on the camshaft cam lies within the interval

$$1.032 \le \overline{Z_{cam}} \le 1.232. \quad (7)$$

The absolute error is

$$\Delta_{\overline{Z_{cam}}} = 0.1. \quad (8)$$

The recovery error is equal to

$$\varepsilon_{\overline{Z_{jour}}} = 8.83\%. \quad (9)$$

A similar methodology was used to analyze the experimental data on the wear of the camshaft journal necks.

The initial processing of the experimental data was carried out separately for two planes and two cross-sections (Fig. 1, *b*). The results of the initial processing of the experimental data for the journals, followed by further processing using the "outlier" method, showed that a similar distribution pattern is observed within individual journals in cross-sections I and II.

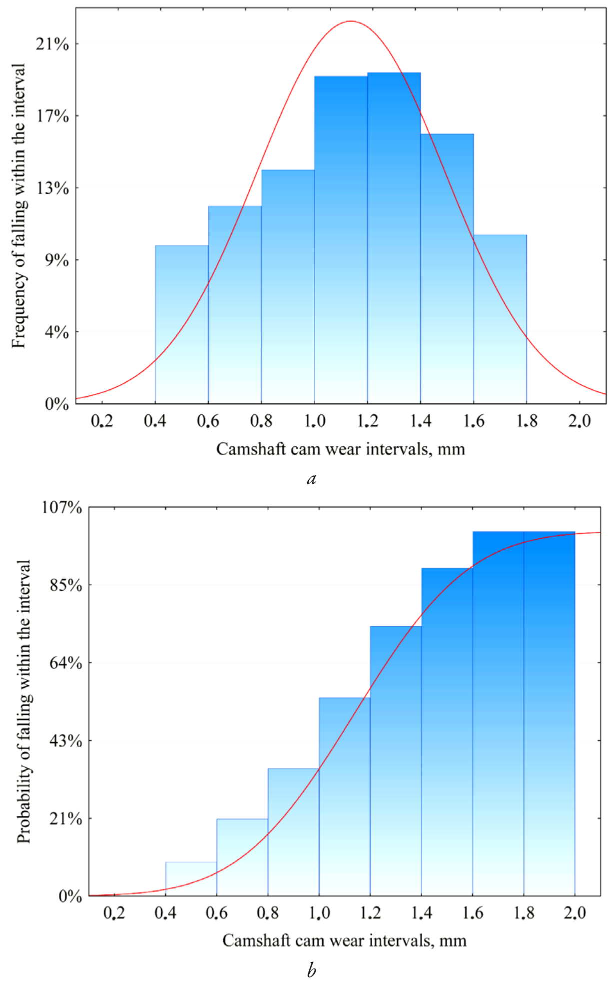

Fig. 4. Cam wear distribution curves: *a* – differential; *b* – integral

Analysis of the sample variances showed that the discrepancy between them, with a confidence level of $\alpha = 0.95$, can be considered random, which allowed to combine these samples in cross-sections I and II. The results of recalculating the point characteristics of the random variable for the necks in planes A and B are given in Table 2.

Table 2

Point characteristics of the random variable representing neck wear

Parameter names	Plane	
	A–A	B–B
Number of valid measurements, *N*	472	477
Percentage of valid values, %	94.54	95.45
Mean, mm	0.329	0.336
Mode	0.32	0.31
Median	0.32	0.31
Minimum	0.07	0.061
Maximum	0.81	0.79
Variance	0.279	0.305
Standard Deviation	0.167	0.174
Coefficient of Variation, %	50.74	51.95
Skewness	0.40	0.54
Kurtosis	–0.303	–0.165

When analyzing the results of neck wear, the following coefficients of variation were obtained: for plane A–A, V = 50.74%; for plane B–B, V = 51.95%. This allows to hypothesize that a Weibull distribution applies to both planes. Furthermore, the shape of the curve on the histogram exhibits a characteristic shift to the left relative to the center of the entire data range, which is typical of a Weibull distribution.

The differential and integral curves of the distribution of camshaft cam wear in the A–A plane are shown in Fig. 5.

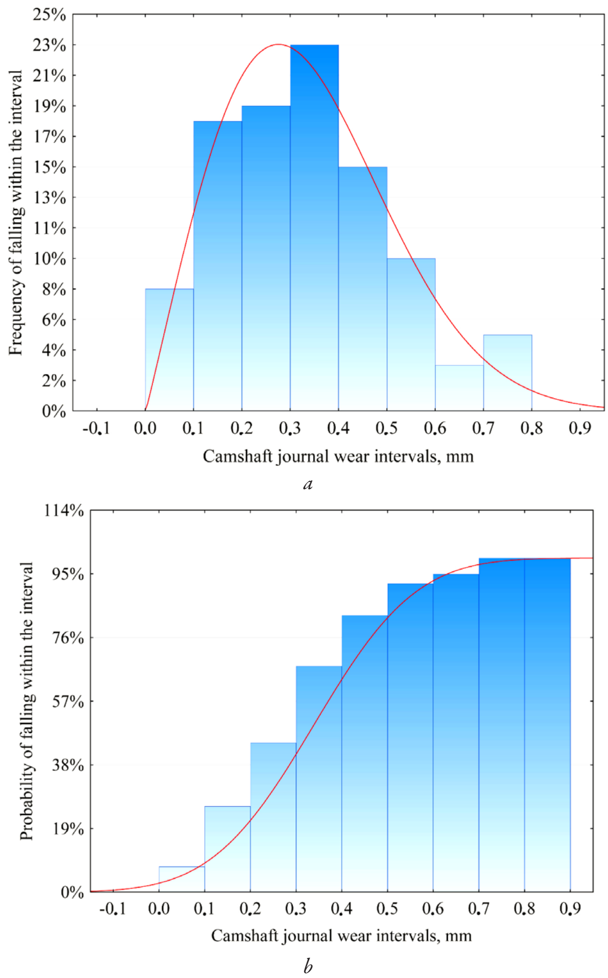

Fig. 5. Distribution curves for wear on journal necks (section A–A): *a* – differential; *b* – integral

The wear range of the camshaft journal bearings, with a confidence level of α = 0.95, falls within the following range.

For plane A–A

$$0.289 \le \overline{Z_{jour}} \le 0.369. \quad (10)$$

The absolute error is

$$\Delta_{\overline{Z_{jour}}} = 0.08. \quad (11)$$

The recovery error is equal to

$$\varepsilon_{\overline{Z_{jour}}} = 4.7\%. \quad (12)$$

For the plane B–B

$$0.296 \le \overline{Z_{jour}} \le 0.376. \quad (13)$$

The absolute error is

$$\Delta_{\overline{Z_{jour}}} = 0.08. \quad (14)$$

The recovery error is equal to

$$\varepsilon_{\overline{Z_{jour}}} = 4.5\%. \quad (15)$$

In addition to measuring and statistically analyzing cam wear, the nature of the wear on this surface was determined. The following defects were identified in the camshaft of a KamAZ lorry engine (Fig. 6).

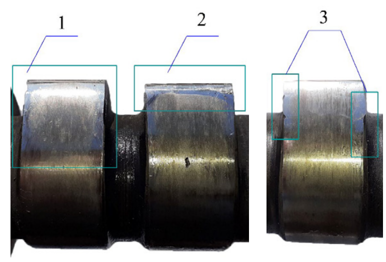

Fig. 6. Typical cam defects: 1 – signs of wear on the profile; 2 – deformation of the tip; 3 – chips and cracks

The nature of cam wear involves metal spalling caused by significant fluctuating loads, which indicates contact fatigue in the surface layers of the metal, leading to the formation of indentations on their surface: crumpling of the cam tip, chips and cracks.

3.3. Deriving the regression equation for camshaft wear

Given the number of cams and journal necks, as well as the specific requirements for surface measurement, a single camshaft requires a minimum of 52 measurements (excluding checks for bending, cracks, wear of the gear journal, and the keyway).

Analysis of the point characteristics (Tables 1 and 2) suggested a certain correlation between the worn components of the camshaft. In components with higher cam wear values, greater wear of the journal necks was observed. This is explained by the fact that under more severe operating conditions, the wear of both camshaft components intensifies equally.

To verify the relationship between the wear of individual camshaft components (cams and journals), a statistical model of component wear was constructed, which can be represented by the corresponding regression equation.

In this context, the wear on the journal surfaces was selected as the independent variables, and the wear on the cams as the dependent variables. This choice of variables is explained by the fact that on all camshafts the number of cams significantly exceeds the number of journals. Consequently, it is sufficient to take measurements, for example, on the middle journal, which is sufficient for a quick assessment of the condition of the remaining cams and journals.

The relationships between the wear of cam and journal surfaces were determined using a linear regression equation with the STATISTICA 12 software package. The results of the data obtained are presented in Table 3.

The regression equation describing this relationship is

$$Z_{cam} = 0.3639 + 1.78 \cdot Z_{jour}, \quad (16)$$

where Z_{cam} – cam wear, mm; Z_{jour} – journal wear, mm.

The data in Table 3 suggest that the correlations are statistically significant; therefore, the regression equation is adequate. The correlation coefficient, which is R = 0.9723, indicates a fairly strong positive relationship between the variables. The coefficient of determination

R^2 = 0.9455 shows that the model explains 94.5% of the variation in the dependent variable "Camshaft wear". This is a fairly high indicator of the model's quality.

Table 3

Results of studies into the interrelationships between the wear of camshaft components

Parameter name	Result
Sample size, N	50
Correlation coefficient, $R(x,y)$	0.9723
Standard error of the estimate	0.0778
The value of the coefficient at x	1.78
Conclusion regarding the significance of the coefficient at x	significant
Calculated Student's t-statistic, correlation coefficient t_r for the coefficient at x	28.85
Calculated Student's t-statistic, correlation coefficient t_r for the free term	14.65
Significance of the independent variable	0.03639
Significance level (p-value)	0.000
Coefficient of determination, R^2	0.9455
Fisher's F-statistic $F(1.48)$, which determines the adequacy of the resulting regression equation	832.73
Significance of the regression equation	significant

A graphical representation of the regression equation is shown in Fig. 7.

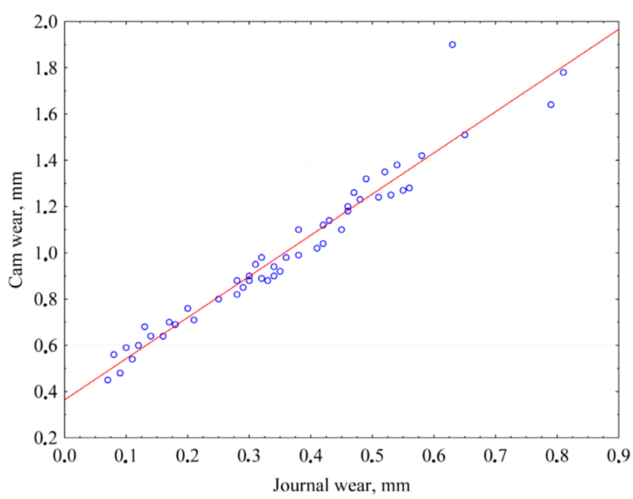

Fig. 7. The relationship between cam wear and bearing journal wear

The representativeness of the sample is demonstrated by data from car repair workshops in Kropyvnytskyi, which ensures its homogeneity. Verifying the generalizability of the results to independent samples of workshops in other regions is a focus of our future research. The minimum number of measurements with a confidence level of $\alpha = 0.95$ and a relative error of $\varepsilon = 0.1$ is $n = 50$, which has been fully achieved in this research. In accordance with the measurement methodology, the total number of valid values is: for the cam – $N = 782$ (97.7%), for the neck (plane A–A) $N = 472$ (94.5%), (plane B–B) $N = 477$ (95.5%).

The reliability of the results obtained was ensured as follows. The homogeneity of variances was tested using Fisher's criterion, which confirmed the homogeneity of the sample and the validity of combining the data. The choice of the theoretical distribution law was verified using Pearson's χ^2 goodness-of-fit test. The adequacy of the regression equation was confirmed by the value of Fisher's criterion. The standard error of the regression estimate is S_{a_i} = 0.0778 mm, which is significantly less than the standard deviation of cam wear S_{a_i} = 0.352. All calculations were performed using the STATISTICA 12 software package (StatSoft, USA), which allows for independent verification of the results by other researchers.

3.4. Discussion

The proposed approach to inspecting components with multiple worn surfaces involves determining the wear on one surface and calculating the wear on another using a regression model that establishes a quantitative relationship between the wear on individual surfaces. This approach allows for a significant reduction in the labor intensity of defect detection work without compromising the reliability of the technical condition assessment of the component. In this paper, the approach is demonstrated using the example of the camshaft of a KamAZ lorry engine.

The practical significance of the proposed approach lies in reducing the labor intensity of defect detection work during camshaft repairs by reducing the measurement volume by a factor of 2.6 and the number of measurements from 52 to 20 per component. Instead of inspecting 16 cams and 5 journals, it is sufficient to measure the wear of the journals, whilst cam wear is determined using a regression equation. The time saved when inspecting a single camshaft is 22 minutes. When inspecting a batch of 100 camshafts, the saving amounts to 3,200 measurements, or over 36 hours.

The procedure for the practical application of the proposed approach involves measuring neck wear (in two cross-sections and two planes), calculating its average value, and determining cam wear using a regression relationship.

The results of this research will be useful for engineering and vehicle repair companies involved in the manufacture and restoration of internal combustion engine components.

The statistical model obtained has the following limitations, which must be taken into account during its practical application:

1. The results obtained relate to a specific component – the camshaft of a KamAZ lorry engine. The use of the regression equation to determine the wear of camshafts in other engines is not permissible due to differences in load conditions, design dimensions, and other factors.
2. Preliminary data was collected at vehicle repair workshops in Kropyvnytskyi. To ensure the research results are widely applicable, verification must be carried out at other workshops under different operating conditions.
3. The statistical model of the camshaft, with a confidence level of $\alpha = 0.95$, is adequate within the size range $0.382 \le \bar{a} \le 1.88$ – for cams and $0.012 \le \bar{a} \le 0.646$ – for journals.
4. As the statistical model was derived for engines undergoing major overhaul, its application to routine repairs and maintenance requires further investigation.

A prospect for further research is the construction of a digital twin of the component – the camshaft.

4. Conclusions

1. A hierarchical diagram of the structure of the camshaft as a system is proposed, in which its individual components – the camshaft journals and cams – constitute subsystems.
2. A statistical analysis of the camshaft wear measurement data revealed the following patterns. Cam wear follows a normal distribution. During major overhauls, cams with wear of 1.0–1.4 mm are most commonly encountered, indicating that the cam's service life has been exhausted within the interval between overhauls. An investigation into the nature of camshaft cam wear revealed the presence of contact fatigue in the surface layers, causing the tops to be crushed and the formation of chips and cracks. Wear on the camshaft journal

necks follows a Weibull distribution. It has been established that the maximum wear (0.3–0.4 mm) significantly exceeds the permissible value (0.12 mm), necessitating the repair of the journals during a major engine over haul.

3. A statistical model of camshaft wear has been developed in the form of a linear regression equation, which establishes a quantitative relationship between the wear of the journal necks and the cams, and allows the amount of wear on one surface to be determined with a predetermined probability based on the known wear value of the other component.

Conflict of interest

The authors declare that they have no conflicts of interest regarding this research, including financial, personal, authorship or other conflicts that could influence the research and its results as presented in this article.

Financing

The research was conducted without financial support.

Data availability

The manuscript has no associated data.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technology in the creation of this work.

Authors' contributions

Ihor Shepelenko: Conceptualization, Methodology, Project administration, Writing – original draft, Writing – review and editing; ***Artem Krasota***: Validation, Formal analysis, Investigation; ***Mykhailo Krasota***: Validation, Investigation; ***Ivan Vasylenko***: Formal analysis; ***Andrey Solovuch***: Investigation.

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