

## Technological Control of the Heredity of Operational Quality Parameters in the Engine Camshaft Recovery

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### Abstract

The technological heredity of the operational quality parameters in the process of recovery and processing of the bearing journals and cams, as well as wearing of the camshaft working surfaces over admissible limits are considered. According to the findings, it is recommended: to control the deformation of the part after machining operations; to eliminate the editing operation after heat treatment; to use a combination of methods and a combination of technological effects in recovering the parts surfaces with wear exceeding the maximum permissible values. The need for surfacing and subsequent tempering processes to ensure consistently high physico-mechanical properties of coating materials and strictly regulate the modes of surface finishing is noted.

### Keywords

Technological heredity; operational quality parameters; wear limit; engine camshaft; surfacing recovery; bearing journals; cams.

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### Introduction

In the repair industry, the transfer of physico-mechanical and geometric quality parameters when performing various machining, welding, surfacing, heat treatment, surface hardening and other operations determines the structure of the material and the surface layer of the part [1 – 4]. Therefore, the negative effects associated with the technological heredity should be taken into account when forming the technological process [3 – 6].

The technological process of recovery and hardening of the camshaft can be divided into the stages of flaw detection; shape recovery and hardening; final surface treatment; running on the stand and further operation. In this regard, the study of all quality parameters was carried out not after each individual operation, but after the selected stages.

### Methods of research

The parameters were measured on the surfaces of the bearing journals and cams, since these surfaces are friction surfaces and are constantly in contact with

other surfaces. On the surface of the bearing journals friction forces are constantly acting, and the cams undergo cyclic loading [3, 4].

The measurement results were entered into the tables in which the data on the number of each journal or cam are vertically arranged, and the data on the classes are presented horizontally. The data were designed in such a way that it was possible to analyze not only the measurement results of different classes of parts, but also the differences in the data for different numbers of journals and cams throughout the entire length of the shaft. On the basis of the tabular data, the graphs were built (Fig. 1 – 7) showing the changes in the quality parameters for selected stages of the technological process of recovering the UMZ-4173 engine camshaft. The graphs analyzed the processes of changing the operational quality parameters and found their patterns.

According to the experimental data, the transfer coefficients of the technological heredity equal to the ratio of individual quality parameters before and after the operation and the mutual influence coefficients of various quality parameters during processing and

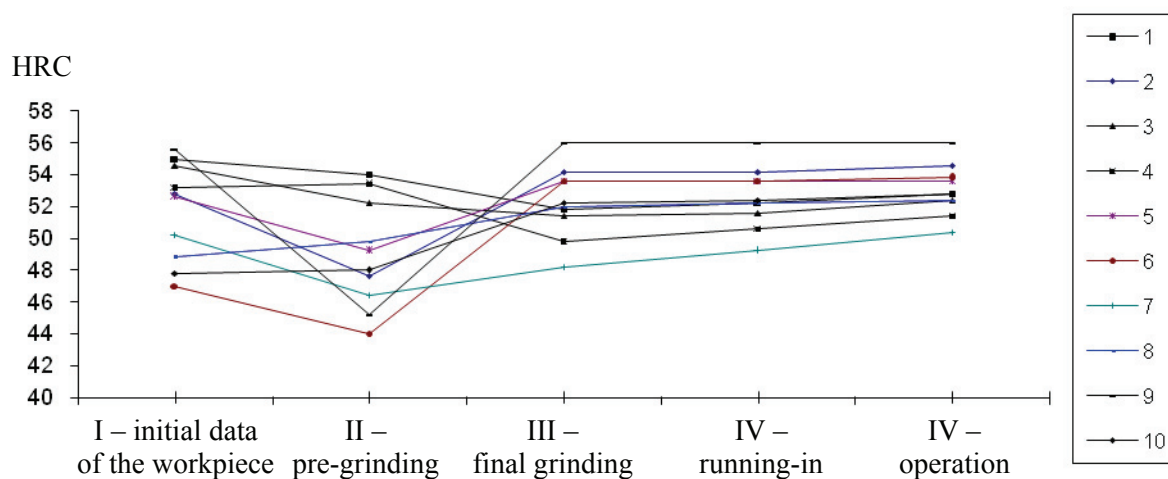


Fig. 1. Dependences of changes in hardness of bearing journals by classes (No. 1 – 10) of camshafts in operations and stages (No. I – V)

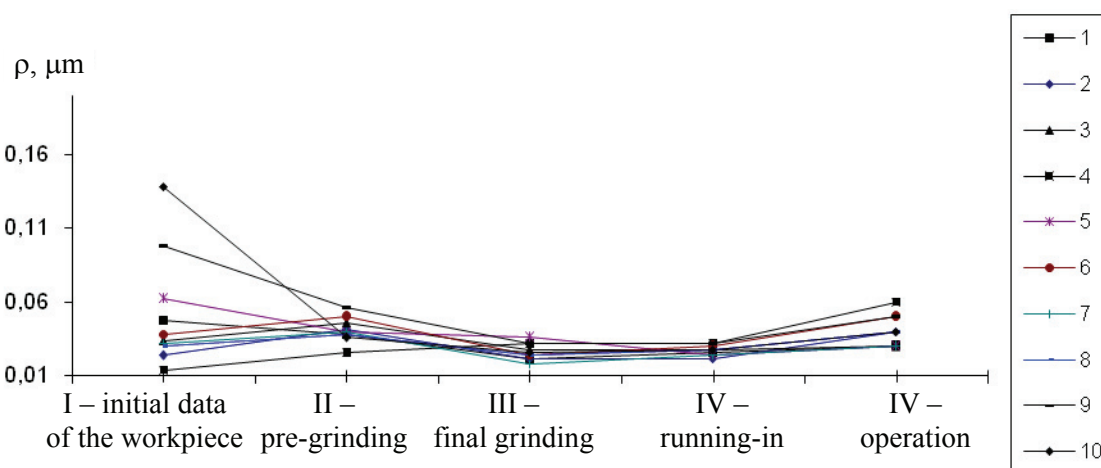


Fig. 2. Dependences of changes in radial runout of bearing journals by classes (No. 1 – 10) of camshafts in operations and stages (No. I – V)

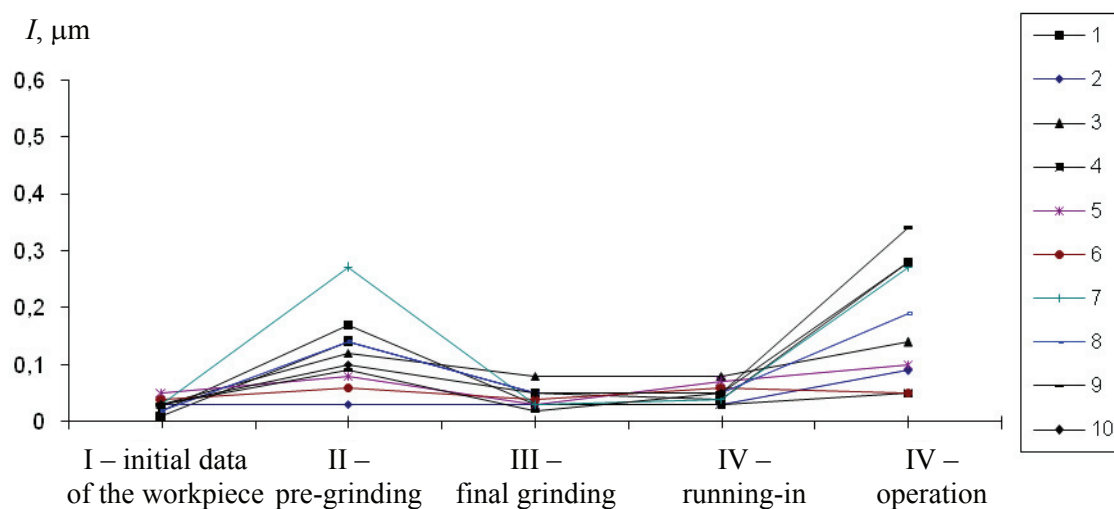


Fig. 3. Dependences of changes in dimensional accuracy of bearing journals by classes (No. 1 – 10) of camshafts in operations and stages (No. I – V)

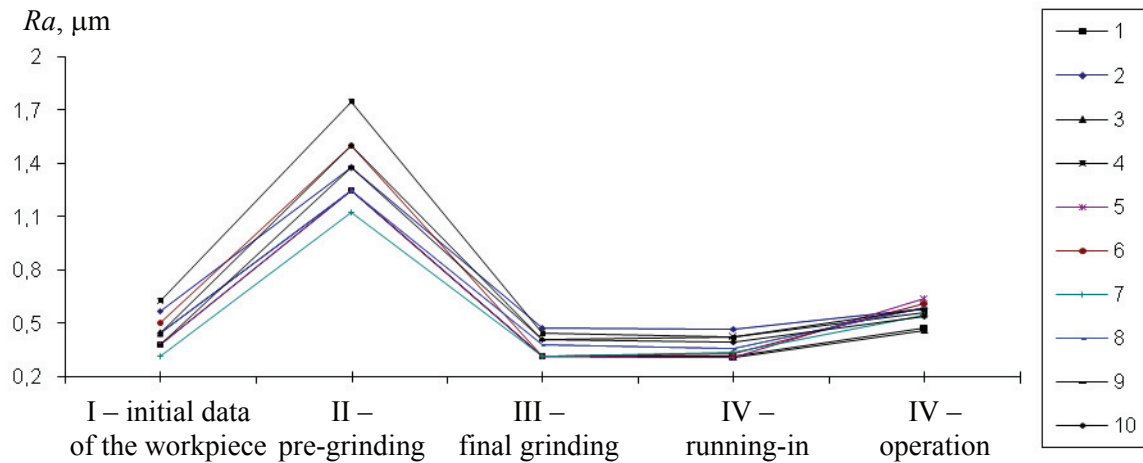


Fig. 4. Dependences of changes in surface roughness of bearing journals by classes (No. 1 – 10) of camshafts in operations and stages (No. I – V)

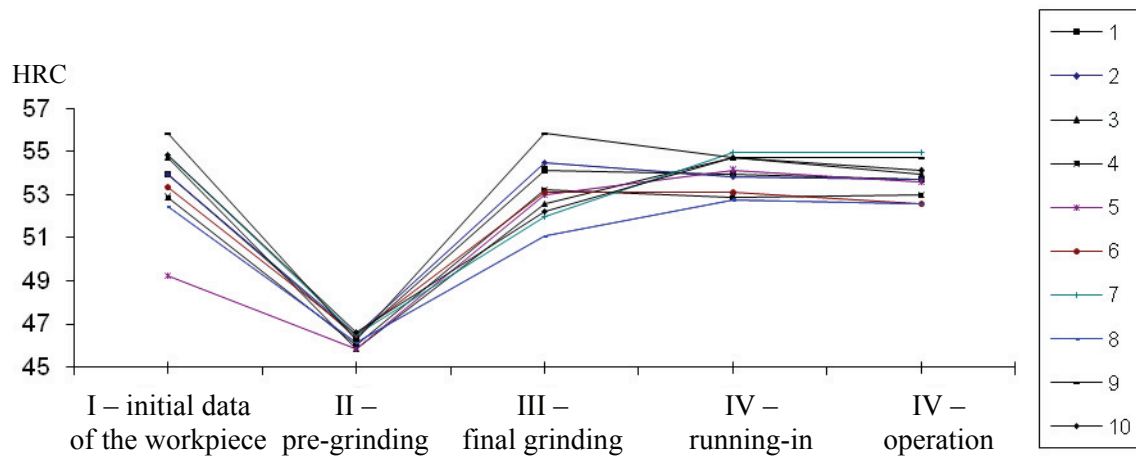


Fig. 5. Dependences of cam hardness by classes (No. 1 – 10) of camshafts in operations and stages (No. I – V)

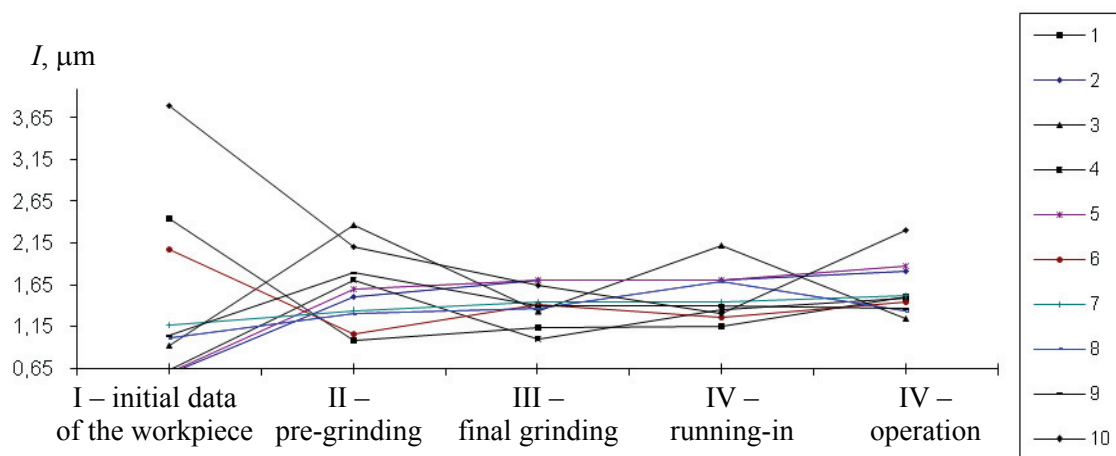


Fig. 6. Dependences of changes in dimensional accuracy of cams by classes (No. 1 – 10) of camshafts in operations and stages (No. I – V)

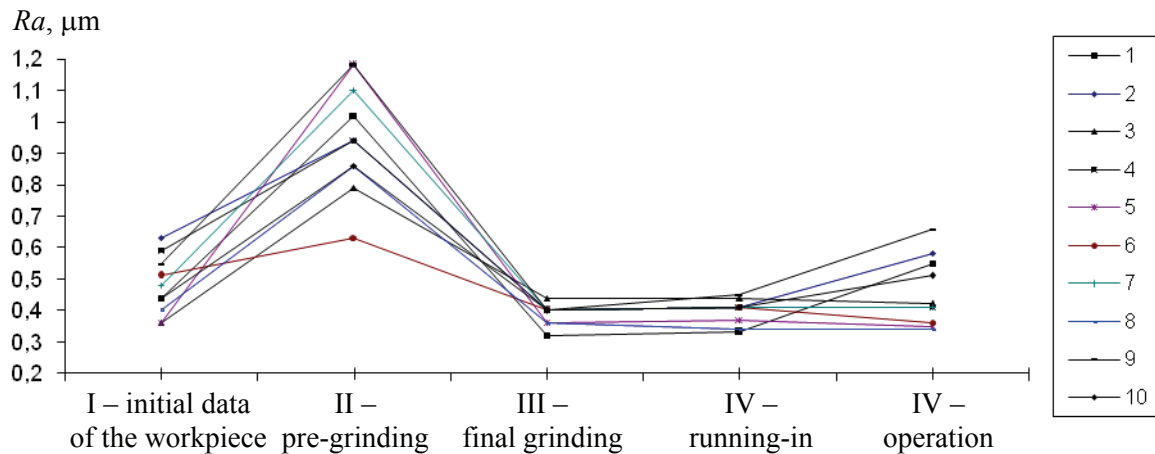


Fig. 7. Dependences of changes in surface roughness of cams by classes (No. 1 – 10) of camshafts in operations and stages (No. I – V)

Table 1

The transfer coefficients  $K$  and the resulting heredity factors  $Kr$  for hardness  $H$ , shape deviations  $\rho$ , dimensional accuracy  $I$  and surface roughness  $R$  of the camshaft bearing journals

| Recovery and operation                  | The quality parameters transfer coefficients |        |        |        |
|---|--|--------|--------|--------|
|   | $K^H$  | $K^P$  | $K^I$  | $K^R$  |
| Workpiece – pre-grinding ( $K_1$ )      | 1.0568                                       | 1.2573 | 0.2500 | 0.3303 |
| Pre-grinding – final grinding ( $K_2$ ) | 0.9369                                       | 1.5606 | 3.9024 | 3.6634 |
| $Krg = K_1 K_2$                         | 0.9901                                       | 1.9621 | 0.9756 | 1.2102 |
| Final grinding – running-in ( $K_3$ )   | 0.9947                                       | 0.9635 | 0.9111 | 1.0092 |
| Running-in – operation ( $K_4$ )        | 0.9913                                       | 0.6850 | 0.1800 | 0.6563 |
| $Kro = K_3 K_4$                         | 0.9860                                       | 0.6600 | 0.1640 | 0.6624 |
| $Kr = Krd \cdot Kro$                    | 0.9762                                       | 1.2950 | 0.1600 | 0.8016 |

Table 2

The mutual influence coefficients  $K$  and the resulting heredity coefficients  $Kr$  for hardness  $H$ , shape deviations  $\rho$ , dimensional accuracy  $I$  and surface roughness  $R$  of the camshaft bearing journals

| Recovery and operation                  | The coefficients of the mutual influence of quality parameters |           |          |          |          |          |
|---|--|-----------|----------|----------|----------|----------|
|   | $K^{Hp}$   | $K^{HI}$  | $K^{HR}$ | $K^{PI}$ | $K^{PR}$ | $K^{IR}$ |
| Workpiece – pre-grinding ( $K_1$ )      | 1256.3107  | 323.5000  | 37.9806  | 0.3237   | 0.0380   | 0.0294   |
| $K_{12} = K_1/K_2$                      | 0.6771   | 0.2708    | 0.2885   | 0.3222   | 0.3432   | 0.0682   |
| Pre-grinding – final grinding ( $K_2$ ) | 1855.3030  | 1194.6341 | 131.6667 | 1.0049   | 0.1108   | 0.4301   |
| $K_{23} = K_2/K_3$                      | 0.9724   | 1.0283    | 0.9283   | 1.7129   | 1.5463   | 3.8668   |
| Final grinding – running-in ( $K_3$ )   | 1908.0292  | 1161.7778 | 141.8340 | 0.5867   | 0.0716   | 0.1112   |
| $K_{34} = K_3/K_4$                      | 1.4521   | 5.5260    | 1.5155   | 5.3528   | 1.4680   | 1.3882   |
| Running-in – operation ( $K_4$ )        | 1314.0000  | 210.2400  | 93.5897  | 0.1096   | 0.0488   | 0.0801   |

Table 3

**The transfer coefficients  $K$  and the resulting heredity coefficients  $Kr$  for hardness  $H$ , dimensional accuracy  $I$  and surface roughness  $R$  of the camshaft cams**

| Recovery and operation                  | The quality parameters transfer coefficients |        |        |
|---|--|--------|--------|
|   | $K^H$  | $K^I$  | $K^R$  |
| Workpiece – pre-grinding ( $K_1$ )      | 1.1594                                       | 0.9061 | 0.5005 |
| Pre-grinding – final grinding ( $K_2$ ) | 0.8698                                       | 1.1138 | 2.4593 |
| $Krg = K_1 K_2$                         | 1.0085                                       | 1.0092 | 1.2310 |
| Final grinding – running-in ( $K_3$ )   | 0.9850                                       | 0.9365 | 0.9720 |
| Running-in – operation ( $K_4$ )        | 1.0051                                       | 0.9503 | 0.8630 |
| $Kro = K_3 K_4$                         | 0.9900                                       | 0.8899 | 0.8389 |
| $Kr = Krg \cdot Kro$                    | 0.9984                                       | 0.8981 | 1.0326 |

Table 4

**The mutual influence coefficients  $K$  and the resulting heredity coefficients  $Kr$  for hardness  $H$ , dimensional accuracy  $I$  and surface roughness  $R$  of the cams**

| Recovery and operation                  | The coefficients of the mutual influence of quality parameters |          |          |
|---|--|----------|----------|
|   | $K^{HI}$   | $K^{HR}$ | $K^{IR}$ |
| Workpiece – pre-grinding ( $K_1$ )      | 34.0339  | 56.5200  | 1.4453   |
| $K_{12} = K_1/K_2$                      | 1.0410   | 0.4714   | 0.3511   |
| Pre-grinding – final grinding ( $K_2$ ) | 32.6943  | 119.8899 | 4.1169   |
| $K_{23} = K_2/K_3$                      | 0.9288   | 0.8949   | 1.1612   |
| Final grinding – running-in ( $K_3$ )   | 35.2002  | 133.9736 | 3.5453   |
| $K_{34} = K_3/K_4$                      | 1.0365   | 1.1413   | 1.0976   |
| Running-in – operation ( $K_4$ )        | 33.9623  | 117.3913 | 3.2299   |

operation were calculated. The calculations were carried out for bearing journals (No. 1 – 5) and cams (No. 1 – 16) in classes (No. 1 – 10) allocated (stratified) depending on the wear degree of the working surfaces of the UMZ-4173 engine camshafts (Tables 1 – 4).

In experimental studies of the operational parameters of the UMZ-4173 engine camshaft, the hardness of the material was taken as the main physico-mechanical parameter. The radial runout, dimensional accuracy and surface roughness were taken as the main geometrical parameters.

#### **The quality parameters heredity when recovering a camshaft**

The geometrical and physico-mechanical parameters are interrelated, therefore it is necessary to analyze the patterns of their changes in a complex in

order to explain the mechanisms of the technological heredity associated with the interaction of properties. So, the radial runout of the surface during operation is greatly influenced by both the dimensional accuracy and its roughness, and with a relatively large surface runout it is impossible to speak of high dimensional accuracy. The physico-mechanical properties of the material have a significant impact on the geometrical parameters of the part.

According to the experimental data, the heredity mechanisms of operational quality parameters in the process of recovering the working surfaces of the UMZ-4173 engine camshafts were analyzed.

The hardness of the journal and cam surfaces at the stage of flaw detection gives a large scatter of data on the camshafts. This is due to the different condition of the shafts that came to overhaul. With an average

hardness value of 55 HRC, the hardness of the shafts of No. 9 and 10 classes is significantly lower (44 HRC).

After recovery operations by surfacing with wire, the hardness drops sharply, since the surface deposited layer without tempering does not have the hardness that the part had before the surfacing. But after heat treatment and subsequent finishing operations, the hardness is not only recovered, but in some cases reaches higher values than the initial workpiece. This indicates that the hardening is carried out in full accordance with the technological process.

The classes of shafts, which at the initial stage had low hardness (No. 9 and 10), also have the lowest hardness values after the finishing treatment as compared to other classes. This obviously manifests the technological heredity.

Analyzing the geometric quality parameters, their dependence on the physico-mechanical characteristics of the surface layer material should be taken into account. The initial radial runout of the camshaft bearing journals surfaces have a very large variation, which indicates a large wear of the bearing journals surfaces. After recovery operations, the runout values slightly stabilize (0.03–0.07 mm), but are still far from the required ones. After the final grinding, the values do not improve and more often remain at the same level. Moreover, in some classes No. 10, the radial runout value deteriorates as compared to the initial one (from 0.01 mm on the initial workpiece to 0.03 mm on the recovered part).

These changes may be the result of editing operations that are carried out in the process of recovering parts. Editing a part, in addition to positive effects (elimination of residual bending, warping or twisting deformations), can also have negative effects on quality parameters.

The changes in the process of recovering the radial runout values in those classes of camshafts in which low surface hardness was noted (classes No. 9 and 10) is very ambiguous. This is a manifestation of the mutual influence of quality parameters in the technological heredity process.

When analyzing the dimensional accuracy of the camshafts surfaces, it should be noted that the changes in the accuracy of bearing journals and cams surfaces differ significantly. The bearing journals surfaces arrive for overhauls sufficiently rolled-in, therefore a large deviation in the dimensional accuracy is not observed. The cams, on the contrary, have a large variation in the values of both the maximum cam size and the minimum one (i.e., the diameter of the cam base). This is due to varying degrees of wear on the cam surfaces.

After surfacing and turning operations, the scatter of the size values for bearing journals and cams is preserved and sometimes increases. But if, after finishing operations, the accuracy of the bearing journals is noticeably improved, although it does not reach the initial values, then the accuracy of the cams does not change, and sometimes (as in the case of class No. 10), it deteriorates compared to previous operations, which is also associated with the heredity phenomena.

The changes in the roughness of bearing journals and cams surfaces are unconventional for machining: after roughing operations, the roughness deteriorates in comparison with the initial condition, and in terms of finishing it improves in comparison with the initial values. Moreover, the heredity processes are similar both on the bearing journals and cams, and the roughness parameters are less affected by other geometric or physico-mechanical quality indicators.

### **Technological control of the heredity of operational quality parameters**

The study of experimental data allowed to determine the main dependences of the technological heredity of the physico-mechanical and geometric quality parameters of the UMZ-4173 engine camshaft during the repair process. The transfer coefficients (Table 1 and 3) show that the technological recovery and hardening processes is fundamentally different from the rational technological machining process. During machining in the manufacturing process, the harmful influence of the technological heredity is eliminated in the initial operations, while in the final operations the heredity coefficients are stabilized.

When recovering during the repair process, both geometrical and physico-mechanical parameters first deteriorate, and then they improve. However, in general, throughout the entire process, the physico-mechanical characteristics are recovered, and the geometric, especially those associated with the surface microrelief, are even improved.

The mutual influence coefficients (Tables 2 and 4) allow to estimate the significance of both technological operations and technological factors in individual operations. Thus, the hardness of the material significantly affects the geometric parameters. For shape deviations, this effect is especially important in the initial operations. In other cases, it is stable in all technological transitions.

The geometrical parameters of the cylindrical surfaces of the bearing journals are weakly inherited, this is especially noticeable in the initial operations.



Moreover, for the surface microrelief (its roughness), the recovery operations are technological “barriers” (since  $K^{pR}$  and  $K^{IR} \rightarrow 0$ ). The further influence of the previous geometrical parameters on the subsequent ones is also not great and affects only the accuracy of processing.

The changes in the hardness of the bearing journals and cams of the UMP-4173 engine camshafts (Fig. 1 and 5) show that the surfacing operations are technological barriers to the recovery of the working surfaces, and the final geometrical parameters of the surface quality are formed during finishing processing.

The high quality of repaired machines can be ensured by introducing new and traditional methods of recovery, hardening and processing of machine parts [3 – 6]. However, they have their own rational areas of application and do not always solve complex tasks of increasing the durability of products in specific operating conditions [1 – 4]. Thus, the economical recovery of the extremely worn-out part surface to a given size is often not ensured with high quality parameters of hardening. Therefore, it seems rational to combine various methods of hardening and machining in the technological process of recovery, as well as various technological effects within the framework of the methods themselves [7 – 10].

In this regard, the technologies and equipment for combined hardening dimensional surface treatment of parts by applying ferromagnetic powders with electromagnetic welding in combination with surface plastic deformation and welding of low-alloyed carbon wires in combination with rotary cutting have been proposed in order to recover the camshafts with varying wear degree of the working surfaces (Fig. 8).

The combination of hardening, recovery and surface treatment of parts in one technological process makes it possible not only to provide the necessary geometric characteristics of the surface during the recovery process, but also to improve the physico-mechanical properties of the surface layer material during hardening [7 – 10].

The study of the camshafts recovery showed that the surface hardness stabilizes (fluctuations within 3–6 HRC) during electric arc surfacing of Hp-30HGSA wire in a CO<sub>2</sub> environment, while the original parts had a significant variation (up to 30 HRC). After surfacing the wire, the hardness set in the technical documentation is ensured by subsequent heat treatment.

To eliminate the scatter of quality parameters of worn surfaces on the hardness of the surface layer and to ensure the physico-mechanical properties of the layer located under the weld wire, it is recommended to use electromagnetic cladding (Fig. 8).

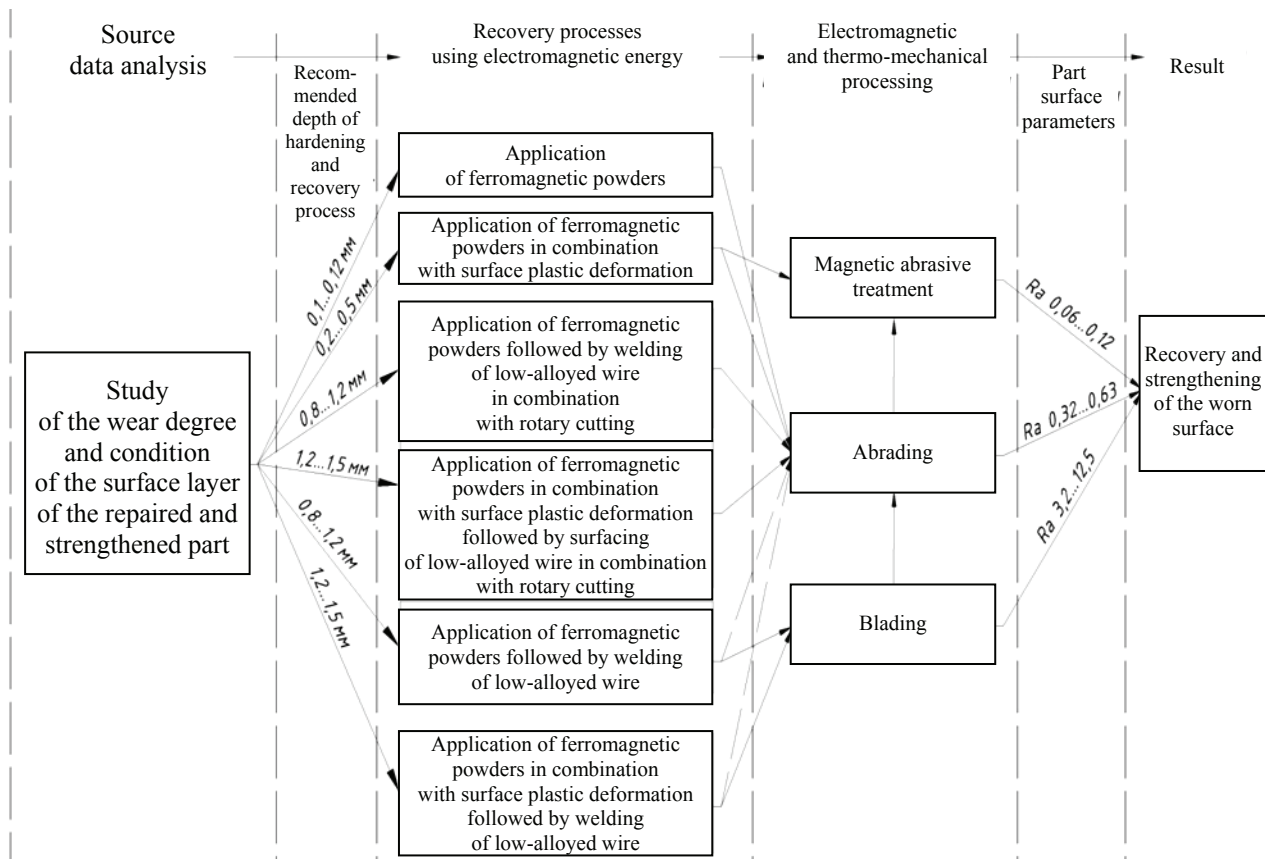


Fig. 8. The diagram of the recovery of the working surfaces of parts with varying wear degrees

When wear of the bearing journals surfaces exceeds the allowable limits, surfacing with wire is carried out on the insufficiently tempered surface. As a result, the hardened layer is formed on the surface basis not solid enough, which leads to the camshaft distortion. Preliminary hardening of the surface with ferromagnetic powder allows doping both the base and the surfaces formed during wire hardening [11 – 13].

The surface geometrical parameters (radial runout  $\rho$ , dimensional accuracy  $IT$ , surface roughness  $Ra$ ) after roughing are inherited in the finishing operations of grinding the bearing journals and cams of the camshaft. The geometrical deviations of surfaces after editing are saved on subsequent machining and assembly operations.

The analysis of the dependences of the influence of technological factors on the heredity of quality parameters made it possible to identify the determining processes of transferring properties when recovering, strengthening and processing worn surfaces of the bearing journals and cams of the UMZ-4173 engine camshaft.

The analysis results showed that in the processes of electromagnetic surfacing of ferropowders and subsequent electric arc surfacing of Np-30HGSA wire on the bearing journals, as well as the arc current strength, magnetic induction, feed rates and main processing movement affect the surface hardness in the process of plasma metallization of the cams using PG-10N-01 powder. The determining parameter for quality control in the surfacing processes is the current strength.

In the final grinding, the hardness HRC and the roughness  $Ra$  of the surface are influenced by the radial and tangential components of the cutting force, which are determined by the depth of cut and feed during grinding, as well as the wheel and workpiece rotation rates. Therefore, in controlling the machining quality, the focus should be on the depth of cut and the feed of the grinding wheel. The use of magnetic abrasive machining of polished profile surfaces can significantly reduce the duration of rolling operations.

According to the studies on the route of recovery operations, it was recommended: to provide stable hardness and uniformity of the coating material in the process of surfacing, and high surface hardness | (54–56 HRC) in the process of tempering; to eliminate straightening operations when recovering the camshaft to reduce the mutual radial runout of the surfaces to 0.02 mm and to ensure the required accuracy of working surfaces.

The conducted research allowed to identify the processes of transferring the properties during recovery, hardening and surface treatment with varying wear degrees of the bearing journals and cams of the UMZ-4173 engine camshaft and to develop regulations for the technological process operations in accordance with them.

## Conclusion

The technological heredity in the process of recovering the bearing journals and cams of the camshaft is non-monotonous, and is fundamentally different from rational heredity with monotonous transfer of properties during machining, while 10–20 percent of indicators related to the shafts, the working surfaces of which are worn out with more than acceptable values, are out of the general dependence of the quality parameters transfer.

When recovering the surfaces, the geometrical and physico-mechanical quality parameters of the camshafts first deteriorate, then improve, so the heredity is described by transfer and is determined by a uniform change in the hardness of the bearing journals and cams, and upon completion of the technological process, the geometrical characteristics are better than the original ones on worn surfaces, and the physico-mechanical properties are recovered completely.

According to the study of the properties transfer processes when recovering the worn surfaces, it was recommended: to control the deformation of the part after machining operations; to eliminate the editing operation after heat treatment; to use a combination of methods and a combination of technological effects in recovering the parts surfaces with wear exceeding the limit values; to ensure stable physico-mechanical properties of coating materials in the processes of surfacing and subsequent tempering; to regulate the depth of cut and the supply of an abrasive wheel when grinding the recovered surfaces.

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