Chapter 6

RESTORING MACHINE PARTS BY ELECTROEROSIVE DOPING AND APPLYING POLYMER COMPOSITES

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There is proposed a new method for restoring surfaces of metal parts that comprises applying a coating onto the worn surface of the part by electroerosion doping (EED) with the use of a metal electrode, which is characterized in that the EED coating is applied under conditions to provide the predetermined surface roughness for the coating applied thereto, the resulted surface is covered with at least one layer of a metal polymer material (MPM), the applied MPM layer is polymerized and hereinafter the obtained MPM layer is subjected to finish machining.

6.1. INTRODUCTION

Among the current trends of modern mechanical engineering, the problems of restoring parts by applying coatings, which have desired properties, and also assessing their qualities are probably the most extensive and branched. A significant number of technological methods for applying coverings and a great variety of fields for their applications as well as a wide range of materials used for the above said purposes make hard taking an objective decision on a choice of a proper coating and an optimal process for its application in a competitive approach.

Meanwhile, the effective use of hardening coatings at manufacturing and repairing of parts is now days considered as one of the most important economic problems, which successful solution would drastically reduce the consumption of complex alloyed steels and alloys, and improve operation, and service life of machines, and mechanisms.

The production aimed at restoring of parts requires a large amount of labor, materials and energy being necessary for applying coatings, providing thermal treatment and machining of the parts. Therefore, cost optimization of the above said resources owing to their best use at timely implementation of production tasks and ensuring normative quality indices are urgent problems.

6.2. ANALYSIS OF RECENT RESEARCH AND PUBLICATIONS

The majority of methods concerning the surface hardening processes should be considered as alternative ones. The same coating material can be applied in several ways. In this case, there would be significantly varied either properties of a coating or a cost of its application. Application conditions can over a wide range alter the combination of the mechanical properties of the base material, so the performance characteristics of coated parts substantially depend on the surface hardening method.

To renew a worn part or worn pairs of parts means to restore their primary (or close to) geometrical, physical, mechanical, physical, chemical and other characteristics (properties), that is, to eliminate the performance defects, restore the dimensions, geometrical configuration, structure, and physical and mechanical properties in accordance with the technical requirements. The restorations of parts and pairs of parts are the most important technical problem of repair manufacture.

According to document [1], working ability and resource of restored parts on average make up of 60% to 80% of the same indices for new ones. However, currently, there are known technological methods (electromechanical, electrical, and other ones), which provide for fully restoring or even increasing primary resources of the parts repaired.

The process of parts restoration provides for saving a significant amount of scarce materials, extending the parts service life by 2 to 3 times, reducing production of marketable spares at manufacturers and also reducing prime costs for repair processes of machinery and equipment. The implementation of centralized services for restoring worn parts, widely applying flow lines and automating the processes for repairing parts contribute to further improving the efficiency of repair production.

At present, there are many different technological methods to compensate a worn metal layer of a part [1–4]. One of the methods for improving the quality of the surface layer and reducing the cost of repairing machines is to provide for repeatedly reshaping the parts with the help of metal coatings and ensuring the parts interchangeability.

The most common methods, their advantages and disadvantages are represented in Table 6.1.

Table 6.1. Technological processes for compensating worn metal layer of a part

Method	Advantages	Disadvantages
Surfacing	Increasing hardness and wear resistance, forming ability to infinitely build up worn surface.	Cracking, high porosity, availability of slag inclusions, reducing fatigue strength, warping, increased environmental hazards.
Electroplating	Saving a part structure, high wear resistance and surface hardness.	Low running-in ability and oil-wetting, reducing fatigue strength, low adhesion, increased environmental hazards.
Metallization	Part material mechanical properties are not changed; high wear resistance; without any warpage.	High porosity (up to 10%), reducing fatigue strength, low adhesion, increased environmental hazards.
Plastic deformation	Increased hardness, reduced surface roughness, increased wear resistance.	Low productivity, possible surface deformation range of 5 to 10 microns and more, possible availability of uniform buildups of metal having thickness of 0.03 to 0.3 mm.
Electroerosive doping	Local surface treatment; doping may be carried out on separate surface portions starting from several mm or more without protecting the rest surface; strong connection between base metal and transferred one; lack of heating all over the part during processing, the possibility to use as the processed materials of pure metals, alloys, metal-ceramic compositions, refractory compounds; increasing hardness, heat resistance, corrosion resistance, wear resistance; lack of obligatory special steps for surface preparation.	Increasing roughness; occurrence of tensile residual stresses in surface layer, reducing fatigue strength.
Applying metal polymer materials	Unlimited building up of worn surface, deformation characteristics being close to the metal, high adhesion.	Need in special surface preparation, including the formation of surface roughness. Availability of relatively low hardness.

As a result of the analysis of the Table 6.1, it can be noted that each of the repair techniques has its advantages and disadvantages. The main drawbacks that negatively affect the final result or significantly increase the cost of repair processes are as follows:

– the presence of distortions and warpages,
– poor adhesion of the applied layer with the base material,
– the presence of pores, cracks and slag inclusions,

- reducing fatigue strength,
- increasing environmental hazards.

Among the considered methods for restoring parts, a great attention should be paid to the methods of electroerosion doping (EED) and application of polymer composites (PC), which have recently been increasingly used in repairing production and nowadays they complement one another.

Thus, the purpose of the work is to improve the quality of the parts being restored by creating a combined process comprising a step of electroerosive doping followed by applying of polymer composites.

6.3. RESEARCH RESULTS

Electroerosive doping (EED) of a surface is a process for transferring material onto the surface with the help of electric spark discharges. The method has a number of specific features:

1. Anode material (alloying material) can form a coating layer on a surface of cathode (the surface to be alloyed) being very strongly bound with this surface. In this case, not only the interface between the applied material and the base metal is absent, but there occurs even diffusion of the anode elements into the cathode.
2. The doping process may occur so that the anode material forms no coating on the cathode surface, but this anode material enriches this surface with its constituent elements through the process of diffusion.
3. The doping process can be carried out at strictly specified places (the radius of a millimeter or more) without protecting the rest of the surface of the part.
4. Electroerosive doping technology for processing metal surfaces is very easy in realization and the necessary facilities are compact and transportable [5].

In spite of the fact that the electroerosive doping process positively influences on the wear resistance of the surface layer, the disadvantaged of this process often limit its implementation for a wide variety of machine parts. These disadvantages are as follows: increasing of roughness of part surfaces after electroerosive doping, uneven surface strengthening, negative influence of erosion discharges on fatigue properties of products, etc...

On the other hand, recently in repairing production, there have been appeared increasing interests to application of new technologies for repairing equipment with the use of metal-polymer materials (MPM), which have the following properties:

- good adhesion to metal,
- deformation characteristics being close to metal,
- slight change in properties with temperature change,

- minimal shrinkage during solidification,
- resistance to external factors,
- absence of external exhausts (discharge) affecting metal,
- minimal surface preparation,
- hardening without pressure and without elevated temperatures,
- long service life without changing mechanical properties,
- ecological safety [3].

It should be noted that in order to achieve good adhesion to a plastic surface of a part, there is need in creating appropriate (necessary) roughness, which is provided by special scour.

Scouring the surface prior to applying of the material is performed with the help of a grinding wheel, file, sandpaper, by milling or with the use of needle cutters.

Taking into account the characteristic features of the above said electroerosive doping method and also by varying doping conditions, it is possible to widely change the surface roughness (Rz) of 1 to 200 microns and more, to restore parts, there is proposed an integrated technological process comprising a step of electroerosive doping followed by applying of metal polymer materials.

In this case, each single technology (the electroerosive doping method (EED) or method of applying metal polymer material (MPM)), in any way, reduces no advantages of each other, but complements them, and eliminates disadvantages being inherent in each technology separately.

The benefits of integrated technology EED + MPM are obvious:

- the continuity of the surface: 100%;
- the roughness is much lower than in the EED;
- hardness is significantly higher than that of MPM;
- owing to the possibility of applying the coatings by EED method with the use of a large amount of materials (any conductive material), one can widely change the mechanical, thermal, electrical and other properties of the working surfaces of the parts;
- the possibility of penetration of a polymer material into the cavities and micro irregularities of the parts being restored eliminates the probability of forming corrosion centers in the above said depressions, which are not filled with the polymer material;
- wear resistance, durability and reliability indices of the parts restored according to the integrated technology are higher than those of parts restored with the use of each single technology.

It should be noted that the integrated technology provides for different variants for forming structure of the restored surface layer.

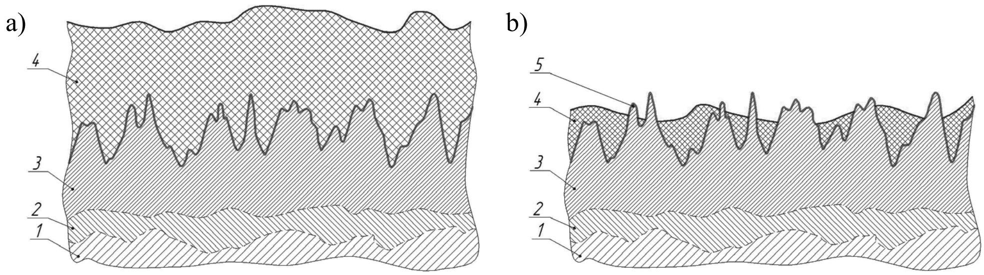


Fig. 6.1. Schematic image for the structure of the restored surface layer of the part: 1 – material of the part, 2 – transition layer, 3 – layer of coating applied by the electroerosive doping (EED) method, 4 – layer of metal polymer material (MPM)

The first embodiment (Fig. 6.1a). Coating layer (3) of any hard wear-resistant metal is applied onto the worn surface of part (1) using the electroerosive doping (EED) method. Thus between the applied metal and the part, there is formed transition layer (2) provided by mutual diffusive penetration of anode and cathode elements into each other. The coatings can be applied with varying discharge energy in compliance with the type of the equipment for realizing EED method in the range of 0.01 to 6.8 J. The more increase of the discharge energy is, the more increase of the thickness of the applied coating and also the surface roughness are. The thickness of the layer may vary depending on the nature of the interaction between the anode and cathode used, for example, in the installation with manual vibrator of Elitron 52-A type or the mechanized installations equipped with the multielectrode heads, such as of Elitron-347 or UIL-9 type, in the first case from 0.01 to 0.25 mm and in the second case from 0.05 to 2.0 mm and in doing so, the height of the microroughnesses (Rz) thus varies from 8.5 to 155.8 microns, and from 20 to 200 microns accordingly. After that, the EED processed surface is applied with metal polymer material.

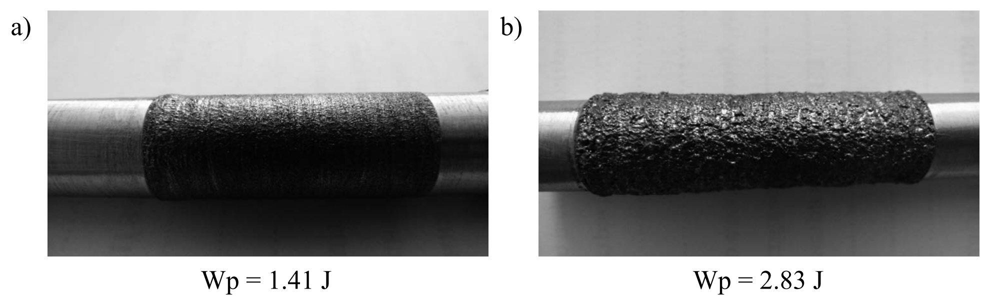


Fig. 6.2. Portions of steel tube with bronze coatings applied at the mechanical installation of UIL-9 model

Figure 6.2 shows the portions of the steel pipe of 10 mm in diameter made of steel 20 with the coatings of brass BrO10Ts1.5N applied at the mechanized installation of UIL-9 model with discharge energy Wp = 1.41 J (Fig. 6.2a) and Wp = 2.83 J (Fig. 6.2b). The values of layer thickness are, respectively, 0.05 and 0.2 mm, and the values of surface roughness (Rz) are respectively, 31.1 microns and 119 microns.

Applying of metal polymer materials (MPM) is one of the processes that determine both the quality of the formed adhesive bonds and the service life of the restored part. The first layer of a metal polymer material is carefully rubbed with a spatula or trowel into the surface of the part to be restored. In the course of rubbing such a metal polymer material penetrates into the cavities and microroughnesses of the part being restored, and such a penetration, on the one and, provides for the improved adhesion process, and on the other hand, it eliminates the risk of occurrence corrosion centers in those depressions not filled with polymer material.

If so formed thickness of a surface layer is sufficient for a part being restored, then the second layer and subsequent ones are not necessary to be applied. After the metal polymer material layer solidification, projecting roughness peaks (5) can be removed with the help of the step of electroerosive doping (EED) using graphite electrode. Polymer composite materials (PCM) are not conductors of electric current, so while performing the step of electroerosive doping, electric discharge (electrical spark) will occur between the graphite electrode and the roughness, whereby the latter will break down resulting in lower level of the roughness in the surface layer of the part being restored.

The second embodiment (Fig. 6.1b). If the thickness of the surface layer for the part, which was restored in compliance with the first embodiment, is not sufficient, such a thickness can be increased by applying of subsequent layers (4) of polymer composite materials (PCM). All the subsequent layers are provided without applying any forces but avoiding the formation of air-filled cavities.

It is necessary to note that if the previously applied layer has not been solidified yet; the next layer can be applied being sure to obtain the uniform and homogeneous layer of the polymer. If the process of the polymerization of the previously applied layer has already occurred, then to connect the newly applied layer with the old one, the surface of the previous layer should be cleaned and degreased, and then it is necessary to rub the newly applied layer with a spatula. The solidified metal polymer material can be treated by any known method including grinding or processing with a blade tool.

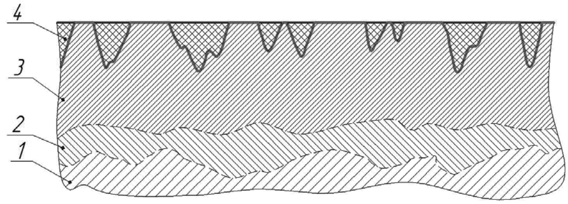


Fig. 6.3. Schematic image for the structure of the restored surface layer of the part: 1 – material of the part, 2 – transition layer, 3 – layer of coating applied by the electroerosive doping (EED) method, 4 – layer portion of metal polymer material (MPM)

The third embodiment (Fig. 6.3). As for the parts working under more tightened operating conditions and requiring higher mechanical properties, these parts are restored by the first method (Fig. 6.3) so that after machining them (grinding or processing with the help of blade tools) to provide for their preliminary determined dimensions, the surfaces of the parts would consist of separate metal sites and areas of metal polymer materials (MPM) (4). In this case, increasing the depth of processing will result in decreasing the surface area of the portions for metal polymer material (MPM), and the portions formed by electroerosive doping (EED) method will, accordingly, increase. Varying the EED-modes (discharge energy) and using the necessary equipment to ensure the special character of the interaction of the anode and cathode (the installations with manual or mechanical vibrators or the installations with multi-electrode head), can be controlled by the ratio of the surface areas formed by the polymer composite materials (PCM) and the surface areas formed by the electroerosive doping (EED) method.

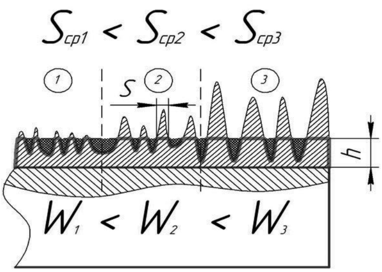


Fig. 6.4. The portions for the part surface area restored under different conditions of the electroerosive doping (EED)

Thus, Figure 6.4 shows three surface portions restored using different discharge energies W. In this case, $W_1 < W_2 < W_3$. Accordingly, the height of microroughness in the third portion is more than that in the second one, and in the second portion it is more than that in the first one. After processing with the use of blade tools, which provide the necessary restoration of the worn layer up to the size of h, the averaged portions of the surface area of the restored metal surface are distributed as $S_{cp1} < S_{cp2} < S_{cp3}$ ($S_{avrg1} < S_{avrg2} < S_{avrg3}$).

When using mechanized units of ELITRON-347 and EIL-9 types of the LuganskPTImash manufacture, the surface roughness can reach 1000–1250 microns depending on the operating conditions of the electroerosive doping process and electrode material applied. In doing so, depending on the EED operating condition, the coating continuity is within 50–80%, while the higher are the condition indices, the lower is the coating continuity. Table 6.2 show the dependence of the electric current produced by the electric generator and the cross-section of the electrodes on the desired thickness of the applied layer.

Table 6.2. Influence of the electric current on the applied coating thickness per a single pass (installation of EIL-9 type)

Operating electric current [A]	**Electrode cross-section [mm^2]**	**Thickness of applied coating per a single pass [mm]**
up to 10	3–5	0.1–0.2
10–20	5–7	0.2–0.3
20–30	7–10	0.3–0.4

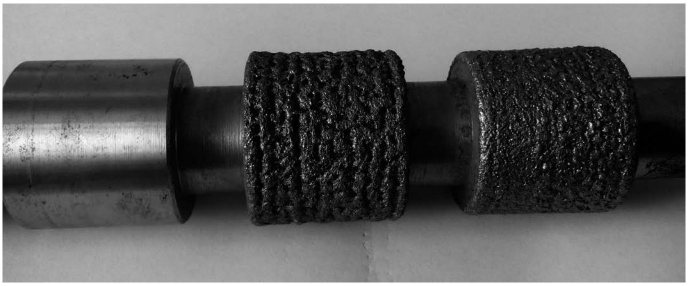
When used as an electrode of stainless steel 12H18N10T or high strength stainless steel BHC-2 (08H15N5D2T) per a pass, the thickness of the coating can be up to 0.6 mm per a diameter with provision of the continuity of the coating of 70% and 60%, respectively. In this case, the roughness of the surface is 300 microns. After 5 passes, the layer thickness reaches 2.8 mm per a diameter and the continuity is reduced up to the range of 50% to 60%, respectively. The values of surface roughness (Rz) for steel grades 08H15N5D2T and 12H18N10T increase and are suitably up to 1250 mm and 800 mm, respectively (Fig. 6.5).

In document [6], there is disclosed an embodiment providing a set of operations to repair the motor shaft with the use of electroerosive doping (EED) method.

As a result of an accident at Odessky Priportovy Zavod (Odessa, Ukraine), there was occurred an eccentric seizure of a motor shaft journal (hereinafter a rotor), which serves as a seat for the bearing on the coupling half side. Under the condition of setting the rotor in the existing centers, beating (eccentricity) of the anchor achieved up to 5 mm.

After centering the rotor and machining as purely of all the shaft journals, their beating became not more than 0.02 mm. Dimensions of the shaft journals after machining are as follows: the shaft journals for bearings are ∅79.8 mm and

∅78.25 mm (on the coupling half), the shaft journals for a coupling half are ∅72.64 mm, free end of the shaft is ∅74.93 mm.



a) b) c)

Fig. 6.5. The coverings on the area portions of the sample made of steel 40X; (a) uncoated, applied by electrodes made of steel 08H15N5D2T (b) and steel 12H18N10T (c); at the mechanized installation of UIL-9 type

All four shaft journals were restored in size using the combined technology comprising electroerosive doping (EED) and surface plastic deformation (SPD) (running-roller) and taking into account the allowance for grinding of 0.4 mm to 0.5 mm per a diameter. In doing so, the EED step alternated with SPD step that is the running-roller step was produced after each EED pass.

EED method was carried out at the installation of EIL-9 type (Fig. 6.6). As an electrode material, there was used the high-strength stainless steel BHC-2 having composition 08H15N5D2T.

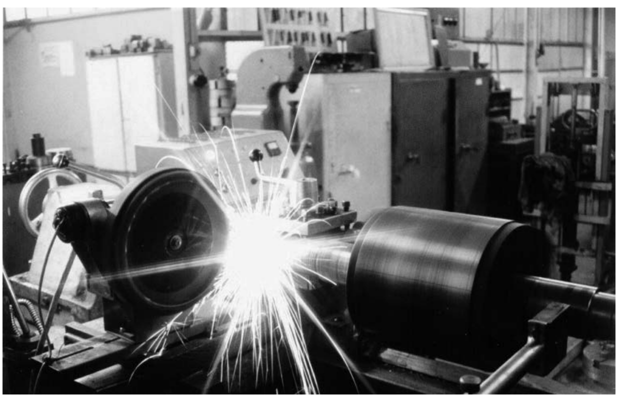


Fig. 6.6. Electroerosive doping (EED) of the rotor for the motor

To restore the dimensions of the shaft journal on the coupling half side, the maximum conditions were provided, whereon the generator operating current was

I_p = 20–30 A, which fact made it possible to increase the shaft journal size up to 0.6 mm per a diameter for a pass. In the course of recovering the shaft journals on the side of the shaft free end, there were used softer conditions whereon I_p = 5–10 A. The thickness of the applied coating was 0.2 mm per a diameter.

Running – rollers process was performed at a lathe using a spring-rod device with D_r = 40 mm and a profile radius r = 4 mm. Smoothing specific force is 3000 MPa. After each pass of electroerosive doping (EED) or each pass of surface plastic deformation (SPD) the surfaces of the shaft journals are thoroughly cleaned with metal brushes.

After polishing the shaft journals in size in compliance with the drawing, there were performed the steps of milling the keyway for depth of $7.5^{0.2}$ mm and balancing the rotor.

Figures 6.7a and 6.7b, respectively, depict the shaft journals on the side of the coupling half and also on the side of the shaft free end.

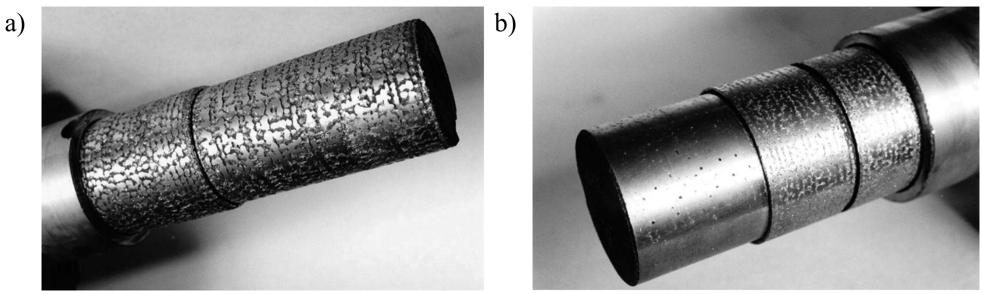


Fig. 6.7. The shaft journals of the motor rotor on the side of the coupling half (a) and on the side of the shaft free end (b)

It should be noted that the quality of the restored surfaces depends on the EED-method conditions. The lower EED-method conditions are, the better the quality of the restored surface is. So, the best quality of the surface is observed at the free end of the shaft of ∅75 mm, which was restored by 0.07 mm per a diameter (see. Fig. 6.7b).

A slightly worse quality is observed at the shaft journal for the bearing of ∅80 mm on the shaft free end side. This shaft journal was restored by 0.2 mm per a diameter, and on its surface, there are present small area portions of up to 0.2 mm depth of. In the middle of the shaft journal, there is a groove designed for arranging a locking ring, which was protected in the process of restoration.

The microreliefs of the shaft journals restored, respectively, by 2.36 mm and 1.75 mm for the coupling half of ∅75 mm and for the bearing of ∅80 mm, are the separate portions having total area of the supporting surface ~75%. These separate portions are firmly attached to the base material and have micropores up to 1 mm deep (see Fig. 6.7a).

It should be noted that without providing for the step of the surface plactic deformation (SPD) after each electroerosive doping (EED) pass, some area portions become of smaller dimensions after performing the polishing step, and, respectively, the total area of the supporting surface will be less.

6.4. CONCLUSIONS

1. In the process of restoring machine parts described in embodiment 1 in particular embodiment 3, the main material to determine the quality of the created surface layer is a coating layer applied by electroerosive doping (EED) method.
2. The subsequent metal polymer layer applied onto the layer created by the electroerosive doping (EED) method is a technological layer that enhances the quality of EED layer, for example, its continuity and tightness in a fixed connection.
3. With the electroerosive doping (EED) method, while changing the conditions of doping process, there can be varied the height of microraughneses and the subsequent processing with the help of blade tools may provide a predetermined area ratio between an applied metal and metal polymer material.

REFERENCES

[1] Csabanny V.Ja., *Car Repair*, Kirovograd District Publishing House, Kirovograd 2007.

[2] Ivanov V.P., *Technology and Equipment for Restoring Machine Parts*, Tekhnoperspektiva, Minsk 2007.

[3] Ishchenko A.A., *Technological Bases for Restoring Industrial Equipment with Modern Polymer Materials*, PSTU, Mariupol 2007.

[4] Panteleenko F.I., Lyalyakin V.P., Ivanov V.P., Konstantinov V.M., *Restoring Machine Parts*, ed. by Ivanov V.P., Mechanical Engineering, Moscow 2003.

[5] Lazarenko N.I., *Spark Alloying Metal Surfaces*, Machinery, Moscow 1976.

[6] Tarelnyk V.B., *Quality Control of Part Surface Lyers by Combined Electroerosive Doping*, MacDen, Sumy 2002.