Improvement of integrated technology for restoring surfaces of steel and iron parts

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Abstract. There have been proposed new technical solutions including operations of applying coatings onto worn surfaces of steel and cast iron parts by electro-erosive alloying method (EEA). In this case, the EEA coatings are applied in two stages. At the first stage, there is applied a layer on the conditions providing the greatest thickness and continuity of the surfaces obtained. At the second stage, the operation is performed by the same electrode and on the conditions of the discharge energy and productivity corresponding thereto, which provide for the formation of the surface having a roughness value being about 2-4 times higher than that at the previous stage. At least one layer of a metal polymer material (MPM) is applied on the surface formed by the above said EEA method, with this layer having been reinforced by at least one wire reinforcement layer before polymerization.

1. Introduction

At long-term operation of machines, wear and tear of their components is accompanied by reduction in operating characteristics thereof. The wear of the working surfaces of the machine parts often requires their complete replacement, which event results in increasing the cost of production. The most important problems of repair and technical maintenance are as follows: supporting of operability, restoration of the resource of machines and equipment, providing their high reliability and the possibility of efficient use. Increasing the wear resistance of repaired machine parts is one of the topical problems of maintenance and repair.

Solution of these problems includes improvement of repair quality by introducing modern methods for a repair process organization and also optimal technologies to provide for strengthening and restoring of the parts. Consequently, as a rule, the resource of the restored parts should be much higher, owing to the efficient recovery methods and improved properties of strengthened surfaces.

2. Analysis of major technical achievements and publications thereon

Modern repair technologies have been developed following numerous methods for restoring parts of machines and equipment. A significant number of technological methods for covering and a variety of application areas of coatings, a wide range of materials for those purposes make it impossible to take an easy way in finding out an objective solution for choosing the coating and the optimal technology for its application under condition of a competitive approach.

According to publication [1], the operability and resource of the restored parts make up, on the average, of 60 to 80% of the above mentioned indicators for the new ones. However, at present, there are known the...
technological methods (electromechanical, electrophysical ones, etc.), with the help of which it is possible not only to completely restore the primary resource of the parts but even to increase it.

The process of restoration of the parts allows to save a considerable amount of scarce materials, to extend their service life by of 2 to 3 times, to reduce the production of spare parts at manufacturing plants and to reduce the primary cost of repairing machines and equipment.

It is one of the processes for improving the quality of the surface layer and reducing the cost of repairing of a machine, which includes providing multiple restorations of the shapes of the parts with the use of metal coatings and ensuring their interchangeability. At present, there are many different technological methods to compensate for the worn-out layer of metal parts [1-4]. Those are the most common methods of them, as well as their advantages and disadvantages that are represented in Table 1.

As a result of the analysis of the table, it can be noted that the main shortcomings that negatively affect the final result or significantly increase the cost of repairs are: the presence of distortions and warpage; weak adhesion of the applied layer to the base; the availability of pores, cracks and slag inclusions; decreasing of fatigue strength; increasing of environmental hazard.

**Table 1. Technologies for compensation of a worn-out metal layer of metal parts.**

| Method                          | Advantages                                                                 | Disadvantages                                                                 |
|--------------------------------|---------------------------------------------------------------------------|----------------------------------------------------------------------------|
| Surface welding                | Increasing hardness and wear resistance, the possibility of unlimitedly increasing the worn surface to restore the same. | The formation of cracks, high porosity, availability of slag inclusions, reduction of fatigue strength, warpage, increased environmental hazard. |
| Galvanic coating               | Preserving the structure of the part, high wear resistance and hardness of the surface. | Low running-in ability and wetting with oil, reduction of fatigue strength, low adhesion, increased environmental hazard. |
| Metallization                  | The part material mechanical properties are not changed, and the part is not subjected to warpage, the layer is characterized by its high wear resistance. | High porosity (up to 10%), reduced fatigue strength, low adhesion, and increased environmental hazard. |
| Plastic deformation            | Increased hardness, reduced roughness, enhanced wear resistance.          | Low productivity, possible deformation of the surface by 5-10 microns or more, and there can be uniform metal lapping of 0.03-0.3 mm thickness. |
| Electroerosive alloying        | Local surface treatment, namely, an alloying process can be carried out in separate areas sized of several millimeters and more without protecting the rest of the surface; there is provided a strong joint between a transferred and base materials; the absence of general heating of the whole part during processing thereof, the possibility of using as processed materials the following ones: pure metals, alloys, metal-ceramic compositions, refractory compounds; providing increased hardness, heat - , wear - and corrosion resistance; there is no need to specifically prepare a surface for conducting the above said alloying process. | Increase of roughness, appearance of tensile residual stresses in a surface layer, reduction of a fatigue strength value of a part. |
| Application of metal polymer materials | The possibility of unlimitedly increasing the worn surface to restore the same, the deformation characteristics being close to metal, high adhesion ability. | There is need in a special surface preparation, including the formation of surface roughness. Relatively low hardness. |
Among the considered methods aimed at restoring parts, there is paid much attention to the method of electroerosive alloying (EEA) and the application of the metal polymer materials (MFM), which are environmentally safe and more and more often used in repair production.

While choosing a technological method of restoration, the maximum wear value, whereat the part becomes unsuitable for use, is of great importance. In general 85% of the machine parts become unsuitable for operation at wear that does not exceed \((0.2 \div 0.3) \times 10^{-3}\) m [5].

According to publication [6], the conducted studies have set that on aluminum alloys, there can be obtained a wear-resistant coating with the use of the EEA method performed by electrodes made of Al-Sn based alloy, which coating wear resistance is 5-6 times higher than that of tempered steel. A specific feature of this coating is the presence of tin oxide micro/nano fibers in its structure which fibers have high microhardness HV 1200 kg / mm\(^2\).

To perform a coating of increased thickness that is up to \(0.3 \times 10^{-3}\) m, there has been used the technology of so-called barrier layers [7]. The essence of the technology is as follows: after applying of 3 to 4 layers of AO20-1 alloy, when the increment of the layer is suspended, there is applied a barrier layer, which insulates the applied coating of AO20-1 alloy from the next layer of the same composition and allows to go on increasing the thickness of the coating.

It should be noted that increasing such an EEA operating condition as a discharge energy value, as a rule, results in reducing the continuity of the formed coating because of an appearance of through pores [8].

To improve the quality of the surface layer restored by the EEA method, we have proposed a process wherein the coating performed by the EEA method is applied in stages, with the layer applied at the first stage under conditions to provide the greatest continuity and thickness of the coating. Then, using the same electrode, there is performed the EEA process under such conditions of discharge energy and productivity corresponding thereto under which, there is performed a surface having a roughness of approximately 2-4 times higher than that at the previous stage. In this case, the metal of the cathode (the part) is ejected at the impulse application points, i.e. there is occurred sputtering of the metal in the most protruding zones of the surface, and in their places, there are formed depressions of a newly created coating, the bottom portions of which are disposed at the level of the surface of the previous coating. As a result, there is occurred a minimum increase in the level of the surface roughness.

As a reserve for increasing the thickness of the restored layer, there can be the combined technologies such as the EEA method and the method for applying metal polymer materials (MPM). In this case, each of the above said technologies in no way diminishes the dignity of the other one, but as combined, they complement one another and their combination eliminates the shortcomings inherent in each technology separately.

The advantages of the integrated technology of EEA + MPM (EEA method and further applying of metal polymer materials) are obvious: surface continuity is 100%; roughness is much lower than at the EEA method, hardness is much higher than at the MPM method. Due to the opportunity to apply the EEA coatings using a large scale of electrode materials, it is possible to vary the mechanical, thermal, electrical and other properties of the working surfaces of the parts within a wide range. Penetrating of the metal polymer materials (MPM) into the depressions and the microroughnesses of the restorable parts excludes the possibility of formation of corrosion foci in these depressions. Wear resistance, reliability and durability of the restored parts are higher than when for those restored with the use of the individual technologies.

It should be noted that when applying the method of the EEA + MPM integrated technology, various variants of surface formation are possible. The EEA method can be used to vary the height of the microroughnesses, and their subsequent processing by a blade cutting method (treatment with a blade of a cutting tool) can provide different ratios between the areas made of the deposited metal and the metal polymer material [9].

Despite the undeniable advantages, the method of the EEA + MPM integrated technology has some drawbacks. First of all, this is a low hardness and strength of the formed surface layer, especially in those cases wherein the MPM layer is disposed above the layer of the coating applied by the EEA
method. The main field of the method application is a restoration of parts in permanent joints (seats for bearings, half couplings, etc.).

Thus, the aim of the work is to improve the method of the EEA + MPM integrated technology for restoring the parts by improving the quality of the coating formed by the EEA method and increasing the hardness and strength of the formed surface layer by reinforcing the same.

3. Methods of the research

From the Technological Instructions of the EEA equipment suppliers, literature sources and work experience, it is known that pure metals (chromium, nickel, etc.), stainless steels, for example, 12H18N10T, bronze, metal-ceramic hard alloys of BK (VC) and TK (TC) groups are recommended as the electrode materials for restoring parts surfaces.

Using the unit of Elitron-52A model, when applying the EEA method, the samples of 20x10x8 and 15x15x8 mm sizes and made of steel 20 were coated with electrodes made of BrO10F1 tin bronze, T15K6 hard alloy and 12H18N10T stainless steel under different conditions of discharge energy. In addition, onto the surfaces of the samples made of high-strength cast iron of VCh-60 grade, there were applied the coatings of chromium, nickel and T15K6 hard alloy using the unit of Elitron-22A model.

In doing so, there were produced three series of samples: for series 1, the coating was applied in one stage, namely, one sample was coated on one condition; for series 2, the coatings were applied in two stages, namely, the first coating was applied on the condition providing the greatest continuity and thickness of the coating, and the second coating was applied on the coarser condition providing a roughness of 2-4 times greater than the previous one; for series 3, the coatings were applied in two stages in the sequence that is the opposite one to series 2.

The thickness of the coating was measured with a micrometer, and the roughness of the surface was indicated on the profilograph-profilometer of 201 model of Caliber plant production.

4. Research results

4.1. Applying the tin bronze coatings

The qualitative parameters of bronze coatings, having been formed in accordance with the three series, are summarized in Table 2. As can be seen from the table, at applying the coating of tin bronze according to series 1, the maximum thickness of the coating (0.1 mm), at 100% continuity, is achieved at the discharge energy of $W_p = 0.20$ J. The surface roughness is $R_z = 21$ μm. The subsequent increase in the discharge energy up to $W_p = 0.35$ J causes, together with the increase in the thickness of the layer up to 0.43 mm, the sharp increase in the surface roughness up to $R_z = 59$ μm and the reduction in its continuity up to 80%. The successive increase in the discharge energy is accompanied by an even greater increase in the surface roughness and a decrease in the continuity. The greatest thickness of the layer, which is 0.92 mm, is formed at $W_p = 0.90$ J. At the same time, the surface roughness and the coating continuity are $R_z = 98$ μm and 60%, respectively. The further increase in discharge energy results in a sharp decrease in the quality of the coating (low continuity, high roughness, burns) and in the electrode burnout.

According to series 2, the first layer was performed of tin bronze, had the continuity of 100% and the thickness of 0.1 mm. The coating was applied on the condition of $W_p = 0.20$ J. Then there was performed the second layer at $W_p = 0.35$ and 0.55 J, where the roughness was about 3 and 4 times, respectively, more ($R_z = 59$ and 82 μm). The total thickness of the layer was, respectively, 0.65 and 0.81 mm, roughness $R_z = 47$ and 58 μm at 100% continuity (Table 2). The further increase in the discharge energy at applying the second layer up to $W_p = 0.90$ J, with a slight increase in the thickness of the layer, results in a sharp increase in the surface roughness from $R_z = 58$ to $R_z = 81$ μm.

The results of the quality parameters of the coatings, which were made of BrO10F1 material on steel 20 in stages according to series 3, were significantly worse than the same for the coatings of series 2 (the continuity of 65-75%, the roughness of $R_z = 85-92$ μm) with slightly different thickness of the applied layer.
Table 2. Dependence of the qualitative parameters of the tin bronze coatings, applied by the EEA method onto steel 20, on the discharge energy value.

| Discharge Energy, $W_p$ | Productivity, cm$^2$/min | Layer Thickness, mm | Roughness, $R_z$, μm | Continuity, % | Surface Image |
|-------------------------|--------------------------|---------------------|---------------------|--------------|--------------|
| **Series 1**            |                          |                     |                     |              |              |
| 0.04                    | 0.4                      | 0.05                | 10                  | 100          |              |
|                         |                          |                     |                     |              |              |
| 0.11                    | 1.5                      | 0.06                | 12                  | 100          |              |
|                         |                          |                     |                     |              |              |
| 0.20                    | 1.6                      | 0.10                | 21                  | 100          |              |
|                         |                          |                     |                     |              |              |
| 0.35                    | 1.7                      | 0.43                | 59                  | 80           |              |
|                         |                          |                     |                     |              |              |
| 0.55                    | 2.5                      | 0.70                | 82                  | 70           |              |
|                         |                          |                     |                     |              |              |
| 0.90                    | 3.4                      | 0.92                | 98                  | 60           |              |
| **Series 2**            |                          |                     |                     |              |              |
| 0.04 + 0.35             | Stage 1                  | 0.4                 | 0.55                | 57           | 90           |
|                         | Stage 2                  | 1.7                 |                     |              |              |
| 0.2 + 0.35              | Stage 1                  | 1.6                 | 0.65                | 47           | 100          |
|                         | Stage 2                  | 1.7                 |                     |              |              |
| 0.2 + 0.55              | Stage 1                  | 1.6                 | 0.81                | 58           | 100          |
|                         | Stage 2                  | 2.5                 |                     |              |              |
| 0.2 + 0.90              | Stage 1                  | 1.6                 | 0.95                | 81           | 100          |
|                         | Stage 2                  | 3.4                 |                     |              |              |
| **Series 3**            |                          |                     |                     |              |              |
| 0.90 + 0.04             | Stage 1                  | 3.4                 | 0.87                | 92           | 65           |
|                         | Stage 2                  | 0.4                 |                     |              |              |
| 0.90 + 0.20             | Stage 1                  | 3.4                 | 0.74                | 85           | 75           |
|                         | Stage 2                  | 1.6                 |                     |              |              |

Thus, the restoration of the steel parts using the EEA method performed with the electrode-tool made of tin bronze of BrO10F1 grade should be carried out in two stages, in this case, at stage 1, the process of forming the coating is carried out at the discharge energy of $W_p = 0.20$ J, and at stage 2 - at $W_p = 0.55$ J. As a result, there is obtained the coating having the thickness of 0.81 mm, the continuity of 100% and the roughness of $R_z = 58$ μm.
4.2. Applying the coating of T15K6 carbide (Sintered hard alloy)

As it can be seen from Table 3, there is obtained the coating of 100% continuity and having the layer thickness of 0.12 mm at the discharge energy of Wp = 0.55 J. The surface roughness is Rz = 21 μm. The further increase in the discharge energy results in increasing the thickness of the layer up to 0.19 mm and in significant decreasing the quality of the coating (the continuity of 85% and the roughness of Rz = 65 μm).

According to the proposed method, when forming the coating in stages with initially using the discharge energy of Wp = 0.55 J, and then Wp = 0.90 J, the thickness of the layer is 0.20 mm, the continuity is of 100% and the roughness is Rz = 37 μm. Applying the coating in the reverse order, that is first at Wp = 0.90 J and then at Wp = 0.55 J results in decreasing the continuity up to 90% and increasing the roughness up to Rz = 54 μm.

4.3. Applying the coating of 12H18N10T stainless steel

In Table 3, there are shown the results of the qualitative parameters of the coatings at EEA of steel 20 by the electrode-tool made of stainless steel 12H18N10T. As it can be seen from the table, the maximum coating continuity of 95% and the layer thickness of 0.08 mm are achieved at the discharge energy Wp = 0.35 J. The surface roughness is Rz = 11 μm. Further increasing in the discharge energy results in increasing the thickness of the layer up to 0.14 mm and significantly decreasing the quality of the coating (the continuity of 80% and the roughness of Rz = 31 μm).

According to the proposed method, when forming the coating in stages with initially using the discharge energy of Wp = 0.35 J, and then Wp = 0.55 J, the thickness of the layer is about 0.12 mm, the continuity is approaching 100% and the roughness is Rz = 17 μm. Applying the coating in the reverse order results in decreasing the continuity up to 80% and increasing the roughness up to Rz = 34 μm.

Table 3. Dependence of the quality parameters of the coatings made of T15K6 sintered hard alloy and 12H18N10T steel, applied by the EEA method on steel 20.

| Discharge Energy, Wp | Productivity, cm²/min | Layer Thickness, mm | Roughness, Rz, μm | Continuity, % | Surface Image |
|----------------------|------------------------|---------------------|-------------------|--------------|---------------|
| T15K6 carbide (Sintered hard alloy) |
| *0.55 | 2.5 | 0.12 | 21 | 100 |
| *0.90 | 3.4 | 0.19 | 65 | 85 |
| **0.55 + 0.90 | Stage 1 | 2.5 | 0.20 | 37 | 100 |
| **0.55 + 0.90 | Stage 2 | 3.4 | 0.12 | 54 | 90 |
| 12H18N10T stainless steel |
| *0.35 | 1.7 | 0.08 | 11 | 95 |
| *0.55 | 2.5 | 0.14 | 31 | 80 |
| Discharge Energy, W_p | Productivity, cm²/min | Layer Thickness, mm | Roughness, Rz, μm | Continuity, % | Surface Image |
|----------------------|-----------------------|--------------------|-----------------|--------------|--------------|
| **0.35 + 0.55**      |                       |                    |                 |              |              |
| Stage 1              | 1.7                   | 0.12               | 17              | 100          |              |
| Stage 2              | 2.5                   |                    |                 |              |              |
| **0.55 + 0.35**      |                       |                    |                 |              |              |
| Stage 1              | 2.5                   | 0.8                | 34              | 80           |              |

* - the coating was applied according to series 1;
** - the coating was applied according to series 2;
*** the coating was applied according to series 3.

Thus, according to the proposed method, the restoration of the steel parts by the EEA method with using the electrode tools made of T15K6 hard alloy and 12H18N10T stainless steel, is most expedient to carry out in two stages, (see Table 3).

It should be noted that the proposed method remains valid for the parts made of cast iron. In Table 4, there are presented the results of qualitative parameters of the surface layers being formed at EEA of the high-strength cast iron of VCh-60 grade with the electrodes made of chromium, nickel and T15K66 hard alloy at the unit of Eliton 22A model.

**Table 4.** Results of qualitative parameters of the formed surface layers at EEA of high-strength cast iron of the VCH-60 grade.

| Electrode Material | Discharge Energy, W_p | Roughness, Rz, μm | Layer Thickness, mm | Continuity, % | Productivity, cm²/min |
|--------------------|-----------------------|-------------------|---------------------|---------------|------------------------|
| EEA of the high-strength cast iron of VCh-60 grade at various discharge energy values |
| Chromium           | 0.13                  | 15.0              | 40                  | 100           | 1.5                    |
|                    | 0.27                  | 17.5              | 50                  | 100           | 1.7                    |
|                    | 0.39                  | 20.4              | 55                  | 95            | 2.0                    |
|                    | 0.55                  | 35.0              | 60                  | 90            | 2.5                    |
|                    | 0.13                  | 13.0              | 50                  | 100           | 1.5                    |
| Nickel             | 0.27                  | 15.5              | 55                  | 100           | 1.7                    |
|                    | 0.39                  | 22.0              | 60                  | 95            | 2.0                    |
|                    | 0.55                  | 33.5              | 70                  | 85            | 2.5                    |
|                    | 0.13                  | 21.0              | 50                  | 100           | 1.5                    |
| T15K6              | 0.27                  | 26.0              | 60                  | 95            | 1.7                    |
|                    | 0.39                  | 34.0              | 80                  | 90            | 2.0                    |
|                    | 0.55                  | 42.5              | 100                 | 80            | 2.5                    |

**Table 5.** Summary of the results of qualitative parameters of the formed surface layers at EEA of high-strength cast iron of the VCH-60 grade according to the proposed method.

| Electrode Material | Discharge Energy, W_p | Roughness, Rz, μm | Layer Thickness, mm | Continuity, % | Productivity, cm²/min |
|--------------------|-----------------------|-------------------|---------------------|---------------|------------------------|
| Chromium           | Stage 1               | 0.27              | 30.2                | 80            | 100                    | Stage 1               |
|                    | Stage 2               | 0.55              | 50                  | 55            | 90                     | Stage 2               |
| Nickel             | Stage 1               | 0.27              | 24.0                | 95            | 100                    | Stage 1               |
|                    | Stage 2               | 0.55              | 29.5                | 95            | 100                    | Stage 2               |
| T15K6              | Stage 1               | 0.13              | 26.1                | 85            | 80                     | Stage 1               |
|                    | Stage 2               | 0.55              | 43.3                | 110           | 100                    | Stage 2               |

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As it can be seen from the table, with increasing the discharge energy for all the electrode materials, the thickness values of the applied coatings and the surface roughness values increase, and the continuity indices decrease. Moreover, the continuity of 100% and the greatest thickness value of the layer are kept for chromium and nickel at $W_p = 0.27$ J, and for T15K6 hard alloy at $W_p = 0.13$ J.

Thus, when restoring the parts made of VHC-60 cast iron applying the EEL method with the use of the electrodes of chromium, nickel and hard alloy, the best quality parameters have been found out for the samples having the coatings formed in two stages, according to the above said proposed method.

Below, there is a description of the methods for reinforcing the MPM materials with wire. Depending on the required qualitative and geometric parameters of the surface to be restored, the process of reinforcement is carried out in various ways.

4.4. Restoring worn surfaces of parts of rotation body type

It is well known that the main cause of a machine part failure is not its breakage, but a wear of its surface layer. Sometimes there is appeared a need in restoring outer surfaces made of soft antifriction metals of the parts of rotation body type, for example, gear supporting fingers after destruction of a Babbitt layer.

In this case, layer 3 of a coating made of any soft antifriction metal (copper, tin, silver, tin bronze, etc.) is applied onto the worn-out surface of part 1 (Figure 1 (a)) by the EEL method. In doing so, between the applied metal and the part, there is formed transition layer 2, which is a mutual diffusion penetration of anode and cathode elements. Coatings can be applied with varying the discharge energy in the range of 0.036 to 6.8 J. Increasing the discharge energy results in increasing both the thickness of the applied coating and also the surface roughness obtained. Thus, the thickness of the layer can vary depending on the nature of the interaction between the anode and the cathode. There may be used either such units as of Elitron 52-A type equipped with a hand-held vibrator, or such units as mechanized devices of Elitron-347 or EIL-9 types equipped with multi-electrode heads. In the first case, the layer thickness may vary of 0.01 to 0.25 mm, and in the second one, it may vary of 0.05 to 2.0 mm, and also the height of the microroughness (Rz) may vary accordingly of 8.5 to 155.8 μm and of 20 to 200 μm and more. After that, metal-polymer material 4 is applied onto the surface processed by the EEA method.

![Figure 1](image-url)

**Figure 1.** Restoring worn surfaces of parts of rotation body type.
Applying a material is one of the operations determining both the quality of the formed adhesion bonds and the service life of the restored part. The layer of the metal polymer material is carefully rubbed with a spatula or any other proper device into the surface of the part to be restored. On rubbing, the penetration of the metal polymer material (MPM) into the depressions and the microroughnesses of the restorable part, on the one hand, provide the adhesion improvement, and on the other hand, it excludes the possibility of the formation of corrosion foci in the depressions not filled with MPM.

Guided by the basic concept of applying MPM, which consists in the fact that its working layer should not be less than 1-1.5 mm, the pitch of the wire winding (t) on the shaft is calculated as follows:

\[ t = d + 1 - 1.5 \text{ mm} \]

where: \( d \) is the diameter of the wire [3].

After winding the wire, it is necessary to continue applying the MPM until the applied layer has completely covered it (Figure 1 (c)).

In this case, to restore the worn surfaces, one can use a wire made of copper, tin, Babbitt, silver, etc.

In certain cases, there is a need to restore worn bearing necks and journal collars (the fitting surfaces), which have a hardness of the order of 35 to 40 units of HRC.

In this case, after applying a coating of a hard and wear-resistant metal by the EEA method followed by a layer of MPM on a worn surface, a heat-treated spring is put on the formed layer, with interference fit. In this case, the pitch of the spring winding should be at least of 1.0 to 1.5 mm. Having put the spring on, it is necessary to continue applying the MPM until it would completely cover the coils of the spring (Figure 1 (c)). As a material of the spring, there can be used the steel of 65G, 9HV2S grades, BrB2 beryllium bronze, etc.

The solidified metal polymer material can be treated by any of known methods, including grinding or processing with a blade cutting tool.

4.5. Restoring worn flat and curved surfaces of parts

At restoring flat and curved surfaces made of soft and antifriction metals, after applying a coating of a soft antifriction metal by the EEL method followed with applying a layer of MPM on the machined worn surface (1), in compliance with the technology described above (Figure 1 (a)), a grid is laid on the layer formed of the antifriction metal. The grid cell size is at least 1.0-1.5 X 1.0-1.5 mm (Figure 2).

**Figure 2.** Restoring of worn flat (a) and curved (b) surfaces.

The grid can be attached outside the surface to be restored by any known method, for example, by contact welding (3). Having set the grid, it is necessary to continue applying the MPM until it would completely cover it (Figure 1 (c)). In the case of considerable wear, overlapping of the grid can be repeated as many times as necessary.

The solidified metal polymer material can be treated by any of known methods, including grinding or processing with a blade cutting tool.
The worn flat and curved surfaces of the parts made of hard and wear-resistant metal are restored in compliance with the above described technology, except that the applied grid is made of heat-treated hard wire.

5. Conclusions

1. There is proposed a new method for restoring the worn surfaces of steel and cast iron parts by the EEA method. The method is characterized in that a coating is applied in two stages. At stage 1, there is applied a layer under conditions providing the largest surface thickness at the greatest continuity. Then at stage 2, onto the obtained surface, there is applied a layer of the coating using the same electrode and the EEL method at such a value of discharge energy and productivity corresponding thereto, at which there is formed a surface having a roughness of approximately 2-4 times higher than at the previous stage. As a result, at a relatively acceptable thickness of the restored layer, the most rational value of roughness is formed and the surface continuity rises up to 100%.

2. As a reserve for increasing the thickness of the restored layer, there can be the combined technologies such as the EEA method and the method for applying metal polymer materials (MPM). In this case, each of the above said technologies in no way diminishes the dignity of the other one, but as combined, they complement one another and their combination eliminates the shortcomings inherent in each separate technology.

3. It is proposed a new method for restoring machine metal parts, according to which onto the surface formed by the EEA method there is applied a layer of MPM, having been reinforced before its polymerization depending on the purpose and geometric features of the surface to be restored, with at least one layer of wire or wire connected to create a grid. As a result, there is formed a surface layer, with its quality, wear resistance, reliability and durability being higher than those obtained when using the EEL method and the method of applying MPM each separately for the worn surfaces restorations.

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