EXPERIMENTAL INVESTIGATIONS ON THE DURABILITY OF TOOL-ELECTRODES AT THE SURFACE PROCESSING BY PULSED ELECTRICAL DISCHARGE

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Abstract: The paper presents results of experimental investigations on the durability of tool-electrodes at the surface processing by pulsed electrical discharge in the gaseous environment. In order to increase the durability of the tool-electrodes by applying pulsed electrical discharge machining (PEDM) in the liquid and gaseous environments it is proposed to construct the tool-electrodes of materials resistant to electroerosion process. The electroerosion of the cathode mass at the processing of metal surfaces by applying PEDM in gaseous environment (air at normal pressure) depends parabolic on the charge voltage of the capacitor battery of the impulse. Investigations of mass erosion of the tool-electrode made of different materials have shown that the minimal erosion of metal surfaces at PEDM has stainless steel, followed by copper and tungsten, therefore it is proposed to construct the tool-electrodes of stainless steel for the used technological process.

Key words: pulsed electric discharge machining, tool-electrode, electroerosion, durability, mass erosion.

1. INTRODUCTION

Actually, in materials processing technologies the methods of forming the protective layers are becoming more and more insistent. Among these a leading place is the formation of deposition layers of metallic powders by applying pulsed electric discharge machining (PEDM) (Topala, 2008). When depositing protective layers, we use perspective methods - PEDM accompanied by material removal at dimensional electro-erosion processing. When depositing powdery coatings with non-contact pulsed discharges, it is possible to deposit mixtures containing non-conductive components. This method is more effective in some cases because it reduces the price of the parts and does not spend expensive materials. To achieve these, special installations, pulse generators and tool-electrodes are used. In order to obtain layers with appropriate properties, it is necessary to avoid electro-erosion of the tool-electrode and the transfer of its material to the processed surface of the workpiece.

2. THE PHYSICAL MODEL OF THE ELECTROEROSION PROCESS

The erosion process is indissolubly linked to the implementation of unconventional technologies. They have found their application at dimensional processing (production of parts, cutting) and superficial treatments (deposits of compound materials, powders, powder compositions, etc.), but nowadays the scope and spread of such technologies in the machine building industry are limited. Up to now, a wide range of research has been carried out to increase the productivity of the process (increase of work frequency of generators, application of electric and magnetic fields, application of ultrasounds, etc.). The obtained results allowed an improvement of the situation but not enough to give the method a new development impulse. The physical phenomenon behind this technological processing method is electroerosion. The classics of this technology (Topala, 2007) have elaborated an illustrative physical picture of this phenomenon for the conditions of pulsed electric discharge in a liquid dielectric environment. This in several sequences can be expressed as follows: in the incipient phase, between electrodes, the conduction channel is formed by the "streamer" effect. As a result, the conduction channel is formed on which the energy accumulated on the capacitor battery is released, the channel expands very quickly. A bubble of gas is formed around it, the volume of which increases causing the depression, so the molten material on the surfaces of the electrodes to be expelled in the gap. The action of the electro-dynamic forces is also not excluded here. If the phenomenon of electro-erosion develops after this picture, productivity would be a direct function on the frequency and the energy of impulses, but this does not happen.

This is also confirmed in the case of electro-spark alloying produced under normal atmospheric conditions - all the more, in this case the formation of a sensible depression is excluded.

An analysis of the results obtained by different researchers (Topala, Rusnac, et al., 2011) indicates that they cannot be interpreted from the point of view of the classical picture. In a series of papers, it has been shown that the surface of the molten metal in the electric field develops a capillary where it causes the formation of conical meniscus on the surface of which particles are broken or the metal is vaporized in the form of ions. A series of works (Topala, et al., 2007) devoted to erosion are currently known, in which this mechanism is supposed to occur. Based on these, the conditions in which the wavelength of these types can be born are mathematically determined. They confirm that regardless of the environment in which the electrical discharge takes place at the electro-erosion process, there are the capillary waves on the surface of the liquid metal in the electric field. The result of the theoretical calculations is confirmed experimentally for a series of metals. From the above, we can describe the electroerosion process as an integral and complex phenomenon that passes through several phases (Topala, Stoicev, 2008).

In the first phase (Figure 1, a), the piercing occurs by reducing its electrical resistance, with the formation of the conductible canal or canals. It connects the electrodes through the "cold" electrode spots - the priming phase. "Cold" spots heat and prepare the surface for power discharge due to the fact that they are born at the surface micro-roughness. The dilatation of the conductible canal is accompanied by the shock and brightness wave;

In the second phase (figure 1, b), "hot" electrode spots are produced which melt the material of the electrodes more or less strongly forming the liquid metal bath. Under the action of the electric field, the surface of the liquid metal is disturbed, on which it emerges where capillaries form the Taylor-shaped meniscus (fig.1, c).

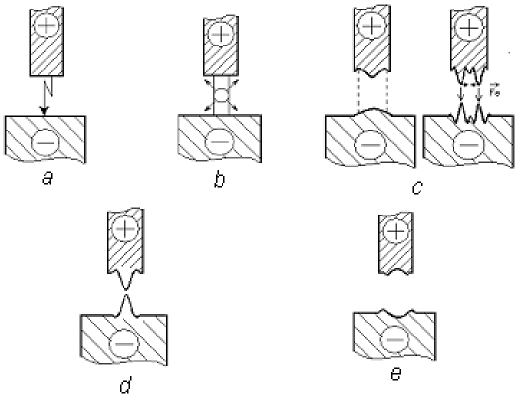

Fig. 1. The theoretical model of the electroerosion process (Topala, Stoicev, 2008)

In the fourth phase (figure 1, d), under the action of the electric field, some particles are extracted from the meniscus, which serve as ion or electron transmitters or from which drops break. In the case of simultaneously formation of multiple canals, due to the fact that parallel currents circulate, they can merge by attracting parallel currents, and the meniscus, respectively, are merged. Meniscus in some cases may short the gap through the formed decks.

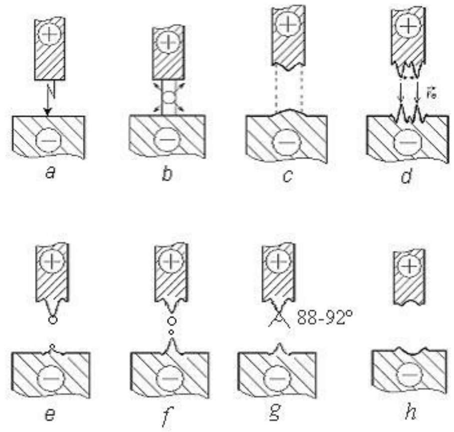

Fig. 2. Phases of the electro-erosion process under normal conditions (Topala, Stoicev, 2008)

In the last phase (figure 1, e) when the accumulated energy on the capacitor is exhausted, the electric field intensity becomes zero. Under the action of weight and surface tension forces, the fluid drains rapidly, being discharged due to the inertia on the edges of the formed crater, where it crystallizes.

The latest author's research demonstrates that the above model can be completed by the following phases (see figure 2) (Topala, Rusnac, et al., 2011):

- priming the impulse of electrical discharge with the formation of the conductible canal. It contacts the surfaces of the electrodes by means of "cold" electrode spots;

– the development of the plasma canal which contacts the surfaces of the electrodes by means of "hot" electrode spots, causes the melting of the surfaces;

– disruption of the surface of the liquid metal with formation of semi-rounded meniscus (under the action of thermal convective movement, high intensity electric field, gravitational forces and surface tension);

– in the case of large intensities of the interstitial discharge currents, two or more canals can simultaneously be produced. Thus, two or more meniscuses can be extracted from the surfaces of the electrodes (they can merge due to Lorentz forces through which parallel currents interact in the same direction);

– under the action of the electric field, due to the superficial distribution of the electric charge, droplets are formed by draining the electrified liquid in the direction of the field action;

– when surface tension forces are exceeded by value those of electro-dynamic, the drops break from the meniscus surface with the transfer on the opposite electrode surface or the displacement from the gap (as we can observe the above processes occur simultaneously on the surfaces of both electrodes, so, after particle rupture, there is an opposite movement of two particle streams, the larger one comes from the anode and the smallest from the cathode. Namely through this can be explained the process of mixing the electrodes' materials with the formation of new alloys in the deposition layers);

– at the process of forming and breaking the drop from the hemispherical meniscus, the last is transformed into a conical one with the angle from the peak in the range of 88...92° (i.e. the angle of sliding of the liquid is about 45° that corresponds to the optimal angle). Taylor cones can also serve as ion extractions to elucidate the electro-erosion process in the vapour state;

– when the electrical discharge ends, two cases may occur: if the extracted material in the form of a meniscus proves to crystallize up to the reverse flow, then it retains its shape and its dimensions; if the material does not crystallize under the action of the surface tension force or under the action of the weight force it flows in the opposite direction, sliding on the hemispherical surface of the crater, is expelled from it and crystallizes in the form of a concentric wave on its edges.

It has been noticed that practically all craters obtained by electroerosion have an ideal shape of a spherical cap. This occurs due to the fact that the energy released on the surface depends on the intensity of the electric field, and therefore the liquid metal bath copies the field ray of the electric field. In this case the hypothesis advanced by Topala is confirmed that the electrode spot (Topala, 2007), which is the cause of different heating and melting of the anode and cathode (under the same conditions of unidirectional electrical discharge) is a point source of heat in which all power lines of the electric field created by the anode and cathode potential drops are closed.

3. METHODOLOGY OF EXPERIMENTAL INVESTIGATIONS

3.1. Description of experimental setup and operating principle

The pulsed electric discharge generator of the experimental setup includes the following blocks: the power pulse generator, the priming block (designed to initiate the electric discharge) and the command block, the role of which is to synchronize the power and priming impulses.

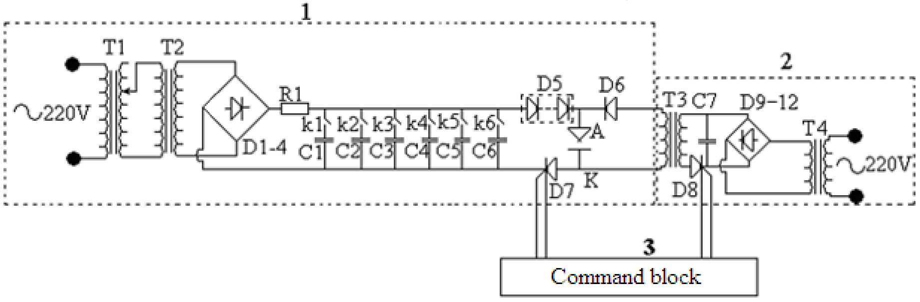

Fig. 3. The main electric circuit of the pulse generator: 1 - the power pulse generator; 2 - the priming block; 3 - the command block

Figure 3 shows the electrical scheme of the generator. The power pulse generator consists of the autotransformer (T1), the power transformer (T2), the rectifier (D1-4), the ballast resistance (R1), the capacitor battery (C1-6), the switches (k1-k6), the diode block (D5) and the thyristor (D7). The priming block contains the following elements: transformer (T4), rectifier (D9-12), capacitor (C7), thyristor (D8) and high voltage transformer (T3). The command block allows not only the pulse synchronization, but also the change of generator operating frequency. The operating principle of the generator, the scheme of which is shown in Figure 3, is based on the accumulation of a quantity of electric energy on the capacitor battery and its discharge into a short duration impulse (τ = 50-220 μs). Out of a DC source, which consists of the autotransformer T1, the power transformer T2 and the rectifier D1-4, through the load impedance R1, the C1-C6 capacities are powered. The T1 autotransformer allows fine-tuning of the working voltage and feeds the impulse generator. The D5 block of diodes is designed to protect the generator from high voltage penetration. Resistance R1 has the load current limiting function, which prevents transformation of pulsed electric discharge into electric arc discharge. During the setup functioning, the C1-C6 capacitor battery and the C7 capacitor are simultaneously charged. The command block emits a signal that causes the D8 thyristor to open. Due to this, the capacitor C7 is discharged through the primary coil of the high-voltage transformer T3 and it starts to circulate the electric current. This electrical current causes the high voltage (breakthrough) to occur at the secondary coil terminals, which are respectively connected to the anode and cathode of the setup. Due to the high tension, the gap is pierced and the conductible canal is formed. At the same time, the control block emits another signal, which causes the D7 thyristor to open and discharge the C1-C6 capacitor battery to form the base pulse. This process is repeated again. The duration between the opening times of thyristor D7 and thyristor D8 is very small and can be adjusted within wide limits due to the command block. The standard impulse generator G5-60 can be used as the command block, which allows both the change of the working frequency and the synchronization of the power and priming impulses.

3.2. Mechanical part of experimental setup

For the variation of the gap size, the device shown in Figure 4 is used in the research process. The device was made using a microscope to accurately determine the distance between the electrodes. This device allows the electrodes to be fixed in the form of bars, balls and wire-wound horizontally in tensioning devices (1). The work table (4) in the research process moves both longitudinally and transversally, with the goal of obtaining unitary meniscus on the surface of the anode. With the handle (2), the gap gross adjustment is performed.

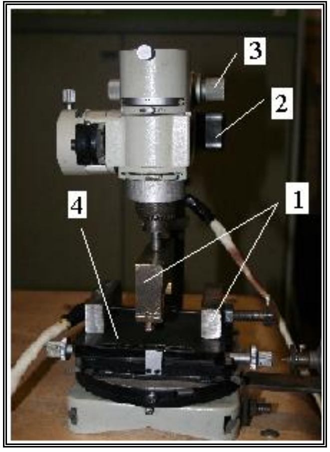

Fig. 4. Device for the gap variation on the base of microscope:
1 - wire electrodes tensioning devices; 2- gap gross adjustment handle; 3- gap fine adjustment handle;
4- work table

For fine adjustment of the gap we used the handle (3). Measurement of the gap was performed using a 0.01 mm precision dial comparator. Once the gap has been established, its size is permanently controlled by the MPB-2 measuring microscope.
For safety, in the measurement process the electrodes have been connected to a current indicator and switched on in a short-circuit. The measurement starts from the moment the circuit breaks, i.e. from the "zero" position of the current indicator (Topala, 2008).

3.3. Function of the working procedure

The principle of hardening method by applying pulsed electric discharge machining (PEDM) is particularly accessible, essentially based on the erosion effect of electrical nature, resulting in a controlled transfer of material from the tool-electrode (TE) to the piece-electrode (PE) (Figure 5).
Thus, under the influence of the electric field due to a controlled pulse generator, it is possible to produce plasma microchannel discharges. Through the TE-PE work gap will transfer the hard material to the surface of the processed workpiece.
The displacement of the electrode on the surface of the workpiece will follow the trajectory of the hardened contour, ensuring that a working gap is maintained for the optimal development of the plasma channel formation caused by the energy of the pulses produced by the electric discharge between the tool-electrode and the workpiece. The quality of deposition depends essentially on maintaining a constant and permanently controlled distance between them.

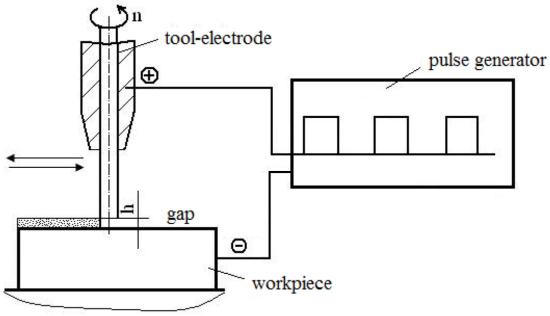

Fig. 5. The workscheme of surface hardening by pulsed electric discharge machining (Topala, 2008)

The feature of this method is that there are no linear or volume changes of the hardened material when forming the coatings. In order to to achieve the hardening by PEDM, the following conditions must be met:

– the high conductivity of the workpiece being processed, the higher the conductivity, the lower the power losses;
– before the hardening, the tool-electrode must be subjected to standard heat treatment;
– the tool-electrode (plate or punch) must be without unevennesses or defects;
– the hardened surfaces must be degreased with technically pure gasoline or alcohol. If the surfaces have protective coatings or are rust-coated, they must first be cleaned with abrasive paper.

3.4. Choosing the tool electrode material

The electrodes were made in the form of cylindrical rods, most often using electrodes with a diameter of 0.8-1 mm, but electrodes of 0.5...2 mm can also be used. The diameter of the electrode is chosen according to the diameter of the craters occurring at the electrical discharge between the tool-electrode and the workpiece. When applying electrodes with diameters larger than 1.5 mm, the density of the coating becomes worse.
The tool-electrodes for the investigations of the

electrical erosion process by applying PEDM have form of Ø2 mm wire made of the following metal materials resistant to electrical erosion: stainless steel 20X13 GOST 5632-72; technically pure copper M0 GOST 859-66 and technically pure tungsten.

3.5. Parameters of the working regime at hardening by PEDM

With the aim to achieve a qualitative deposit we must take into account the parameters of the regime that are directly involved in the hardening process (Topala, 2008):

a) electrical parameters: charging voltage, (V); the capacity of the condencer battery, C (F); the working current intensity, I (A);

b) temporal parameters: the duration of impulse, τ (s);

c) technological parameters: the rotation frequency of the electrode, n (rot/min); the feed, v (mm/rot); the tool-electrode diameter.

Where necessary, more moderate regimes for finishing tools can be adopted to obtain a low roughness and more intense machining regimes for roughing tools for high productivity.

When choosing the working regime, the following moments are also considered:

- increasing the electrode frequency increases the amount of deposited material;
- increasing current intensity and voltage increases the deposition thickness;
- increasing pulse frequency causes the increase of amount of material transferred to the cathode.

3.6. Determination of mass erosion

The tool-electrodes for electrical erosion investigations were connected to the discharge circuit of the impulse generator as anode, the rectangular section surface made of steel C45 was served as the counter-electrode.

In order to determine the influence of material, shape and dimensions of the tool-electrodes and the energetic processing regime on the electro-erosion mass value, the investigations were carried out in the regime of maintaining 2 minutes of consecutive electrical discharge at the 4 Hz frequency for all types of materials used as cathode electrodes, followed by weighing at the analytical balance VL-200 with a measuring accuracy of 10^{-4} g.

The attempts were repeated again, thus obtaining the addition or mass erosion of the electrodes. Test results can be represented as a table or graph.

4. RESULTS OF EXPERIMENTAL RESEARCH

4.1. The dependence of the execution material on mass erosion

The results of investigations of the cathode mass erosion of metal surfaces at the processing by applying PEDM in gaseous environment depending on the material of the tool-electrodes are shown in figure 4. As can be seen from figure 6 the dependence has a parabolic character, being the most pronounced for tungsten, and the most resistant to electrical erosion for stainless steel.

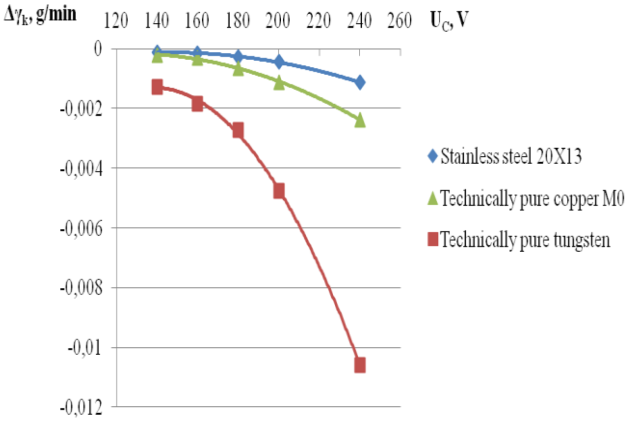

Fig. 6. Dependence of the charging voltage of the capacitor battery of the impulse generator on the cathode mass erosion depending on the tool-electrode material

The more essential erosion of the tungsten cathode is due to the more intense oxidation of its active surface, which leads to the disruption of the material mass. To avoid this drawback, it is proposed to use tungsten electrodes in inert gaseous processing environments. Regardless of the fact that the copper alloys and cast iron are most often used in the process of electric erosion in liquid environment, in the case of processing in gaseous environment the oxidation erosion of their active surface increases.

4.2. The dependence of the energy regime on the mass erosion

The influence of the charging voltage of the capacitor battery of the impulse generator on the tool-electrode erosion are shown in figures 7 - 9.

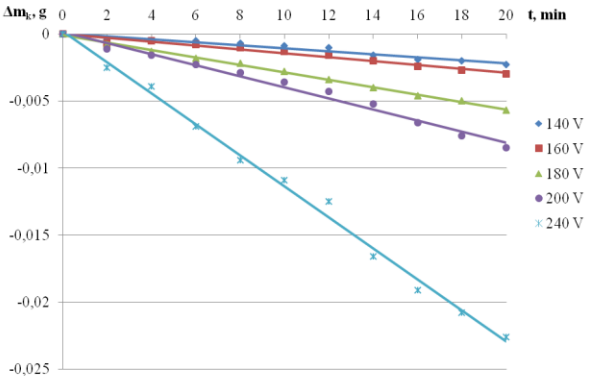

Fig. 7. Erosion of the mass tool-electrode of stainless steel 20X13 depending on the charge voltage of the capacitor battery of the impulse generator

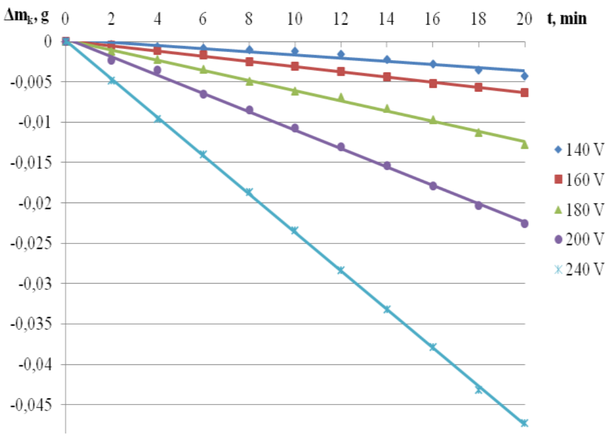

Fig. 8. Erosion of tungsten tool-electrode depending on the charge voltage of the capacitor battery of the impulse generator

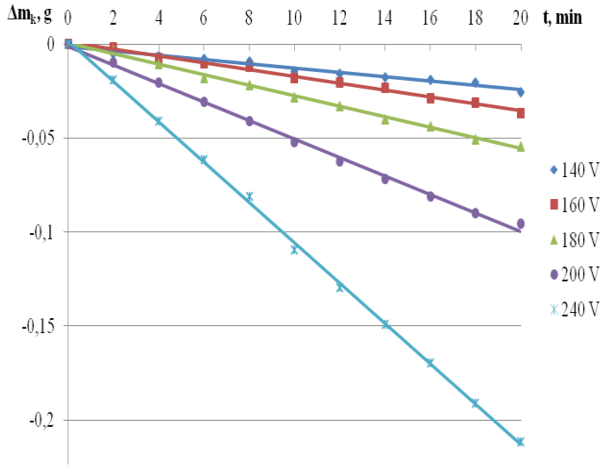

Fig. 9. Erosion of the mass of tool-electrode of technically pure copper M0, depending on the charge voltage of the capacitor battery of the impulse generator

As we can see from these figures the dependence is linear, i.e. with the increase of processing time, the mass erosion of the electrodes increases linearly. Increasing the charge voltage on the capacitor battery increases the energy emitted in the gap and on the electrode surfaces, which leads to the intensification of the electrical erosion process.

5. CONCLUSIONS

Analyzing the results of the experimental researches on the mass erosion of electrodes in the processing of metal surfaces by pulsed electrical discharge in gaseous environment we can draw the following conclusions:

– the dependence of the erosion of the cathode mass of the electrodes on the charge voltage of the capacitor battery of the impulse generator has a parabolic shape for all the studied materials of tool-electrode;

– the erosion speed for the particular processing regime is constant so the erosion dependence graph is a straight line;

– the analyze of electrode-cathode mass erosion from the investigated materials showed that the minimal erosion of metal surfaces by PEDM has stainless steel, followed by copper and tungsten;

- notwithstanding the fact that copper alloys and cast iron are most often used material for electrodes in the electroerosion process in liquid environment, in the case of processing in gaseous environment the oxidation erosion of their active surface increases.

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