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SURFACE SMOOTHING USING ULTRASONICALLY ASSISTED PULSE ELECTROCHEMICAL MACHINING

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Abstract

The aim of electrochemical smoothing is to decrease surface roughness and removed damaged in former operations surface layer. Conventional electrochemical machining (ECM) with DC current make it possible to received surface roughness parameter Ra ~0.5 – 1.0 μm, what is in many cases satisfactory. However in some cases (injection moulds) it is necessary to achieve surface roughness parameter Ra < 0.1 μm. In order to obtain such small surface roughness parameter it is necessary to carry out smoothing process using pulse electrochemical machining (PECM) or ultrasonically assisted pulse electrochemical machining (USPECM). In the paper the results of smoothing using PECM and USPECM process are presented.

1. INTRODUCTION AND PROBLEM FORMULATION

One of efficient way of increasing machined detail accuracy and quality of its surface is to carry out electrochemical machining process with pulse voltage [1, 2, 4, 6, 7]. Material excess is removed here as a result of electrochemical dissolution accompanied by heat generation. Heat and product of dissolution process should be removed as soon as possible out of interelectrode space. The highest accuracy and the best surface quality is obtained when current density is high (over 100 A/cm^2). Because of this condition the interelectrode gap thickness should be as small as possible. Another very important factors are time of voltage pulse and time of interval between successive voltage pulses. Generally, machining accuracy increases together with voltage pulse time decrease, however at the same time metal removal rate significantly decreases. Time of interval between pulses should be long enough to transport out of interelectrode gap heat and electrochemical reaction products generated during voltage pulse.

Former investigations carried out with constant voltage [8] proved that efficiency of electrochemical dissolution process can be increased by introduction of electrode tool ultrasonic vibrations. Electrode – tool ultrasonic vibrations can also decrease electrode polarization, support the electrolyte flow and transportation out of interelectrode space heat and electrochemical reactions products. As a results the conditions for surface roughness parameter decrease are created.

Taking into account above mentioned advantages of conventional electrochemical machining supported by electrode - tool ultrasonic vibrations the experiments of pulse electrochemical machining supported by electrode - tool ultrasonic vibrations have been carried out. Some results of these experiments are being presented below.

2. EXPERIMENTAL TESTS

The range of PECM application depends on accuracy, surface quality and metal removal rate which can be achieved during machining. Because of this fact it has been decided that experiments will be carried out with constant but as high as possible electrode tool feed rate. The same interelectrode gap is small what gives possibility to obtain high current density. In order to achieve for small interelectrode gap thickness satisfactory conditions of electrolyte flow and transportation out of interelectrode space heat and electrochemical reactions products the ultrasonic vibrations of electrode tool has been applied. On this assumption the results of the process depend mainly on time of voltage pulse, time of interval between successive voltage pulses and intensity (power) of electrode ultrasonic vibrations.

Experiments have been carried out using electrochemical machine-tool EOCA 40 equipped with special pulse electrical supplier, ultrasonic head and tooling for electrode - tool and samples clamping.

Taking into account results of analysis of phenomena occurring into interelectrode gap during one voltage pulse the following factors have been taken into account:

- **input factors:**
  - interelectrode voltage: U = 15 – 23 V,
  - electrode – tool feed rate: v_f = 0.1 – 0.9 mm/min,
  - pulse time: 1 – 9 ms,
  - interval time: 1 – 5 ms,
  - power of ultrasonic vibrations: P = 0 – 120 W;

- **output factors:**
  - surface roughness parameter Ra [μm],
  - interelectrode gap thickness S_k [mm],
  - metal removal rate V_w [mm^3/min],
  - pulse current I_{imp} [A];
- **constant factors:**
  - shape and electrode-tool and machined surface F = 175 mm^2,
  - machined material: steel NC6,
  - electrode-tool material: brass,
  - electrolyte: 15% water $NaNO_3$ solution,
  - electrolyte temperature: 20°C
  - initial interelectrode gap thickness: S = 0.2 mm,
  - electrode – tool displacement: h = 1.7 mm

As function of investigated object the neural net which characteristic was presented in [8] has been applied.

During tests electrode-tool is displaced in direction of machined surface with velocity v_f (Fig.1). Electrolyte flow into interelectrode space through the hole in the sample. Between electrodes the voltage pulses occur with appropriate pulse and interval time duration.

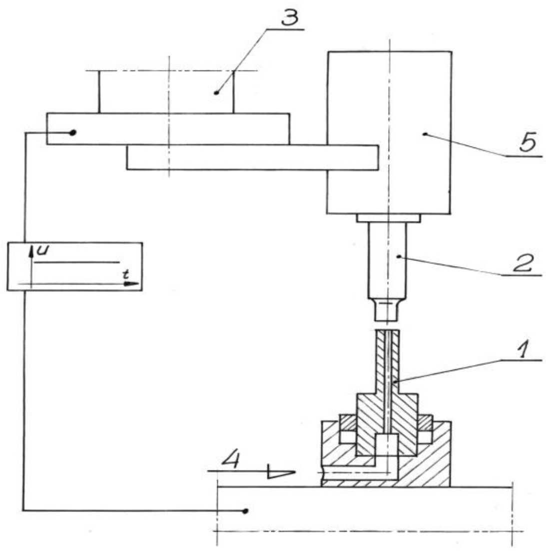

Fig.1. Scheme of test stand for investigations of PECM and USPECM process supported by electrode ultrasonic vibrations; 1 – workpiece, 2 – electrode - tool, 3 – tool plate of machine-tool EOCA 40, 4 – hole for electrolyte supplying, 5 – ultrasonic head.

3. RESULTS OF EXPERIMENTS WITHOUT ELECTRODE ULTRASONIC VIBRATIONS

Results of investigations have been presented below. At first the results of experiments without electrode-tool vibrations have been presented (Figs 2 – 6). Then the comparison between technological indicators for machining with and without electrode ultrasonic vibrations have been described (Figs 7 - 10).

From analysis of phenomena occurring into interelectrode gap results that electrode ultrasonic vibrations have influence on electrode polarization, pulse current, interelectrode gap and surface roughness parameters. So it right to assume that in quasi steady state of the PECM and USPECM processes metal removal rate significantly depends only on electrode tool feed rate as it results from Fig.2.

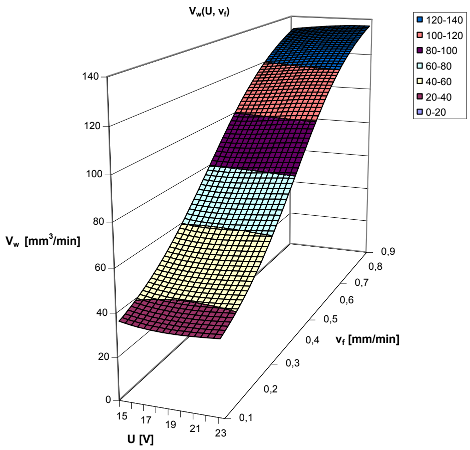

Fig.2. Relationship between metal removal rate and electrode tool-feed rate and interelectrode voltage $V_w=f(v_f,U)$ for pulse time t_i, = 5 ms, time of interval t_p = 3 ms when machining without electrode ultrasonic vibrations (P = 0 W).

For constant interelectrode voltage and electrode-tool feed rate values of process technological indicators depend significantly on pulse and interval time (Fig 3 – 6). For the smallest value of pulse time (1 ms) and the biggest value of interval time (5 ms) the smallest value of interelectrode gap thickness and the highest value of pulse current have been reached (Figs 3 and 4). For these conditions it has been possible to achieve the smallest value of surface roughness parameter Ra (Fig. 5). Though the principle that the highest current density the smallest surface roughness parameter is true in analysed case. This principle is also confirm in Fig. 6.

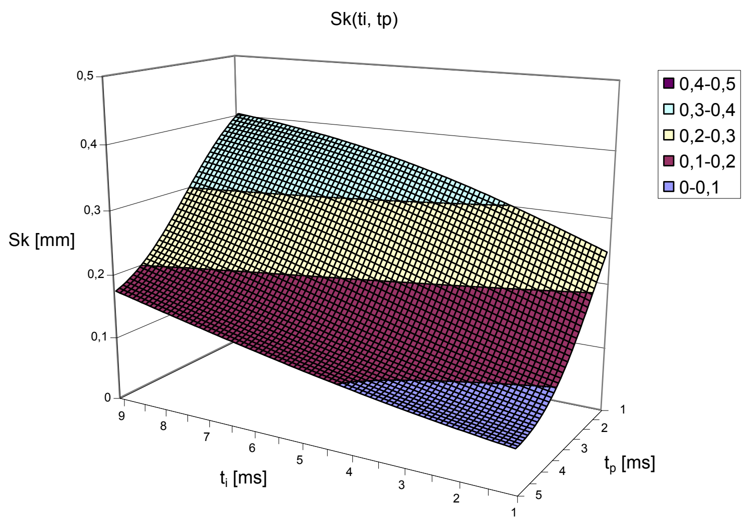

Fig. 3. Relationship between interelectrode gap thickness and pulse and interval time $S_k = f(t_i, t_p)$ when electrode feed rate v_f = 0.5 mm/min, interelectrode voltage U = 19 V, ultrasonic vibrations power P = 0 W.

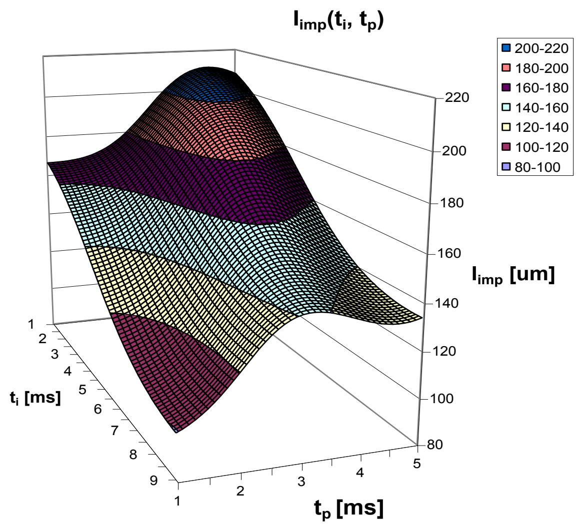

Fig. 4. Relationship between pulse and interval time $I_{imp}=f(t_i, t_p)$ when electrode feed rate v_f = 0.5 mm/min, interelectrode voltage U = 19 V, ultrasonic vibrations power P = 0 W.

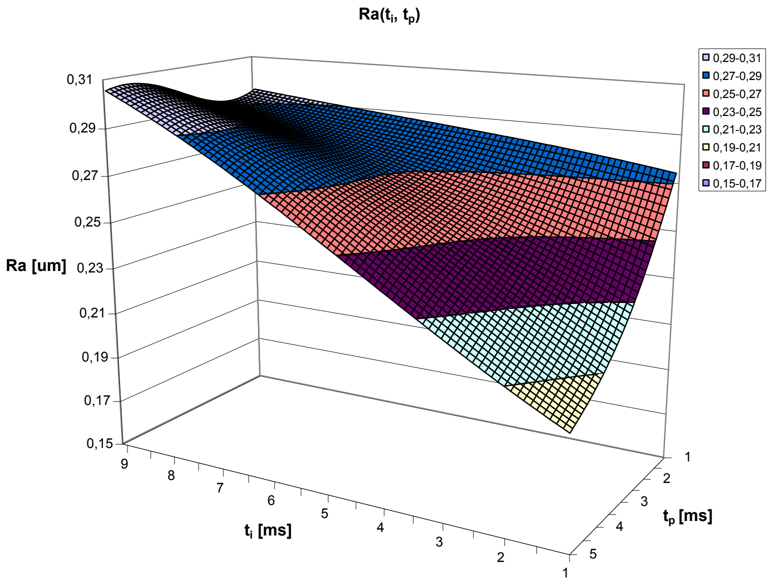

Fig. 5. Relationship between surface roughness parameter Ra and pulse and interval time Ra = f(t_i, t_p) when electrode feed rate v_f = 0.5 mm/min, interelectrode voltage U = 19 V, ultrasonic vibrations power P = 0 W.

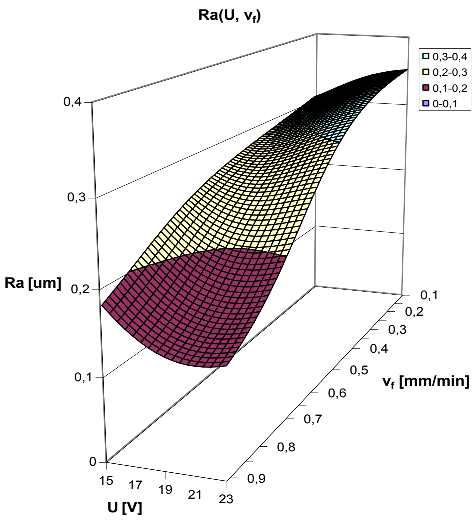

Fig. 6. Relationship between surface roughness parameter Ra and interelectrode voltage U and electrode-tool feed rate v_f: Ra = f(v_f, U) for pulse time t_i = 5 ms and interval time t_p = 3 ms when machining without electrode ultrasonic vibrations (P = 0 W).

4. RESULTS OF EXPERIMENTS WITH ELECTRODE ULTRASONIC VIBRATIONS

Below some results presenting influence of electrode-tool ultrasonic vibrations on USPECM machining process are described.

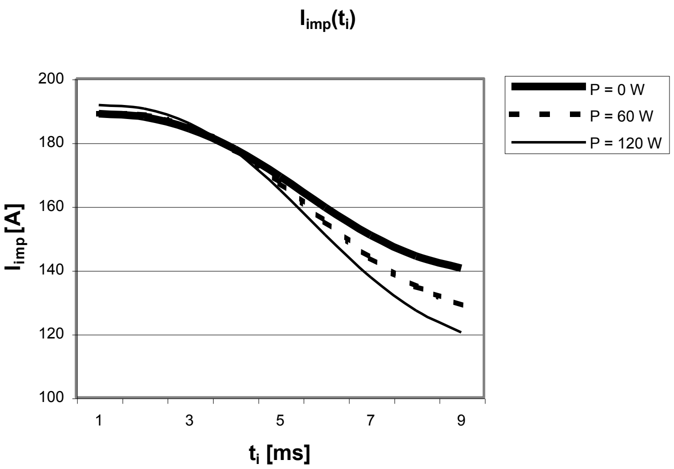

Fig. 7. Relationship between pulse current and pulse time for different power of ultrasonic vibrations when time of interval t_p = 3 ms, interelectrode voltage U = 19 V, electrode – tool feed rate v_f = 0.5 mm/min.

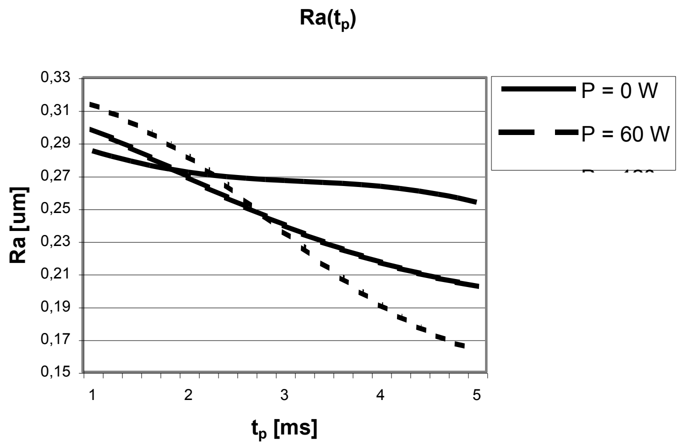

Fig.8. Relationship between surface roughness parameter Ra and interval time t_p for different power of ultrasonic vibrations when pulse time t_i = 5 ms, interelectrode voltage U = 19 V, electrode - tool feed rate v_f = 0.5 mm/min.

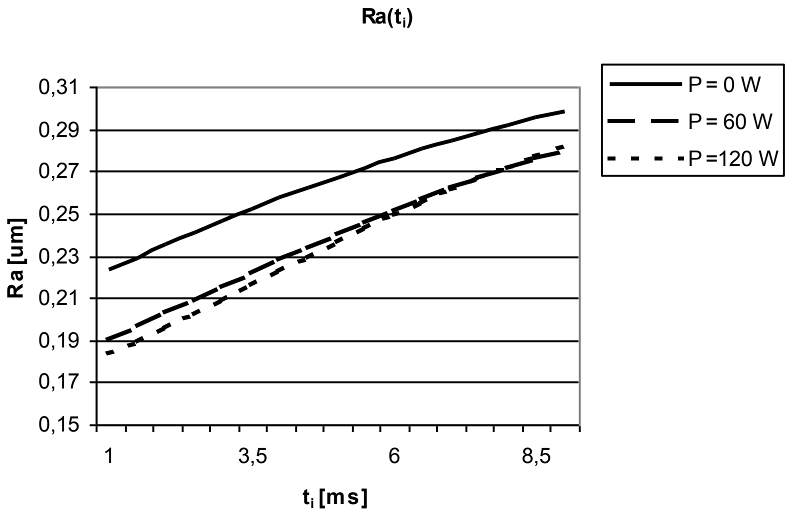

Fig. 9. Relationship between surface roughness parameter Ra and pulse time t_i for different power of ultrasonic vibrations when interelectrode voltage U = 19 V, time of interval t_p = 3 ms, electrode – tool feed rate v_f = 0.5 mm/min.

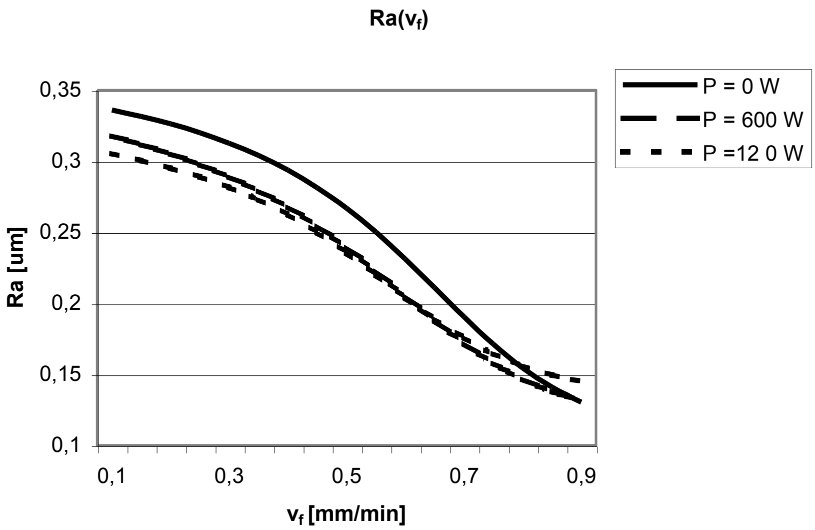

Fig. 10. Relationship between surface roughness parameter Ra and electrode-tool feed rate v_f for different power of ultrasonic vibrations when interelectrode voltage U = 19 V, time of interval t_p = 3 ms, time of pulse t_i = 5 ms.

From Figs 7 - 10 results that application of electrode - tool ultrasonic vibrations change course of phenomena occurring into interelectrode space. When power of ultrasonic vibrations is increased the intensity of cavitation phenomena also can increase. As a result the significant disturbances in electrolyte flow can take place. It is possible that into interelectrode gap the mixture of cavitation bubbles and spaces without electrolyte (after bubble collapse) are created what can be a reason of mean conductivity of interelectrode gap increase and then pulse current decreasing (Fig. 6). In majority cases the smallest values of surface roughness parameter Ra are obtained for machining with the highest power of electrode tool ultrasonic vibrations and for the smallest pulse time (Fig. 9), the highest interval time (Fig. 8) and the biggest electrode tool feed rate (Fig.10). Some differences from above mentioned principle occur for smaller values of interval time (Fig.8) and the highest values of electrode-tool feed rate (Fig. 10). When interval time is in the range 1 – 2 ms heat and electrochemical reaction products are not satisfactory removed from interelectrode space before successive pulse time occurs, what can be a reason that surface roughness is bigger for bigger power of ultrasonic vibrations (Fig.8).

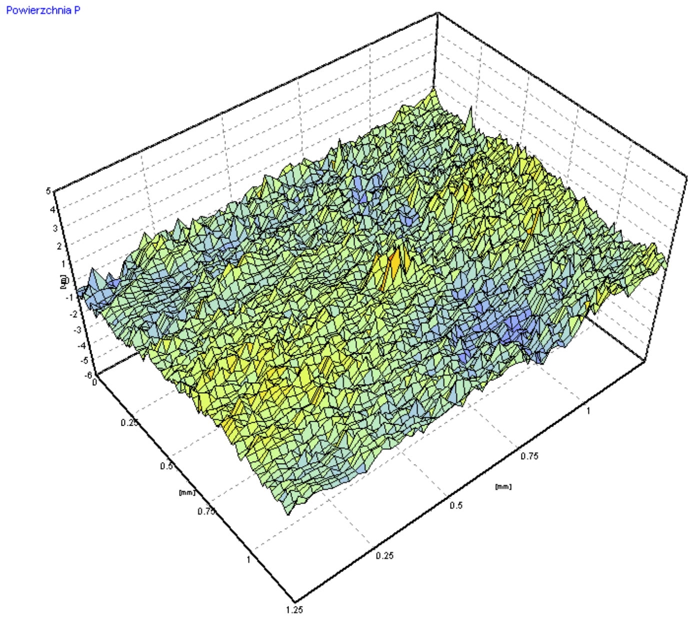

Fig. 11. Space surface geometrical structure after machining without electrode ultrasonic vibrations (P = 0 W) when: v_f = 0.5 mm/min, U = 19 V, t_i = 5 ms, t_p = 3 ms; Space surface parameters: SPp = 2.577 μm, SPv = 1.56 μm, SPz = 4.137 μm, Spa = 0.337 μm, SPq = 0.428 μm, SPsk = 1.683, SPku = 3.565

Together with electrode – tool feed rate increase up to 0.9 mm/min significantly decreases interelectrode gap thickness what can be a reason for reaching higher values of surface roughness parameter for higher power of electrode ultrasonic vibrations (Fig.10). The smallest value Ra = 90 nm has been obtained for pulse time 1 ms and interval time 3 ms when electrode-tool feed rate was 0.5 mm/min, interelectrode voltage 19 V and power of ultrasonic vibrations P = 60 W. It indicate that investigations aiming to obtain lower surface roughness should be in the future carry out for time of pulse smaller than 1 ms.

In above mentioned considerations only parameter Ra has been taken into account. The influence of electrode – ultrasonic vibrations on microgeometrical structure of machined surface is much more complicated.

In the Figs 11 and 12 the 3D-surface parameters when machining with and without electrode ultrasonic vibrations has been presented.

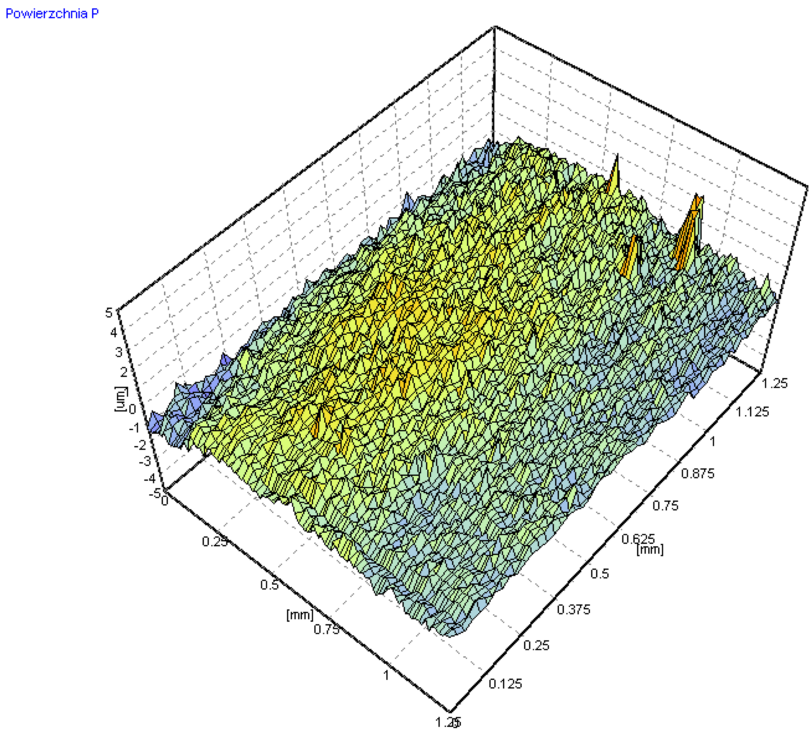

Fig. 12. Space surface geometrical structure after machining with electrode ultrasonic vibrations (P = 120 W) when: v_f = 05 mm/min, U = 19 V, t_i = 5 ms, t_p = 3 ms; Space surface parameters: SPp = 2.87 μm, SPv = 1.54 μm, SPz = 4.376 μm, SPa = 0.493 μm, SPq = 0.609 μm, SPsk = 1.567, SPku = 2.922

5. SUMARISING

From above presented experimental tests results and considerations it results that electrode ultrasonic vibrations change the course of the dissolution process and values of technological indicators of the USPECM process by changing the conditions of electrochemical dissolution process [3, 5, 8, 9]. Introduction of electrode ultrasonic vibrations can be a reason of:

- creating shock wave and cavitation phenomena which are accompanied by micro jets and pulse pressure in boundary layer,
- generating some amount of heat what can increase temperature in machining area,
- changing the course of chemical reactions in aqueous solutions.

As a result of above mentioned phenomena it is possible for optimal process parameters to:

- improve the heat and reactions products removal out of machining area,
- support diffusion and decrease the rate of passivation processes,
- decrease the potential drops in the layers adjacent to electrodes,
- increase coefficient of machinability,
- create the optimal hydrodynamic conditions from surface roughness parameter Ra point of view,
- decrease the surface roughness parameter Ra in comparison to classical and pulse electrochemical machining without ultrasonic vibrations.

The electrode ultrasonic vibrations complicate the course of phenomena occurring into interelectrode gap by creating the occurrence of the new phenomena (cavitation). For more precise description of the USPECM process the further investigations are necessary.

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