ELECTROCHEMICAL MACHINING SUPPORTED BY ELECTRODE ULTRASONIC VIBRATIONS

Adam Ruszaj, Maria Zybura-Skrabalak, Sebastian Skoczypiec, Robert Żurek
The Institute of Metal Cutting,, ul. Wroclawska 37a, 30-011 Kraków, POLAND

ABSTRACT

In case of machining small surfaces the main problem, which should be solved is optimal electrolyte flow. One of the ways for solving this problem is introduction of electrode ultrasonic vibration. It is right to assume that ultrasonic vibration can support heat and electrochemical reactions products transportation out of machining area. In the investigations the influence of the machining parameters, such as power of ultrasonic vibrations, interelectrode voltage electrode, feed rate on final interelectrode gap thickness, current density and indicators of machined surface micro-geometry (surface roughness parameters R_a and R_z) have been taken into account. The results of investigations have it proved that the electrochemical machining assisted by electrode ultrasonic vibrations in case of machining small surface can improve significantly surface quality in comparison to classical electrochemical machining.

KEY WORDS: *Electrochemical machining, ultrasonic vibrations, micromachining*

1. INTRODUCTION AND PROBLEM FORMULATION

Electrochemical machining has its classical fields of application in space, aircraft and domestic industries applications. It results from the fact that after electrochemical machining it is possible to receive high quality of surface layer [1]. Recently electrochemical machining has widened its range applications for machining of small details, especially when the high surface layer quality and high accuracy are expected [2]. High surface layer quality can be reached only in optimal conditions of electrolyte flow, heat exchange and optimal removal of dissolved material out of machined area. In many cases, because of the small electrode dimensions, it is difficult to machine in the electrode tool the hole for electrolyte supplying.

In some machining processes, which use ultrasonic vibrations, the energy is used for direct removal of material allowance (for instance ultrasonic machining for shaping the hard and short materials). In other machining process, which use ultrasonic vibrations, the energy is used as a factor for supporting the rate of basic processes. In investigated cases, thanks to ultrasonic vibrations the intensification of electrochemical processes by increasing the diffusion of metal ions take place. The classical ultrasonic machining is mainly used for machining of ceramic materials [3, 4, 5, 6]. The frequency of tool vibration can be changed in range from 19 to 23 kHz. The amplitude is changing in the range from 20 to 30 μm. The ultrasonic vibrations, and mainly the ultrasonic field which is creating during tool vibration, have the significant influence on the kinetics of electrodes processes. Perusich and Alkine [7, 8] have presented the results of investigations, which have been carried out in the sixties. They indicated that ultrasonic vibration increases the rate of electrochemical dissolution. They have carried out the investigations for dissolution process of iron in 2 N solution of sulfuric acid supported by ultrasonics with frequency of 1.58 MHz and power density up to 7.8 kW/cm^2. They estimated that with sufficiently high intensities, ultrasound was found to affect

significantly the time of passivation and to hinder repassivation completely. During other investigations, it was suggested that ultrasonic vibrations prevent the crystallisation of a salt or hydrate from forming on the surface and keeping the metal in a state of active dissolution. The ultrasonic waves focused on the immersed electrode tool, caused a vibrational displacement of the liquid in the machining area. If the amplitude of the oscillation would be sufficiently large, cavitation bubbles would form, increase in size then, and finally implode in a manner that creates micro-jets of high intensity at the workpiece surface.

Also Kozak [9] has suggested that, when electrode tool vibrated with frequency exceeds 18 kHz, the ultrasonic wave gives possibility for creating the cavitation micro-bubbles near the workpiece surface. In the area adjacent to electrode surface the micro-jets with high velocity (10^2 m/s) are created what gives the possibility of increasing the intensification of mass, electric charge and heat transportation, and increase the dissolution rate. These phenomena are particularly useful electrochemical machining, when the passivation layer is being created. This passivation layer can be destroyed thanks to the high pulse pressure (about 10^2 MPa) created by the ultrasonic vibrations.

The results of electrochemical machining process investigations supported by electrode ultrasonic vibrations are presented below. The general aim of these investigations was to find out differences between classical ECM and electrochemical process supported by ultrasonic vibration.

2. DESCRIPTION OF EXPERIMENTAL TEST STAND

The scheme of test stand is presented in Fig. 1. This test stand has been mounted in the working chamber of the electrochemical machine tool type EOCA 40 produced by the Institute of Metal Cutting. The above mentioned machine tool was described in details in [10]. The main additional parts of the test stand are ultrasonic head and its generator. They have also been worked out at the Institute of Metal Cutting. The maximum power of ultrasonic head is 160 W and amplitude is 10 μm.
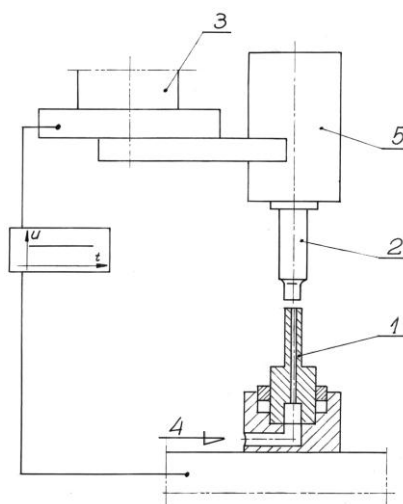

Figure 1. Scheme of test-stand for experiments: 1- workpiece, 2 – electrode - tool, 3 – head, 4 – electrolyte supplying, 5 – ultrasonic head.

3. RESULTS OF EXPERIMENTS

Experimental tests have been carried out for two ways of machining. The first one was for case with electrode ultrasonic vibrations. The other one was the classical electrochemical machining process. The scheme of test stand has been presented in the other paper prepared for ISEM XIII Conference [11]. Experiments have been carried out for the following range of process parameters: power of ultrasonic vibrations $P = 20 - 120$ W, interelectrode voltage $U = 8 - 22$ V, electrode tool feed rate $v_p = 0.2 - 1.4$ mm/min. As machined material the NC6 steel has been applied, electrode has been made of brass. Electrolyte was 15% water solution of NaNO$_3$, initial interelectrode gap was 0.1 mm and depth of machining 0.9 mm in both cases. The surface of the machined surface was 47 mm^2. Other information can be found in the below presented Figures 2 - 15.
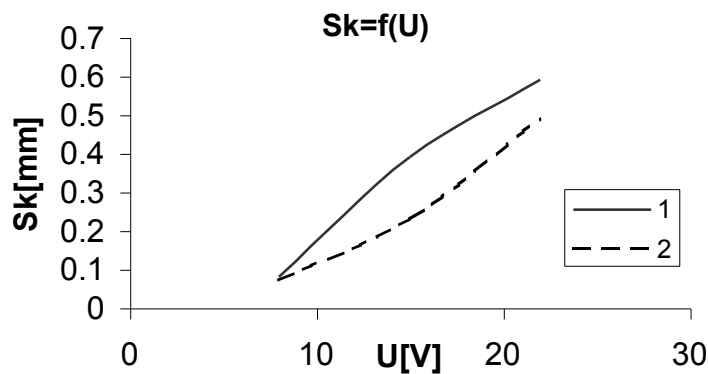

Figure 2. Relationship between final interelectrode gap thickness S_k and interelectrode voltage U for electrode feed rate $v_p = 0.8$ mm/min and electrolyte pressure $p_e = 3$ kG/cm^2; 1-traditional ECM supported by USM with power of ultrasonic vibrations $P = 70$ W, 2 – traditional ECM machining.
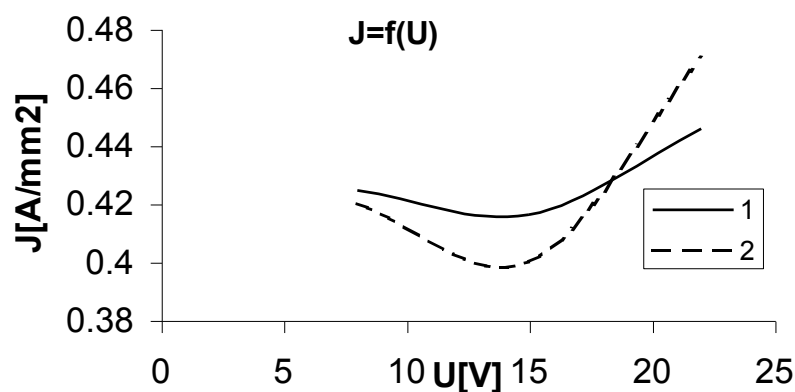

Figure 3. Relationship between current density J and interelectrode voltage U for electrode feed rate $v_p = 0.8$ mm/min and electrolyte pressure $p_e = 3$ kG/cm^2; where: curve 1 and 2 – the same as in Fig. 2.
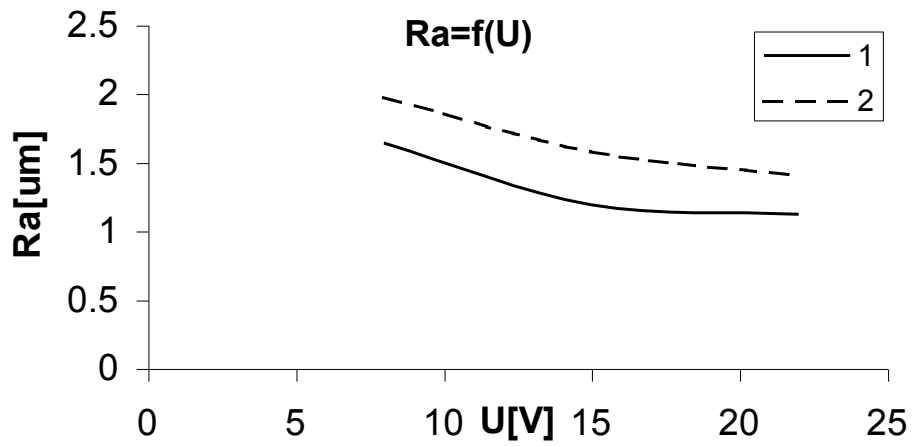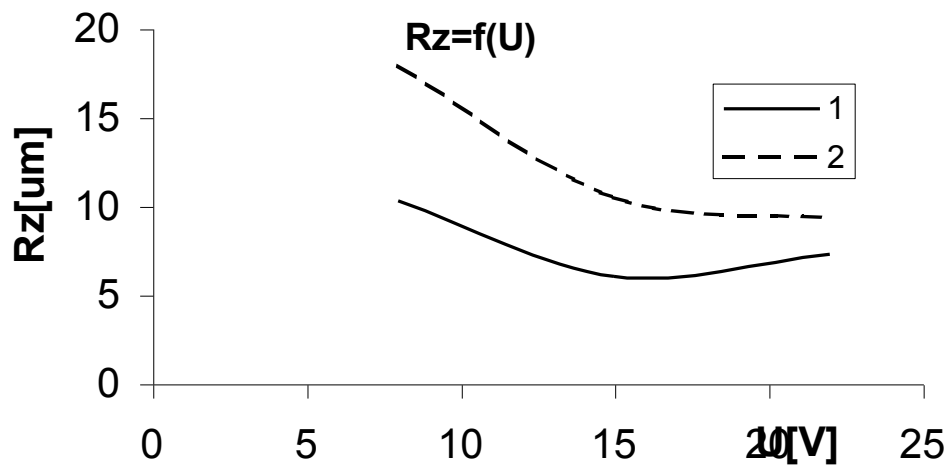
Figure 4. Relationship between surface roughness parameters R_a and interelectrode voltage U for electrode feed rate $v_p = 0.8$ mm/min and electrolyte pressure $p_e = 3$ kG/cm^2; where: curve 1 and 2 – the same as in Fig. 2.

Figure 5. Relationship between surface roughness parameters R_z and interelectrode voltage U for electrode feed rate $v_p = 0.8$ mm/min and electrolyte pressure $p_e = 3$ kG/cm^2; where: curve 1 and 2 – the same as in Fig. 2.
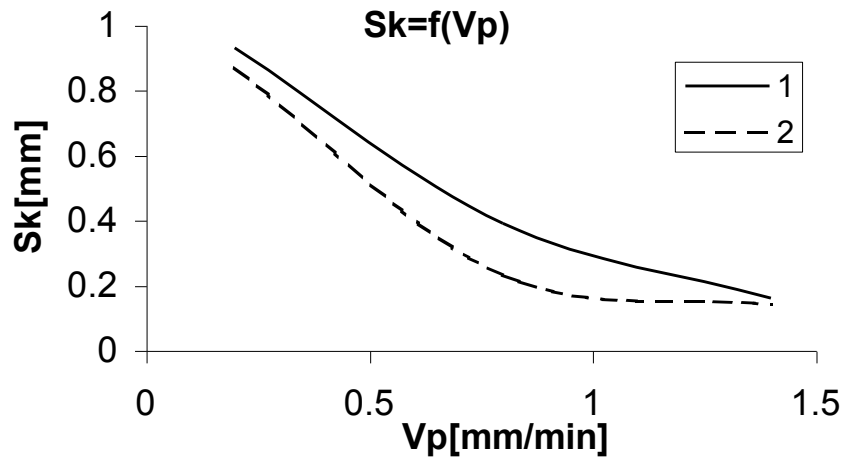
Figure 6. Relationship between final electrode gap thickness S_k and electrode feed rate v_p for interelectrode voltage U = 15 V and electrolyte pressure p_e = 3 kG/cm^2; 1- traditional ECM supported by USM with power of ultrasonic vibrations P = 70 W, 2 – traditional ECM machining.
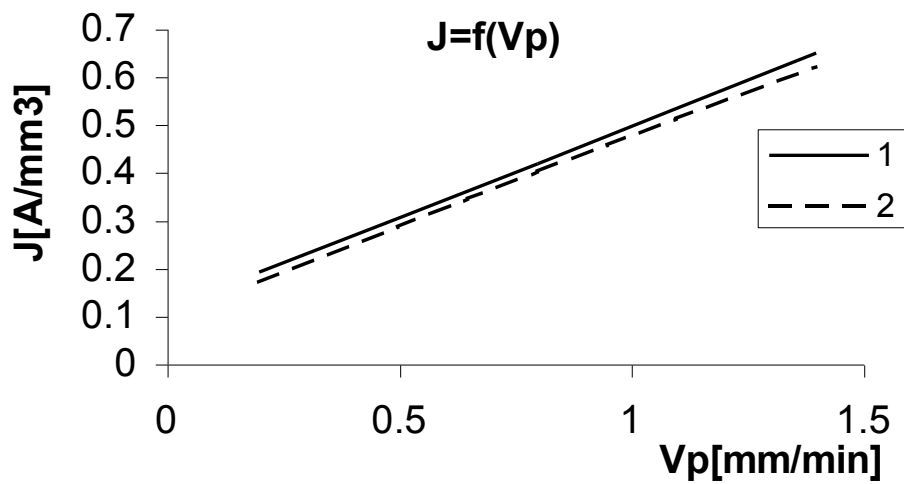

Figure 7. Relationship between current density J and electrode feed rate v_p for interelectrode voltage U = 15 V and electrolyte pressure p_e = 3 kG/cm^2; where: curve 1 and 2 – the same as in Fig. 6.
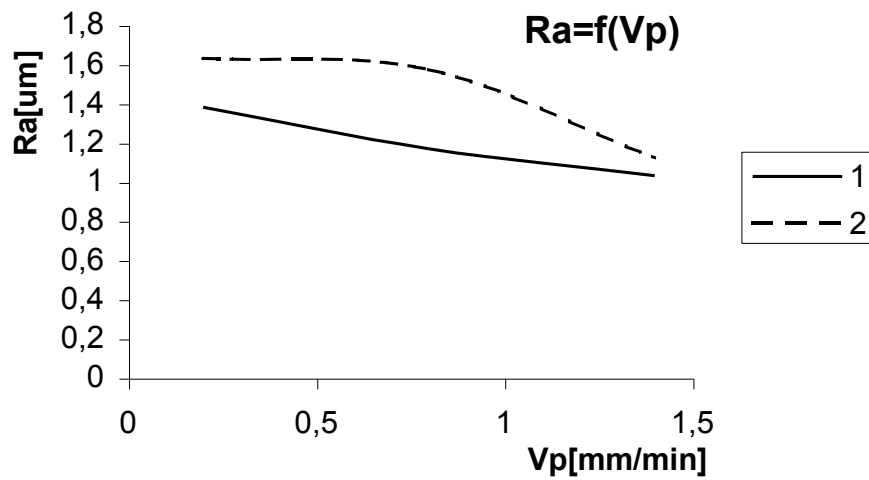
Figure 8. Relationship between surface roughness parameters R_a and electrode feed rate v_p for interelectrode voltage U = 15 V and electrolyte pressure p_e = 3 kG/cm^2; where: curve 1 and 2 – the same as in Fig. 6.
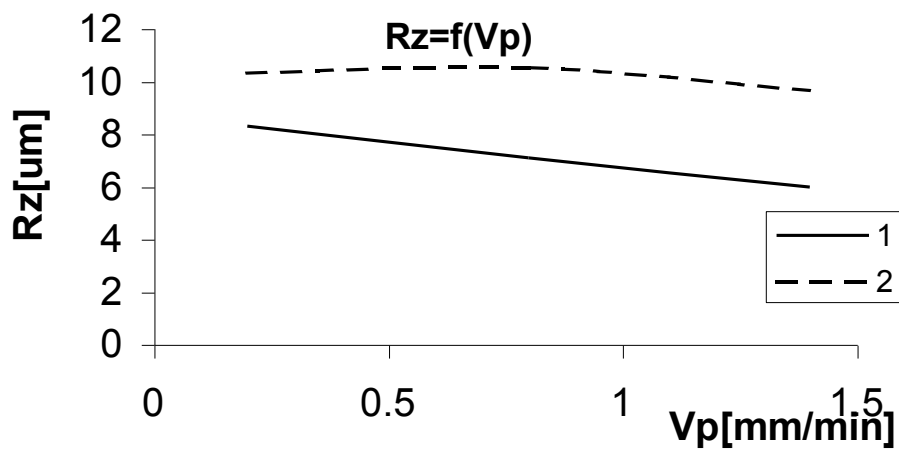

Figure 9. Relationship between surface roughness parameters R_z and electrode feed rate v_p for interelectrode voltage U = 15 V and electrolyte pressure p_e = 3 kG/cm^2; where: curve 1 and 2 – the same as in Fig. 6.
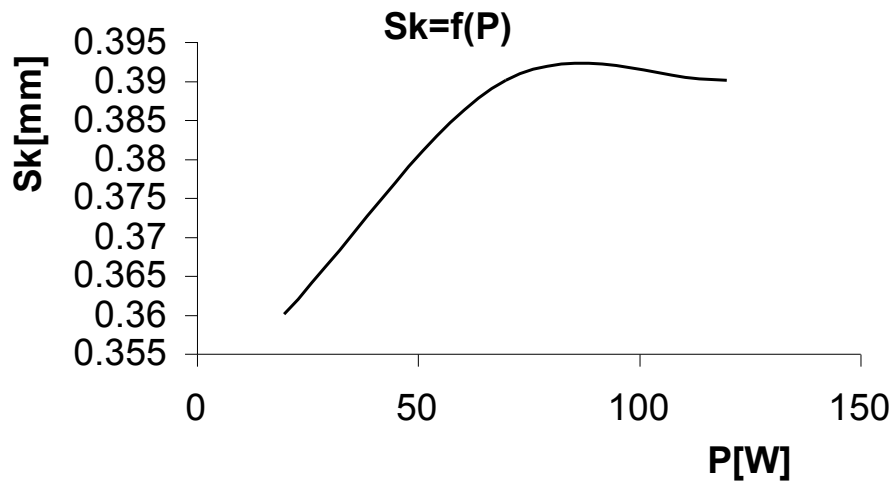
Figure 10. Relationship between final interelectrode gap thickness S_k and power of electrode ultrasonic vibrations P for interelectrode voltage $U = 15$ V, electrode feed rate $v_p = 0.8$ mm/min and electrolyte pressure $p_e = 3$ kG/cm^2.

Figure 11. Relationship between current density J and power of electrode ultrasonic vibrations P for interelectrode voltage $U = 15$ V, electrode feed rate $v_p = 0.8$ mm/min and electrolyte pressure $p_e = 3$ kG/cm^2.

Figure 12. Relationship between surface roughness parameter R_a and power of electrode ultrasonic vibrations P for interelectrode voltage $U = 15$ V, electrode feed rate $v_p = 0.8$ mm/min and electrolyte pressure $p_e = 3$ kG/cm^2.
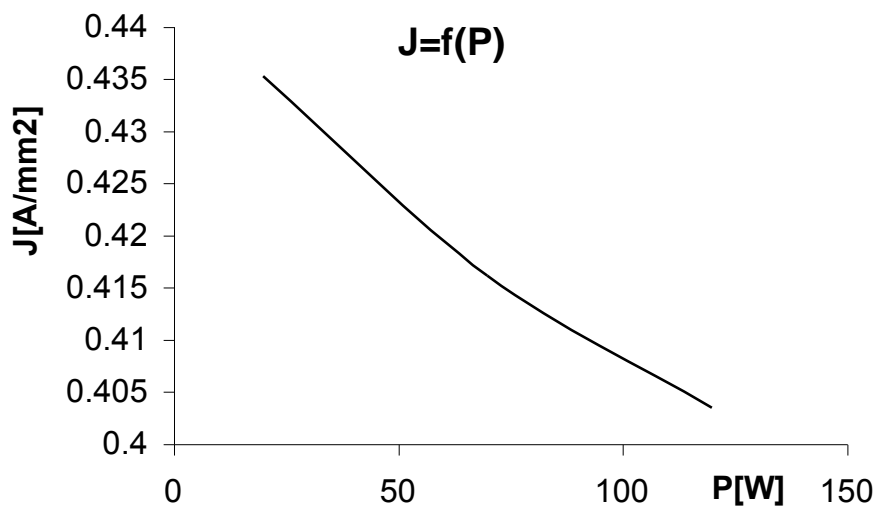

Figure 13. Relationship between surface roughness parameter R_z and power of electrode ultrasonic vibrations P for interelectrode voltage $U = 15$ V, electrode feed rate $v_p = 0.8$ mm/min and electrolyte pressure $p_e = 3$ kG/cm^2.
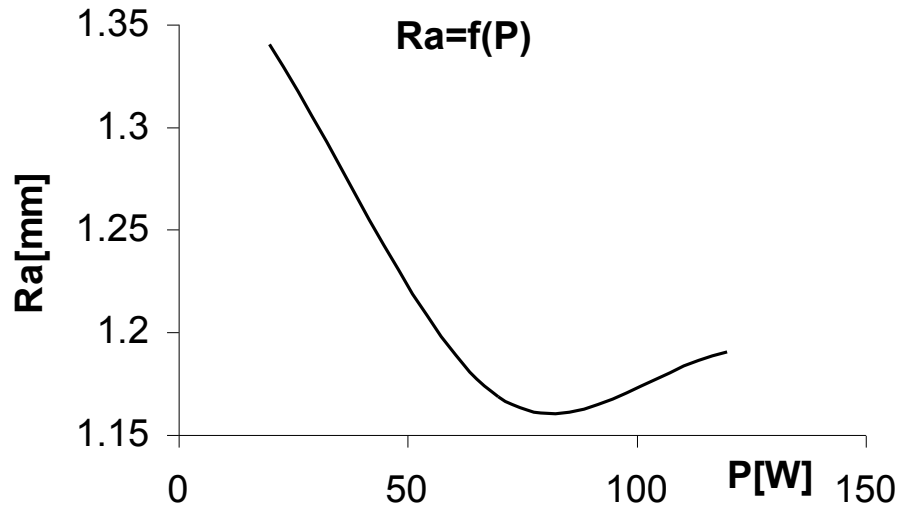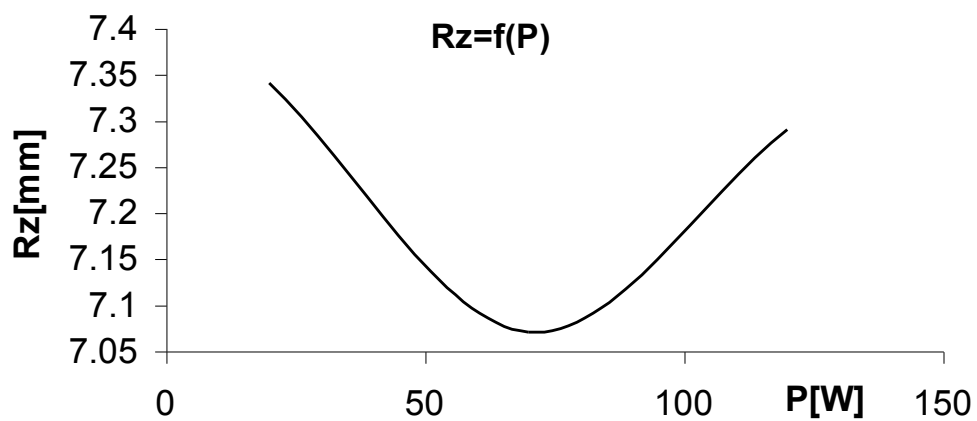
Figure 14. Comparison of surface roughness parameter R_a for different ways of electrochemical machining; 1 – with constant current, 2 – with pulse current, 3 – traditional ECM supported by USM
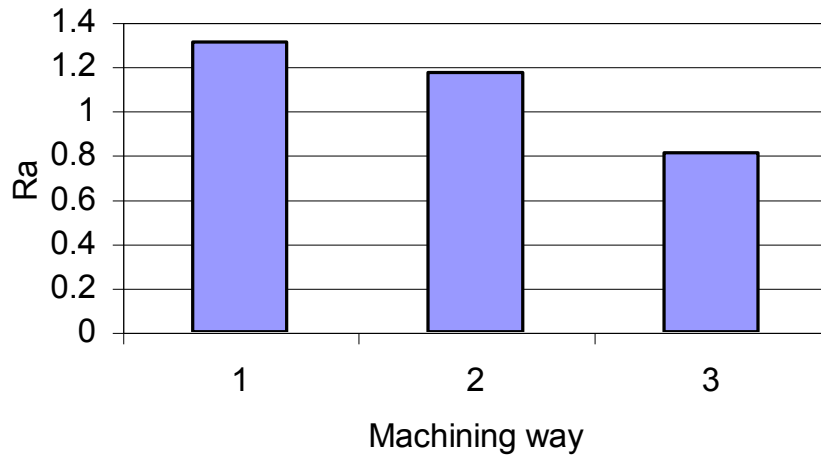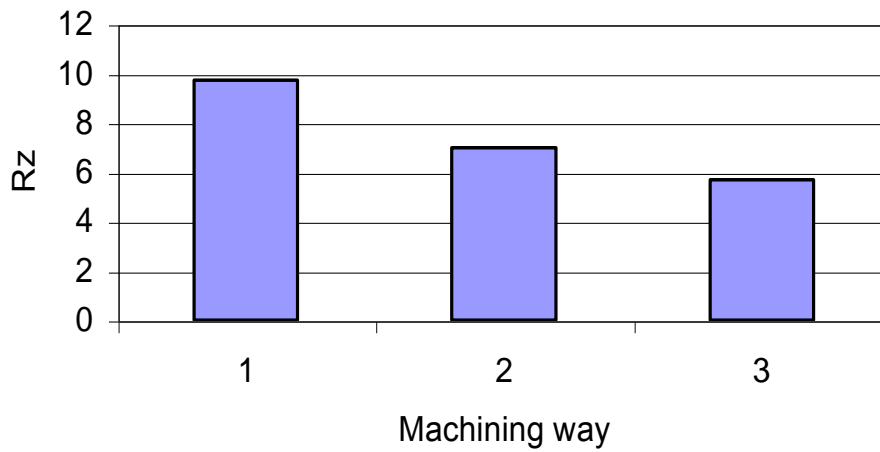

Figure 15. Comparison of surface roughness parameter R_z for different ways of electrochemical machining; 1 – with constant current, 2 – with pulse current, 3 – traditional ECM supported by USM

The discussion of above presented characteristics is presented bellow.

4. ANALYSIS OF EXPERIMENTAL RESULTS

In analysis of experimental tests results the basic for electrochemical machining process relationship 1 and 2 will be applied.

The relation [1] is taking into account for the final interelectrode gap S_k estimation:

$$S_k = \frac{\eta k_v \kappa (U - \Phi)}{v_p}$$ [1]

where:

ηk_v - coefficient of electrochemical machinability,

κ - electrolyte conductivity,

U - mean value of interelectrode voltage,

Φ - voltage drop in the electrolyte films adjacent to the electrode and workpiece,

$v_{p.}$ - feed rate.

The relation [2] is considered for current density J estimation:

$$J = \frac{v_p}{\eta k_v}$$ [2]

When electrode feed rate is constant, together with interelectrode voltage increase interelectrode gap thickness also increases (Fig. 2). And in case of electrode ultrasonic vibrations interelectrode gap thickness is higher. It results from the fact that ultrasonic vibrations decrease improve electrolyte flow into interelectrode gap and decrease values of Φ or increase value of ηk_v, what can be a reason of interelectrode gap thickness increase (eq. 1). Interelectrode voltage has also influence on current density J (Fig. 3). This relationship is more difficult to be explained. At first together with U increase current density decreases, however in case of ultrasonic vibrations is bigger. Decrease of current density can be explained by η and (or) k_v increase. When U is small interelectrode gap thickness is also small and condition of electrolyte flow are not optimal. Together with increase of U the interelectrode gap thickness S_k also increases and conditions of electrolyte flow (especially in case of electrode ultrasonic vibrations) becomes better what can be a reason of η and (or) k_v increase. Because some values of U, current density J increases and become lower in case of electrode ultrasonic vibrations what can be explained by decrease of η, because of interelectrode gap thickness increase. It is worse to remind that in case of machining with electrode ultrasonic vibrations interelectrode gap thickness is higher (Fig. 2)

The ultrasonic vibrations give the increase of heat and dissolution products transportation out of interelectrode area. So, the electrolyte properties are homogeneous in the whole volume of interelectrode gap. This gives conditions for creating the uniformly dissolution of the machined surface, so decrease the parameters of machined surface roughness during traditional ECM supported by USM in comparison to the traditional ECM machining (Figs 4 and 5).

In case of electrode – tool feed rate influence on technological indicator investigations (when U = const and P = const) all relationships can be explained directly from equations 1 and 2. Interelectrode gap thickness S_k, and surface roughness parameters R decrease and current

density J increases together with electrode feed rate increase (Figs. 6 and 7). In case of machining with electrode ultrasonic vibrations surface roughness parameters R_a and R_z are significantly lower than in case of classical electrochemical machining (Figs 8 and 9).

The power of ultrasonic vibration also has influence on process technological investigations. From Figs 10 – 13 result that there two areas of ultrasonic power influence on technological indicators. When power P increases from 20 to about 70 W the interelectrode gap thickness increases, current density and surface roughness parameters R_a, R_z slightly decrease. For power higher than 70 W interelectrode gap thickness is constant and J, R_a, R_z slightly increases. So, in investigated case P about 70 W is optimal from the surface roughness point of view.

The comparison of the value for surface roughness parameters, which have been created during different ways of electrochemical machining, is presented in Fig. 14 and 15. The interelectrode voltage was 15 V during all experiments. It is seen that the smallest values of the surface roughness are for traditional ECM supported by USM ($R_a = 0.82$ μm and $R_z = 5.78$ μm).

5. CONCLUSIONS

Above presented results of electrochemical machining assisted by electrode ultrasonic vibrations in case of machining small surface indicate that this way of machining can improve significantly surface quality in comparison to classical electrochemical machining. Because of this fact the electrochemical machining assisted by ultrasonic vibrations is in comparison to pulse electrochemical machining a reasonable alternative in micromachining processes.

Generally the ultrasonic vibrations influence on the process of electrochemical machining results from the fact that they:

- improve the heat and reactions products removal out of machining area,

- because of direct mechanical electrolyte influence on electrode and machined surface support diffusion and decrease the rate of passivation processes; as a result it is possible to decrease potential drops in the layers adjacent to electrodes Φ, increase coefficient of electrochemical machinability ηk_v and create the optimal hydrodynamic conditions from surface layer point of view.

The traditional ECM supported by USM will be optimise in case of small surfaces machining for different materials in the future investigations. The main criterions of optimisation will the quality of surface layer.

BIBLIOGRAPHY

1. Rajurkar, K.P., Zhu, D., McGeough, J. A., Kozak, J., De Silva, A. "New developments in electro-chemical machining", Annals of the CIRP, Vol. 48 (2), pp. 567-579, 2000.

2. Datta, M., Shenoy, R.V., Romankiw, L.T. "Recent advances in the study of electrochemical micromachining", Manufacturing Science and Engineering ASME, PED Vol. 64, pp. 675-692, 1993.

3. Khairy, A.B.E. "Assessment of some dynamic parameters for the ultrasonic machining process", Wear, No137, pp.187–198,1990.

4. Prabhakar, D., Ferreira, P.M., Haselkorn, M. "An experimental investigation of material removal rates in rotary ultrasonic machining", Transactions of the North American Manufacturing Research Institution of SME, Vol. XX, pp. 211-212, 1992.

5. Glimore, J.R. "Ultrasonic machining and polishing", Manufacturing Science and Engineering ASME, PED-Vol. 64, pp.785 – 793, 1993.

6. Oczoś, K. E. "Kształtowanie ceramicznych materiałów technicznych", Oficyna Wydawnicza Politechniki Rzeszowskiej, 1996.

7. Perusich, S.A., Alkire, R. C. "Ultrasonically inducted cavitation studies of electrochemical passivity and transports mechanisms. I. Theoretical., J. Electrochem. Soc., Vol. 138 (3), pp. 700-707, 1991.

8. Perusich, S.A., Alkire, R. C. "Ultrasonically inducted cavitation studies of electrochemical passivity and transports mechanisms. II. Experimental., J. Electrochem. Soc., Vol. 138 (3), pp. 708-713, 1991.

9. Kozak, J. "Analiza procesu obróbki elektrochemicznej elektrodą drgającą", Materiały V Konferencji Naukowo-Technicznej, EM'97 (ELECTROMACHINING), Golub-Dobrzyń, pp. 204-211, 1997.

10. Ruszaj, A., Dziedzic, J., Czekaj, J., Krehlik, M. „Electrochemical machining with electrode displacement controlled in tree axes", Proceedings International Symposium for Electromachining, ISEM XI, Lausanne, Switzerland, pp. 553 – 563, 1995.

11. Ruszaj A., Czekaj J., Chuchro M., Skrabalak G. "Electrochemical machining with short interelectrode voltage pulses", paper prepared for presentation during International Symposium ISEM XIII.