Same Technological Aspects Of Electrochemical And Electrodischarge Micro-Machining

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Summary Significant increase in many industries for Micro-Electro-Mechanical – Systems (MEMS) application is a reason of dynamic development in the field of micro-technologies what make it possible to produce microelements of dimensions lesser than 1000 μm. For micro-details manufacturing the conventional and unconventional methods are being applied. Significant position in micro-details manufacturing take electrochemical (μ - ECM) and electrodischarge (μ - EDM) machining.

1. INTRODUCTION

In micro-machining processes material can be removed as a result of [6, 7]:

- **Mechanical forces**

In this case material is removed by mechanical force through plastic or brittle breakage and typical examples are: cutting (drilling, milling, turning), sandblasting, grinding, ultrasonic machining, punching. In cutting processes, grinding and punching it is possible to obtain a good geometrical correlation between the tool path and the machined surface. In ultrasonic machining and sandblasting it is impossible because abrasive is not fixed on the tool. In these processes the elastic deformation of the micro-tool and the workpiece influeces machining accuracy and the limit of machinable size. Here the diamond and hard ceramics are suitable for use as tool or abrasive materials.

- **Melting and vaporization**

Here material is melted, in some cases, vaporized by heat generated by various physical phenomena. Material is usually removed by pressurized gas generated by different sources. Typical examples: EDM (Electrodischarge Machining), LBM (Laser beam machining) and EBM (Electron beam machining). The proper dimensions and machined surface roughness is reached by reducing the pulse energy to realize the micro-machining, by controlling the electrical parameters. It is obtain in : EDM by very short pulses application and in LBM and EBM the beam shape is controlled by an optical system to sharply focus on the target. Mechanical properties of workpieces don't influence the machining process because there is no mechanical contact and the temperature generated by these processes can easily exceed the boiling point of workpiece materials. Thermal properties (melting point, boiling point, heat conductivity, efficiency and heat capacitance) influence machining process. Disadvantages are: uncertainty in specifying the workpiece dimensions (in EDM, there is a discharge gap), in LBM and EBM, the focused spot of beam is not clear; in each case on machined surface a heat affected layer on the machined surface is created, however is is possible to reach rather high localization of the process and high realibility in material removal.

- **Ablation**

Here material is removed by vaporization, skipping the phase of melting usually when Excimer laser and Femtosecond laser are applied. As a result surface layer is only slightly affected by heat generation and it is possible to reach a high dimensional accuracy. Main disadvantages are low efficiency in material removal and high cost of equipment. Size of microshapes depends on optical system possibilities.

- **Dissolution**

In this case material is removed as a result of chemical or electrochemical reactions in liquid. Typical example is electrochemical machining (ECM). The removal mechanism is based on ionic reaction on the workpiece surface. The main advantages of this process are almost zero machining forces and high quality of the surface layer what results from the fact that material is removed atom by atom in temperature lower than 373 K. It is worth to underline that machined surface is free from additional residual stresses and that metal removal rate don't depends on workpiece mechanical properties. The basical disadvantage of the ECM process is low localization of the process and high sensitivity on nonmetallic inclusion in machined material or nonmetallic layers which are sometime created on machined surface during machining, what is a reason of lower than in EDM realibility in material removal.

- **Plastic deformation** The shape of product is specified by copying the shape of a die or mold. The production speed is very high and dimensional accuracy depends on the accuracy of die or mold, the partial recovery from deformation, the spring-back phenomenon and flowability of the workpiece material which is softer than that of die or mold.**Solidification**

In this process a liquid or a paste is solidified in a mold; typical examples are injection molding and die casting. The basical application of these processes is mass production. Accuracy depends on tool (mould, die) accuracy, wear during manufacturing and metallurgical phenomena occurring (material flow, cristalization, bubles formation aso).

- **Lamination**

Material is solidified layer-by-layer (Sterelitography-SL and other Rapid Prototyping techniques - RP). Advantages of this process are: easy creation of internal shapes without tool as die or mold and short time of manufacturing process designing. The disadvantages are narrow choice of materials and limited dimensional accuracy.

- **Recomposition**

Metal ion in an electrolyte are deionized to become solid and to form a shape. This process is applied in electroplating or electroforming. Using this technology it is easier to fabricate concave than convex micro-shapes usually in mass production. Machining accuracy depends on the accuracy of mold.

2. MIKROELECTRODISCHARGE MACHINING (μ - EDM)

In electrodischarge machining process material is removed as a result of thermal phenomena which occur during electrical discharges in dielectric between electrode-tool and workpiece (Fig.1).

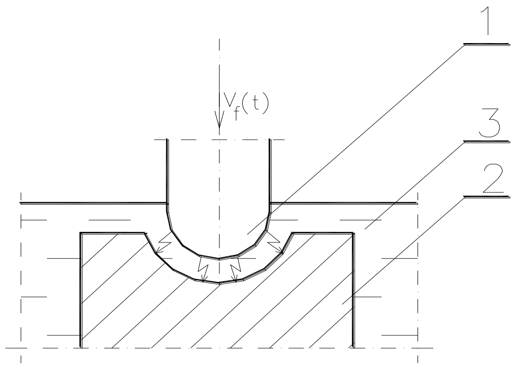

Fig.1. Scheme of electrodischarge sinking: 1 – elektrode - tool, 2 – workpiece, 3 – dielectric, v_f *(t)* – electrode-tool feed rate [11].

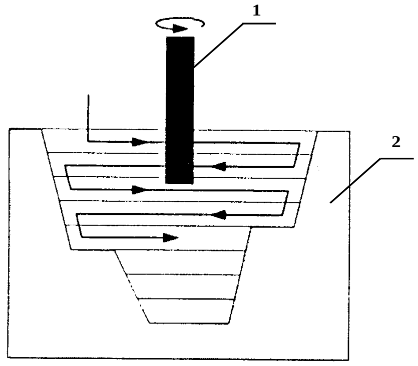

Fig..2. Scheme of electrodischarge milling process: 1 – elektrode - tool, 2 – workpiece [8, 9]

Mean temperature in electrodischarge channel is about 6 –12 thousand K [1, 10]. Because of this fact some portion of workpiece material is removed as a result of evaporating and melting. Part of heat generated in plasma channel is transported to electrode tool and because of that fact also some part of electrode material is removed. This fact is a significant disadvantage of EDM process; especially when machining micro-parts. Electrode-tool material removal should be as small as possible. An indicator of material ability of being a good material for electrode-tool is its electroerozion resistance, which had been defined by K. Albiński [2]:

$$S = (1-\nu)\frac{T\lambda}{E\alpha} \tag*{1}$$

where: S – electroerozion resistance, E - Young’s modulus, T – temperature of melting, α - coeficient of linear termal expansion, λ - coeficient of termal conductivity, ν - Poisson ratio.

Using relaionship (1) it is possible primary evaluation of material ability of being electrode-tool. Electrode tool wear can be for choosen material significantly decreased by using proper shape of voltage pulse and optimisation of process parameters. However because of electrode tool wear cost of manufacturing tools is quite significant, especially when machining freeform surfaces in drilling operation, where shape of workpiece is received as reproduction of electrode-tool shape in machined material. In order to decrease electrode-tool wear on workpiece accuracy and costs of EDM machining it is very useful to apply electrodischrge milling process [Fig.2]. Here, workpiece shape is received as a result of electrode-tool trajectory reproduction in machined material. Of cource in both cases it is necessary to correct electrode tool shape (drilling) or electrode-tool trajectory (milling), however in the second case is easier and cheper. The problems which have to be solved or at least to be taken into account when going from makro to mikro machining are discussed below.

- **Manufacturing micro-electrode-tool;**

Usually machine-tools for μ - EDM are equipped with a special unit for electrode manufacturing[6].Very important is choosing high electroerozion resistant material for electrode-tool; for instance electrode tool can be made of composite materials (CuW) and its diameter which can be reached is: 5 - 300 μm. The electrode-tool diameter is very imprtant when machining cavities (internal surfaces) because it limits dimentions of machined microdetail. Using special materils for electrode-tool and special strategy of machining it is possible to decrease electrode-tool wear to ~ 1%[6].

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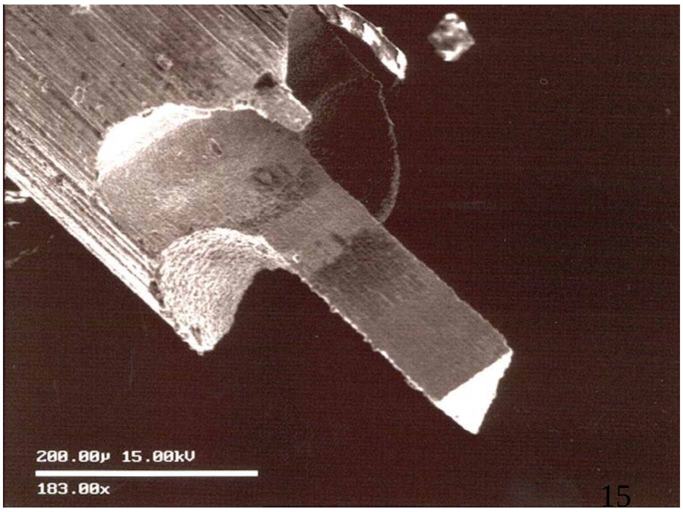

Fig.3. Electrode-tool for Micro-EDM[6].

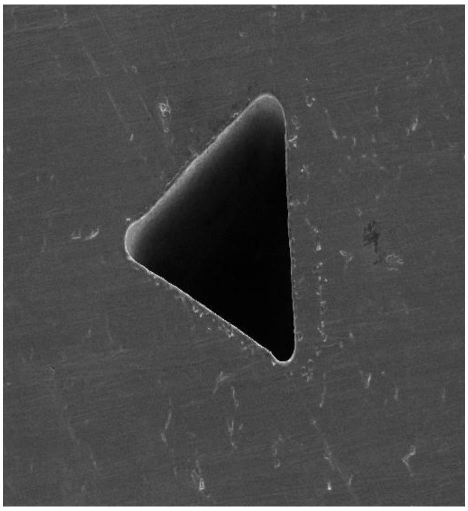

Fig.4. Micro-hoole machined using EDM with triangular electrode-tool [6].

- **Decreasing interelectrode gap thickness and amount of material removed during one electrical discharge;**

In macromachining it is possible to decrease interelectrode gap thickness by decreasing pulse time and pulse curent amplitude (Figs 5 - 8). In micromachining the special generators are applied which make possible to obtain energy of electrical pulse lesser than 1μJ. It is possible when voltage amplitude is about 10 – 40 V and pulse time is very short. In EDM milling there is one more parameter for controlling. thickness of material during one electrode pass – it is velocity of electrode-tool displacement along space electrode-tool trajectory. Changing electrode-tool velocity it is possible to change thickness of removed material during one electrode pass in wide range, even when using typical machine-tool for macro-machining [11].

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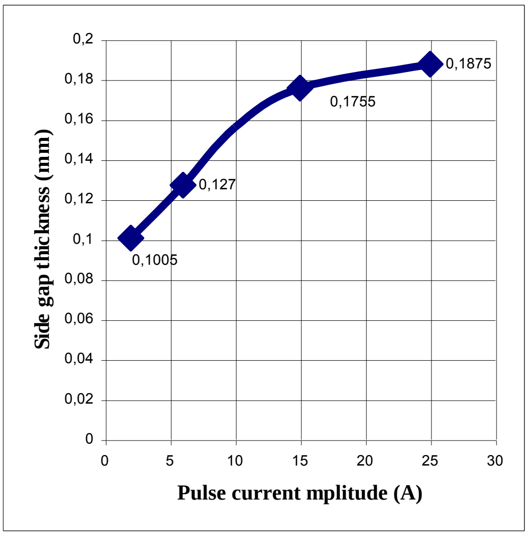

Fig.5.. Relationship between side gap thickness and pulse current amplitude: electrode diameter (Cu) – 1[mm], pulse time – t_i = 200 [µs], dielectric kerosine, workpiece material: St 3 [5].

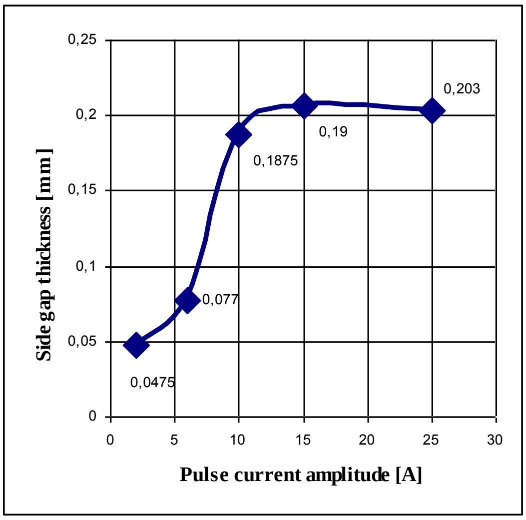

Fig.7 Relationship between side gap thickness and pulse current amplitudej: electrode diameter (Cu) – 1[mm], pulse time – t_i = 200 [µs], dielectric kerosine, workpiece material: stainless steel [5].

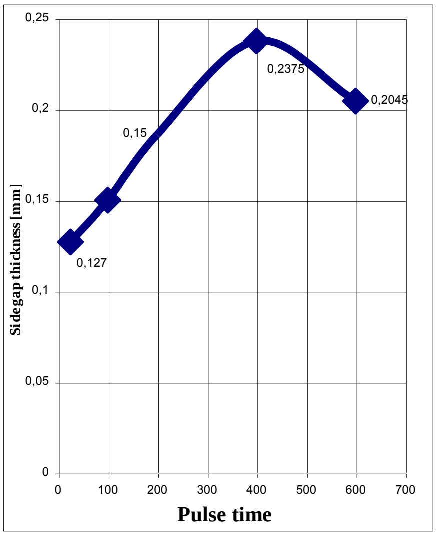

Fig.6. Relationship between side gap thickness and pulse time ti [µs]; electrode diameter (Cu) – 1[mm], pulse current amplitude – A = 10[A], dielectric kerosine, workpiece material: St3 [5].

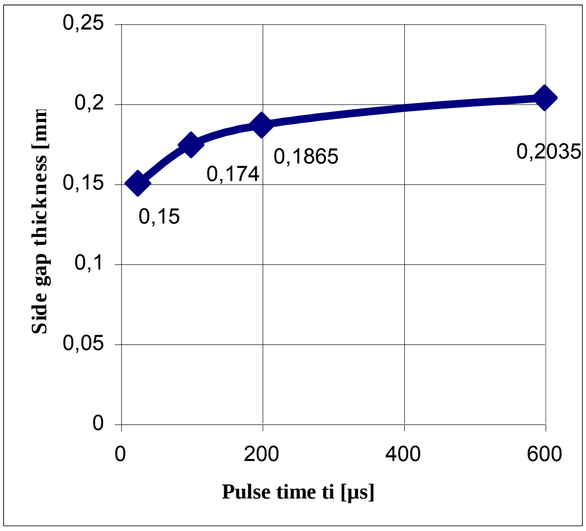

Fig.8.. Relationship between side gap thickness and pulse time ti [µs]; electrode diameter (Cu) – 1[mm], pulse current amplitude – A = 10[A], dielectric kerosine, workpiece material: stainless stee [5].

- **Special requirements machine-tool construction:**

In order to machine μ - parts it is necessary to have machine-tool equipped with drive system working with high precision of movement and high accuracy repeated positioning, special unit for on-machine electrode-tool preparation, rapid response of control mechanism, special . optical observation system All above mentioned conditions can be reached when using SARIX machine-tools

2. ELECTROCHEMICAL μ-MACHINING

In many cases. mechanical parts of micro-mechanisms can be manufactured using electrochemical machining process (ECM). However in mass production ECM and EDM processes are applied rather for manufacturing micro-tools as micro-moulds, micro-dies a.s.o. When ECM is applied for above mentioned micro-tools manufacturing it is possible to apply two basical presented below cases: Electrochemical Sinking (Fig. 9) and Electrochemical Milling (Figs10,11,12).

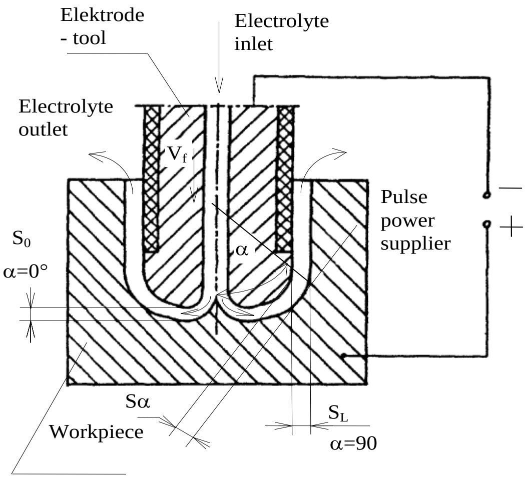

Fig. 9..Scheme of electrochemical sinking

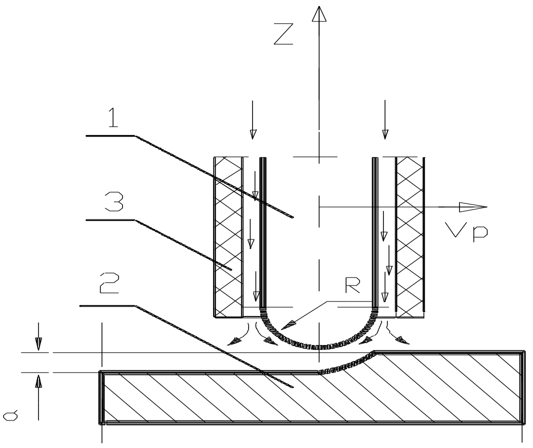

Fig. 10. Scheme of machining with universal electrode – tool (1), 2 - workpiece, 3 – nozzle for electrolyte supplying, a – thickness of material removed during one electrode pass

From electrode kinematic point of view EC Sinking is similar to ED Sinking and ECMilling is similar to EDMilling but way of material removal is quite different. In EDM material is removed as a result of above characterised thermal process and in ECM as a result of electrochemical dissolution. In electrochemical dissolution workpiece material is removed in electrochemical reactions atom by atom in temperature lowr than 373 K. On electrode –tool surface as a product of electrochemical reactions the Hydrogen is generated.. As a result workpiece surface layer has the same properties as body material, surface roughness is significantly lower than those after EDM and electrode-tool wear don't occur. However electrochemical dissolution process localization is worse than in EDM and it is the main disadvantage of this process. Dissolution process is also very sensitive for nonmetallic inclusions or nonmetallic layers created on machined surface during machining. Because of luck of electrode tool wear it is not necessary to introduce electrode-tool rotation,however Electrode-tool rotations improve hydrodynamic conditions, what is also very important.In order to find our possibilities of removing small layers of workpiece the mathematical modeling of the ECM process as in Fig.10 had been carried out [12]. Some results of mathematical modeling are presented below (Figs 12, 13, 14}.

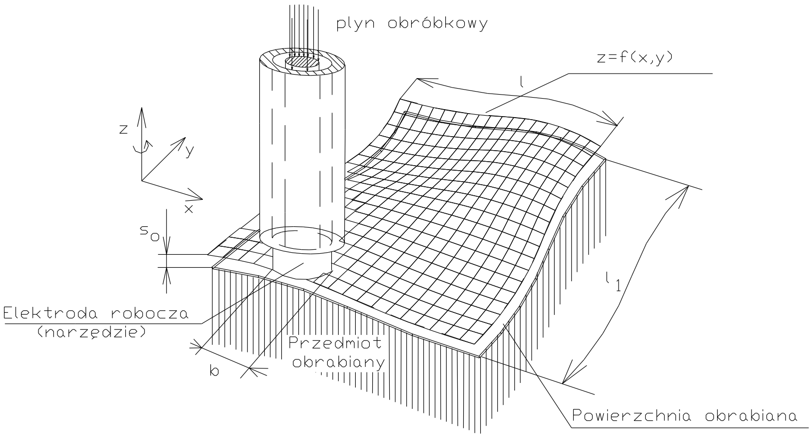

Fig. 11. Schemate of ECMilling with cylindrical flat electrode.

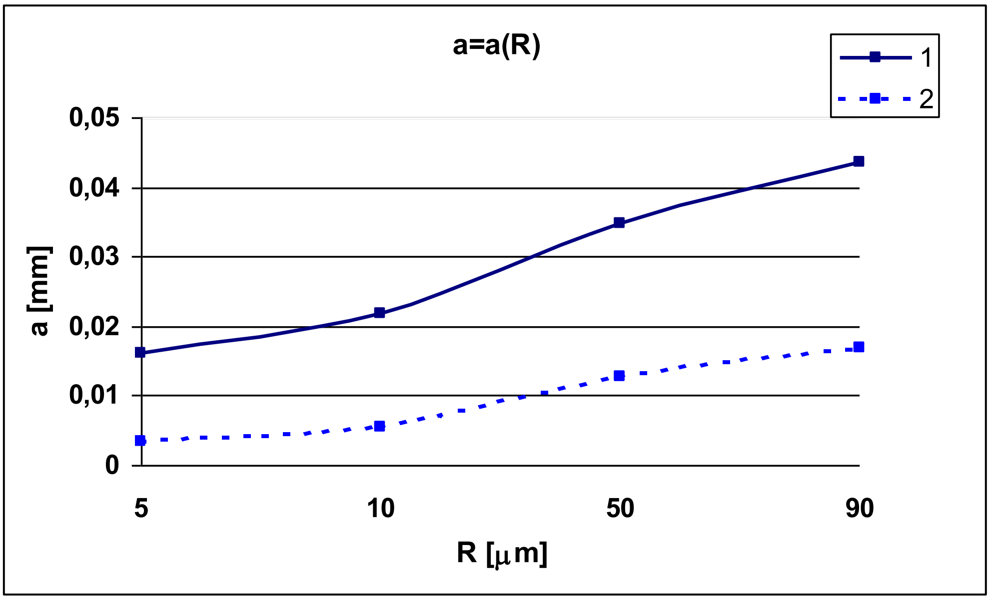

Fig.12..Relationship a = f(R); 1 – interelectrode voltage $U=5\ V$, initial distance between electrode and workpiece $S_o=5\ \mu m$, velocity of electrode-tool displacement over machined surface $v_p=5\ mm/min$; 2 - $U=20\ V$, $S_o=50\ \mu m$, $v_p=35\ mm/min$

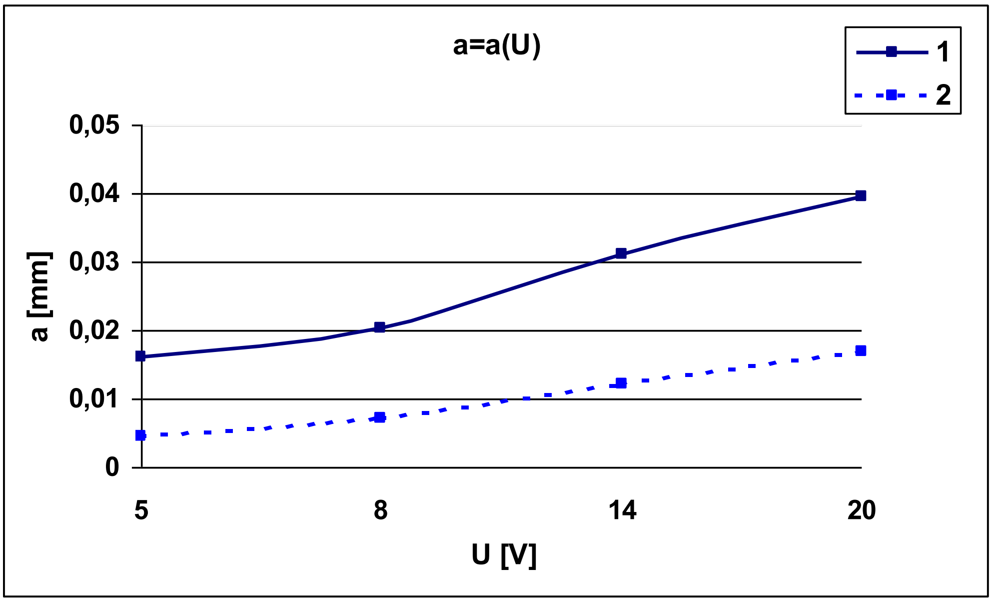

Fig.13..Relationship a = f (U);1 - *R=5 μm*, S_o*=5 μm*, v_p*=5 mm/min*; 2 - *R=90 μm*, S_o*=50 μm*, v_p*=35 mm/min*

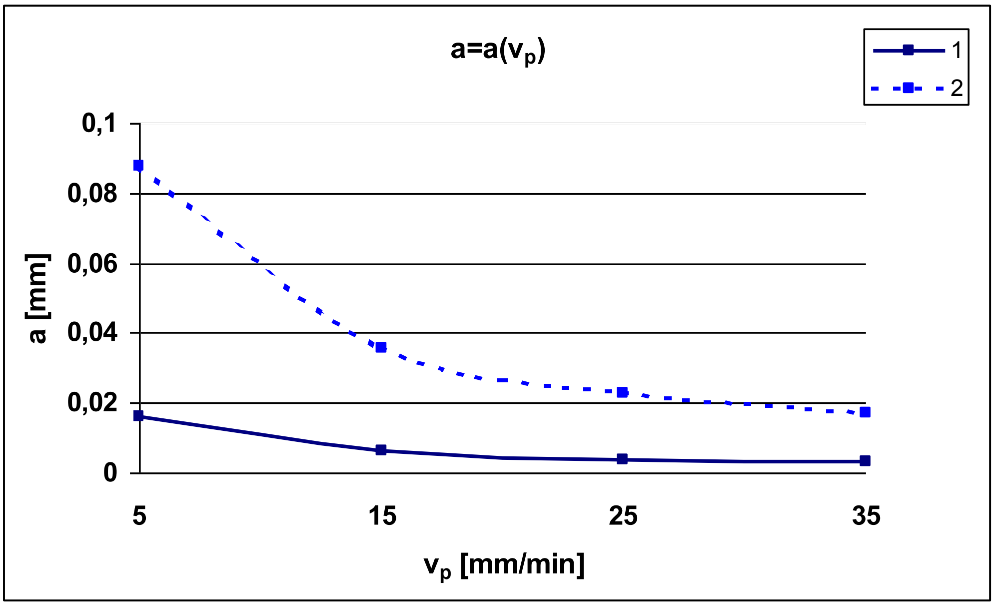

Fig.14..Relationship a = f(v_p) for the following process parameters: 1 - *R=5 μm*, *U=5 V*, S_o*=5 μm*; 2 - *R=90 μm*, *U=20 V*, S_o*=50 μm*

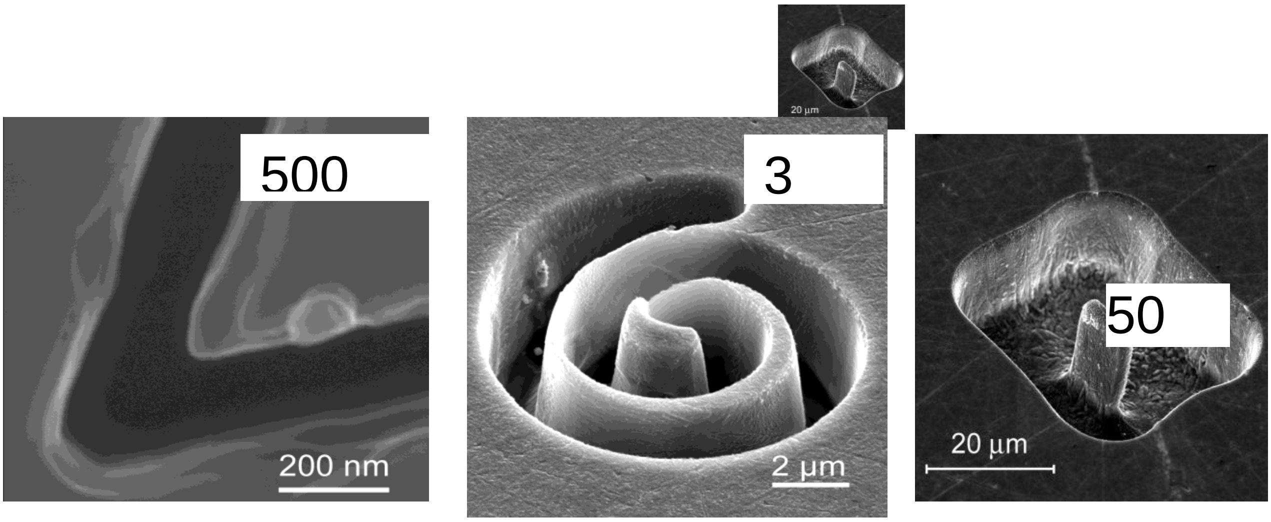

Fig.15. Geometrical structures machined using Pulse ECM with pulse time: 500 ps,3 ns, 50 ns, Results of research did by: M. Kock, V. Klammroth, L. Cagnon and R. Schuster, Fritz-Haber-Institut der Max-Plank-Gesellschaft, Berlin, Germany [15].

From Figs12, 13, 14 it results that changing electrode – tool dimensions and some process parameters it is possible to decrease significantly thickness of workpiece material removed during one electrode pass. However in practice one of basical ECM problems is to carry out dissolution process with high localization and with small interelectrode gap thickness. In order to reach this conditions pulse interelectrode voltage was applied (U = 2 – 10 V) and low concentrated special electrolytes (np. 0,1 M H_2SO_4, 0.2 M HCl lub 1 – 3 % $NaNO_3$). However the best resuts had been achieved in case of machining with ultrashort voltage pulses smaller than 60 ns and pause time about 1 – 2 μs. [1, 4, 11]. In Fritz-Haber - Institut der Max-Plank – Gesellshaft in Berlin ECM milling with pulse time of 500 ps had been successfully applied. Using so short voltage pulses it is possible to increase significantly dissolution process localization and the same ECMmachining accuracy.

In electrochemical machining with pulse time 1 – 60 ns cylindrical electrode-tools with diameter 5 - 30 μm ,are applied and holes with diameter about 5 μm can be machined. Application of pulse time about500 ps – 50 ns make it possible to create geometrical structures as in Fig. 15. Thanks to these above mentioned achievements the dynamic increase in μ - ECM prospective practical application take place

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1. RECAPITULATION

any conductive material regardless its hardness and other mechanical properties. However because of rather low metal removal rate and high electrode-tool wear μ-EDM is suitable for simple parts with small batch production (μ - tools for μ - casting, . μ - punching, a.s.o.) μ-EDM and μ-ECM processes applications is the fact that these processes cannot be applied for machining nonconductive materials. Significant limitations for μ-EDM results also from low metal removal rate, high electrode-tool wear, heat damaged layer creation, high randomness of the process depending on interelectrode gap thickness, dimension of cavities (concave surfaces) is limited also by electrode size. In comparison to μ-EDM, in μ-ECM process there is no electrode-tool wear and surface layer has very good quality (smaller surface roughness parameters, not additional stresses a.s.o.). The main disadvantage of μ-ECM process is lower dissolution process localization, however it is partly overcame by using **ps** and **ns** voltage pulses. Metal removal rate in μ-ECM process is significantly higher than in μ-EDM, however it is also suitable rather for bath production. Both processes (μ-ECM and μ-EDM) can be efficiently applied for μ-mould and μ-dies production for casting, injection and punching operations.

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