# Primary Experimental Research of Electrochemical Micromachining Process

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## Abstract

In the paper a special test – stand for μ - ECM machining has been described. Presented test – stand gives possibility to shape microparts in the way of classical electrochemical sinking or electrochemical milling (μ - ECM - CNC). The most characteristic features of this test – stand are special drive and control units which make it possible to displace an electrode – tool with high accuracy along space trajectory and special pulse supplier which can generate nanosecond voltage pulses. Taking into account results of primary theoretical and experimental research, the possibilities and conditions of manufacturing micro-holes and micro-sculptured surfaces has been presented.

**Keywords**:
Micro electrochemical machining

## 1 INTRODUCTION

Microelements are defined as parts with smaller dimensions than 0.5 mm and can consist of outer and inner sculptured surfaces. Manufacturing of micro - details is a dynamically developing area of production technologies. The most popular methods are μ - turning, μ - drilling, μ - grinding, μ - plastic forming, μ - laser beam machining, μ - electrodischarge machining and μ - electrochemical machining. Taking into account micro-elements size, workpiece material and needs of high surface quality one can state that micro-machining by electro-physical and chemical processes are very reasonable alternative for traditional machining methods [1].

Electrochemical machining (ECM) is an important technology in machining difficult-to-cut materials and to shape complicated contours. Because of its advantages ECM has a traditional fields of application in space, aircraft and domestic industries for shaping, deburring and finishing operations. In ECM material is removed by electrochemical dissolution process, what cause that part is machined without inducing residual stresses, in temperature lower than 100 K and without tool wear. It is worth to underline, that material removal rate does not depend on material mechanical properities (depends mainly on chemical composition). Features of ECM make theoretically possible material unit removal as the size of ions cause that ECM can be effectively applied in machining of micro-details.

In recent years mask method has been used for micro-fabrication using the ECM principles [2]. It has been succesfully applied in the production of printed circuits boards [1], however, this method has limitation on the accuracy and complex shape generation. Therefore industry needs cause, that more advanced method based on ECM principle should be developed.

Generally, allowance in μ - ECM can be machined in two following ways:

- **sinking (**Figure 1b**)**: electrode - tool is displaced in machined surface and workpiece is created as the reproduction of electrode - tool shape In this case dimensions and shape of machined surface depends on electrode size, electrolyte supply method and possibilities of electrode shaping, therefore sinking can be effectively used for holes machining;
- **machining with universal electrode-tool** - ECM – CNC or ECM milling, (Figure 1a). In this case the shape of machined surface is the reproduction of simple shape electrode trajectory in 3D space. To achieve optimal flow of electrolyte and adequate dissolution products evacuation from interelectrode gap, electrode can rotate or vibrate during machining. Dimensions of machined part are connected with electrode size and interelectrode gap thickness.

Taking into account advantages of simple micro-cylindrical electrode tool application - ECM milling gives opportunity to shape complex micro cavities and sculpture surfaces of micro forming tools.

One of the main problems in ECM is to achieve high localisation of dissolution reactions during machining with small interelectrode gap thickness. For the purpose of machining localisation small interelectrode voltage (U = 2 – 10 V) and pure electrolytes are applied, however the biggest development in μ-ECM research is the use of ultra short pulses of nanosecond duration [3, 4, 5]. Thus electrochemical dissolution localisation was significantly increased, up to nanometre precision and μ-ECM become competitive methods, especially in machining tools for micro forming. Thanks to process feature and significantly higher material removal rate in comparison to others methods (i.e. μ-EDM) application of μ-ECM in this area gives possibility to save time and increase of tool life.

Below, some principles of μ - ECM, designed test stand and results of primary investigations carried out in The Institute of Advanced Manufacturing Technology has been presented.

## 2 PRINCIPLES OF μ-ECM PROCESS

As has been mentioned above micro-elements can be manufactured efficiently using Pulse Electrochemical Machining (PECM) process (Figure 1) and the most efficient method for machining sculptured surfaces is ECM milling. In Figure 1a scheme of ECM-milling has been presented. In case of micro-elements, in order to achieve necessary workpiece accuracy - pulse time

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should be less than 100 ns (i.e. 2 – 60 ns with period 1 – 2 µs). Long pause time in comparison to pulse time gives possibility to discharge the double layer and to create condition for flushing the gap and remove heat and dissolution products.

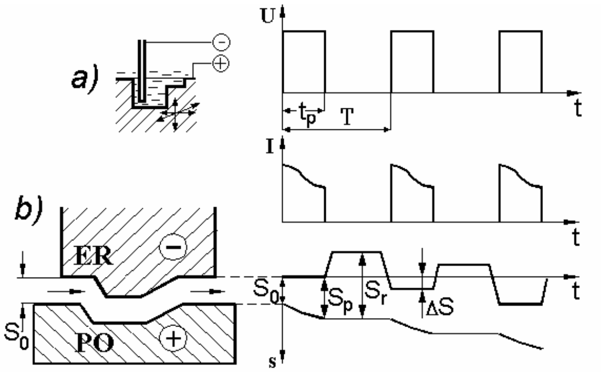

Figure 1: Scheme of PECM, a – scheme of ECM milling, b – scheme of ECM sinking, $t_p$ – pulse time, T – pulse period.

As has been presented in the Figure 2, the interelectrode gap can be defined as electrical circuit. Upon the application of pulsed voltage between the tool and workpiece, the electrodes' double layers capacitances $C_k$ and $C_a$ are periodically charged and discharged. The double layer charging time is depends on its capacity, and electrolyte resistance: $\frac{S}{\kappa}$ (S – gap thickness, κ - electrolyte conductivity). For small interelectrode gap, where $\frac{S}{\kappa}$ is small, time of double layer charging is small, what causes that electrodes polarize faster and dissolution process starts much earlier, than in areas, where distance between electrodes is bigger (because of bigger electrolyte resistance). In this areas double layer is charging slower and dissolution occurs later. This phenomenon is applied in µ-ECM to localize the dissolution during machining. Detailed characteristic of dissolution with ultrashort voltage pulses has been described in [6].

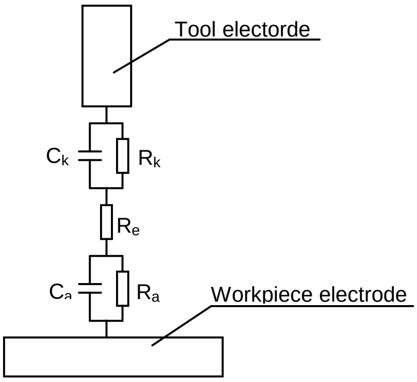

Figure 2. Electrical scheme of the interelectrode gap during electrochemical machining [6].

Localization of electrochemical dissolution process can be described with relationship between electric charge transferred thought the gap and gap thickness. In [6] function:

$$q = \frac{A}{S^n} \qquad (1)$$

has been proposed as the main µ-ECM process characteristic. The exponent n describes dissolution process localization, and as has been shown in [6] n increases with voltage and pulse time decrease. To achieve high machining accuracy n should be as high as possible.

Described above µ-ECM process principles, conditions and limits are the basis to make assumptions for µ-ECM prototype machine designing. They are connected with µ-ECM kinematical variants, size of electrode tool and machined element and with parameters of power supplier. Below, designed in the Department of Unconventional Production Processes of IAMT µ-ECM test stand and primary µ-ECM investigations have been presented.

## 3 TEST STAND AND PRIMARY EXPERIMENTS

The test stand for electrochemical micromachining of micro-details has been built and developed in the Department of Unconventional Production Technologies of the Institute of Advanced Manufacturing Technology. The micro machine tool was prepared upon literature analysis as well as on the Department long-term experience in electrochemical machining processes.

The test stand consists of seven main parts (Figure 3):

- the machine body with fixed drives set with voltage pulse transmission system and the table for sample fixing,
- observation system consisting of laboratory microscope of 100 times magnitude,
- nanosecond pulse generator,
- drive control system,
- electrolyte delivery system,
- PC computer with driving software,
- ventilation system.

The test stand gives possibility to carry out research of µ-ECM at scope of electrochemical sinking and machining with universal electrode-tool (milling with 3D tool displacement). Below the construction of main test stand elements has been described.

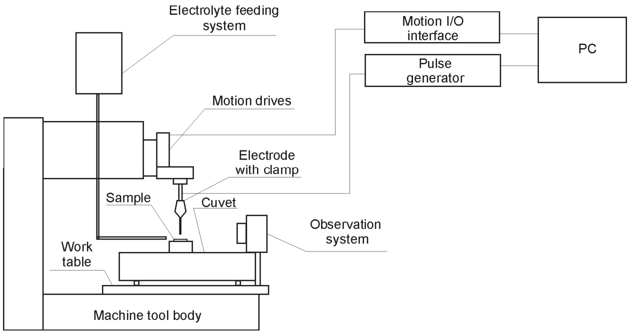

Figure 3: Scheme of designed µ-ECM test stand.

### 3.1 Drive system

In micro details machining parameters of drive are very important and are in straight connection with accuracy and stability of machining. Proper selection of drive, gear and control system are main factors connected with accuracy of tool positioning. In micro details machining we expect high resolution (< 0.1 µm) and high accuracy of movement along desired trajectory (especially in µ - ECM – CNC machining). In presented test stand set of three high-resolution motorized translation stages has been applied. These drives are produced by Physike Instrumente (PI) company. Drives are connected with PCI motor controller (installed in PC) via C-809 motion I/O interface, which gives possibility to control electrode movement with LabView application.

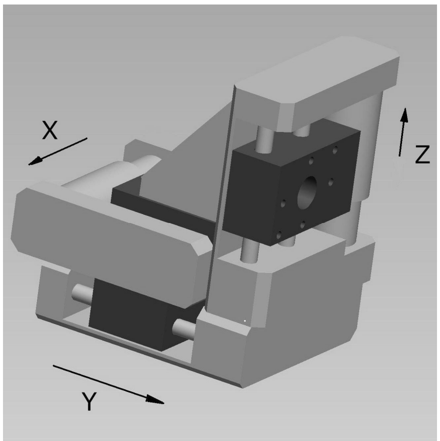

Figure 4: Scheme of M-111.DG drives assembly.

### 3.2 Nanosecond pulse generator

One of the main factors, which are connected with application ECM in micro-details machining is characteristic of proper energy source. As has been described in previous paragraph, application of nanosecond voltage pulses is very important for the high localization of the electrochemical reactions. It can improve accuracy of machining to the nanometre range. Therefore special nanosecond pulse generator was developed in IAMT. It was designed especially for micro – details machining. Parameters of the generator are presented in Table 1. Thanks to the applied power supplier, designed test stand gives possibility to make research with very small thickness of the interelectrode gap, what gives possibility of reaching accuracy of machined detail.

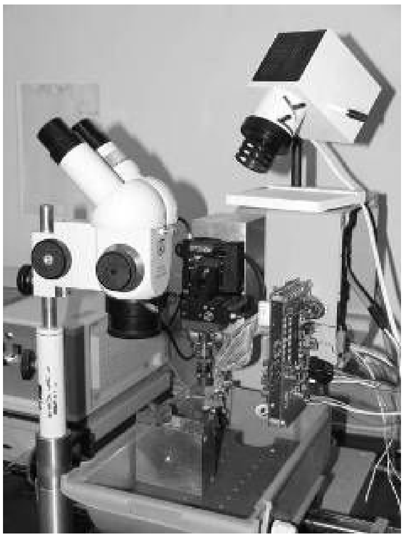

Figure 5: Micro ECM test stand.

| | |
|---|---|
| Power supply | 230 V~ |
| Power consumption | max 70 W |
| Working voltage | 2,5 V do 20 V continuous set |
| Pulse time | 100 ns – 5 µs, set step 20 ns |
| Pause time | 100 ns – 5 µs, set step 20 ns |
| Working current | max 3 A |

Table 1. Parameters of ultrashort pulse power supplier.

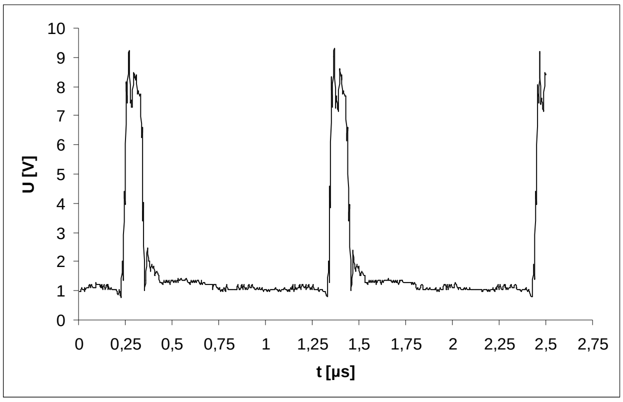

Figure 6: Voltage pulse shape for pulse time $t_i$=100 ns and pause time $t_p$=1000 ns.

Power supplier can be current or voltage source and pulses can be unipolar or bipolar. The most important issue was to ensure unipolar and repetitive voltage pulses. This demand has been fulfilled by special electronic system for signal shape control together with constant pause between pulse times.

### 3.3 Primary investigations

To test designed µ-ECM stand, the primary investigations have been carried out. It was aiming to test whole machine elements. The stainless steel was chosen as machined material and electrode tools were prepared from following materials:

- Pt, diameter 127 µm,
- Cu, diameter 250 µm,
- W, diameter 25 µm.

Examples of electrodes' tips used in the test have been presented in Figure 7 and 8 (pictures prepared by Scanning Electron Microscopy).

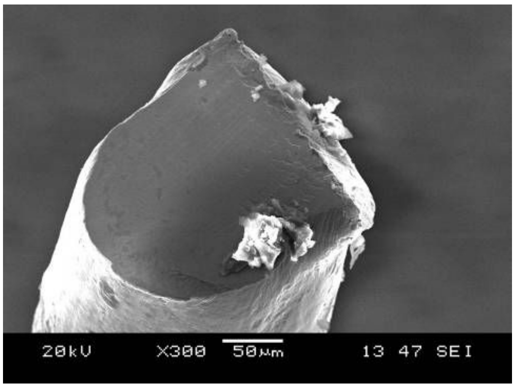

Figure 7: Tip of cut Cu electrode, diameter 250 µm.

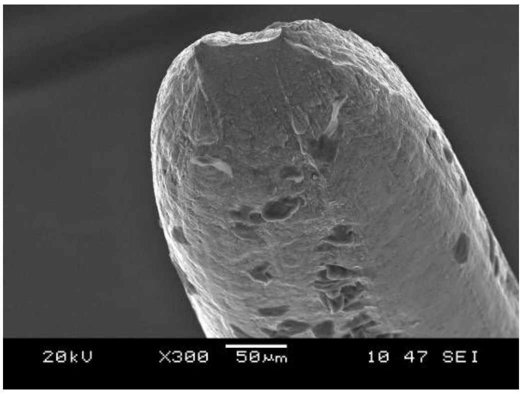

Figure 8: Tip of torn Cu electrode, diameter 250 µm.

For electrode fixing triple jaw self-clamping grip from ALBRECHT company was used. The grip is equipped with nonius, what gives possibility to clamping tools of 0 to 1,5 mm diameter.

To simplify estimation of machining results, primary test was focused on drilling not-through holes. The drilling was carried in 10% solution of $NaNO_3$, and in 0,1 mole solution of $H_2SO_4$. Taking into account presented in the Figure 9, 10 and 11 machined holes, one can state, that accuracy of machining is not adequate (i.e. hole drilled with 25 µm electrode is 4 times higher in diameter). Also shape of the hole is not cylindrical. These errors depend on machining voltage and pulse time and result from pure electrochemical dissolution localisation. It is connected also with proper electrolyte selection (sort and concentration).

During tests several holes have been drilled, what gives possibility to test parts of test stand and shows some crucial problems occurring during machining. In example, during further research following problems should be resolved:

- preparing of the electrode tip,
- positioning of the electrode;
- electrolyte supplying into the gap (application of the electrode vibrations is taking into account).

Designed test stand is adapted to µ-ECM milling, therefore further investigation should be also carried out with 3D electrode movement.

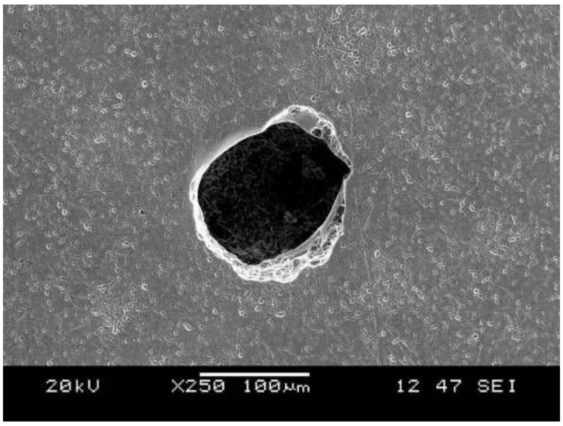

Figure 9: Hole drilled in steel plate; tungsten electrode diameter 25 µm, tool feed rate: 3 µm/min, $t_i$ = 100 ns, $t_p$ = 1000 ns, voltage U = 10 V, electrolyte: 0.1 M solution of $H_2SO_4$.

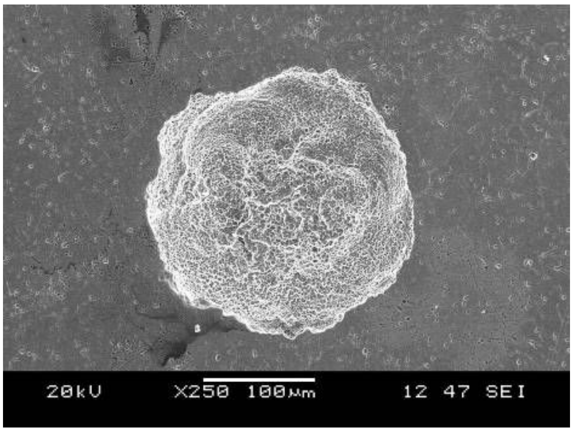

Figure 10: Hole drilled in steel plate; copper electrode diameter 250 µm, tool feed rate: 40 µm/min, $t_i$ = 100 ns, $t_p$ = 1000 ns, voltage U = 10 V, electrolyte: 0.1 M solution of $H_2SO_4$.

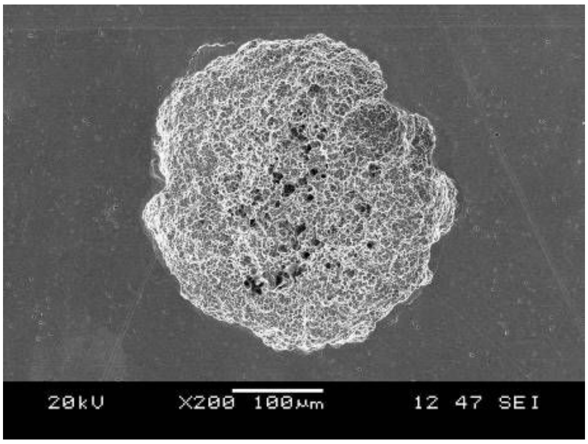

Figure 11: Hole drilled in steel plate; copper electrode diameter 250 µm, tool feed rate: 3 µm/min, $t_i$ = 100 ns, $t_p$ = 1000 ns, voltage U = 10 V, electrolyte: 0,1M of $H_2SO_4$.

## 4 SUMMARY

Based on literature data and experience of Department of Unconventional Production Technologies test stand for µ-ECM was designed. This machine tool is dedicated for machining micro-holes, cavities and other sculptured surfaces research. Application of ultrashort voltage pulses supplier and accurate drive electrode – tool system gives possibility to obtain high dimensional micro-details accuracy and good surface layer quality. During primary research several drilling tests were carried out, thus primary parameters for machining and problems, which should be solved during further research have been determined.

## 5 REFERENCES

[1] Rajurkar K.P, Levy G., Malshe A., Sundaram M.M., McGeough, Hu X., Resnick R., DeSilva A., 2006, Micro and Nano Machining by Electro-Physical and Chemical Processes. Annals of the CIRP, vol. 55/2/2006, pp. 643 – 666.

[2] Datta M.: Micromachining by Electrochemical Dissolution (in book: Micromachining of Engineering Materials), 2002, edited by McGeough J.A., Published. by. Mercel Dekker, Inc., 2002, pp. 239 - 276.

[3] Kock M., Kirchner V., Schuster R., 2003 Electrochemical micromachining with ultrashort voltage pulses – a versatile method with lithographical precision. Electrochemica Acta 48, pp. 3213 – 3219.

[4] Schuster R., Kirchner V., Allongue P.,, Ertl G., 2000, Electrochemical Micromachining. Science, vol. 289, pp. 98 – 101.

[5] Se Hyun Ahn, Shi Hyoung Ryu, Deok Ki Choi, Chong Nam Chu, 2004, Electro – Chemical microdrilling using ultra short pulses. Precision Engineering, vol. 28, pp. 129 – 134.

[6] Gulbinowicz D., Electrochemical micromachining with ultrashort voltage pulses. PhD Thesis, Warsaw University of Technology, 2006.