The conception of EC/EDMM sequential process for micro-tools manufacturing

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Summary: In the group of methods applied for machining of technological equipment and tools for micro-casting and micro-forming, special attention is paid on application of electrochemical (ECMM) and electrodischarge (EDMM) micromachining. In the paper the description of ECMM and EDMM and conception of both processes combination into single, sequential process has been presented. This proposed method gives possibility to minimize disadvantages and emphasizes advantages of electrochemical and electrodischarge micromachining processes. Presented technological characteristics of ECMM and EDMM machine-tools gives possibility to identify versatile functional subsystems, what is the base for EC/EDMM hybrid sequential machine tool design.

1 INTRODUCTION

In group of methods designed for machining of technological equipment and tools for micro-casting and micro-forming special attention is connected with application of unconventional processes, such as: ElectroChemical (ECMM) and ElectroDischarge (EDMM) MicroMachining. In aspect of shaping 3D sculptured surfaces both processes are carried out with application of universal electrode and the part shape is a result of tool path reproduction in machined surface.

In ECMM material is removed thanks to electrochemical dissolution with application of ultrasohort voltage pulses [2, 4, 5, 7], what gives possibility to machine parts made of current conducted material, without significant influence of workpiece mechanical properties on material removal rate. ECMM gives possibility to machine part without tool wear, with good surface quality and many times higher in comparison to EDMM material removal rate. On the other hand accuracy of electrochemical dissolution process is not satisfactory and irregularity of material structure has great influence on machining results. In EDMM every current conducted material, despite of its mechanical properties can be shaped with satisfactory, higher than in ECMM accuracy. However, the EDMM process has two main disadvantages, such as electrode tool wear and low material removal rate, what significantly decrease its area of application.

Characteristics of both methods indicate a number of similarities in machining process and essential complementary advantages. The discussed conception of EC/EDMM process consist at combination EC and ED process into sequential hybrid machining method which will be carried on single machine tool. Proposed EC/EDMM process gives possibility to minimize disadvantages and strengthen the advantages of electrochemical and electrodischarge micromachining. Thanks to such combination significant decrease of machining time is possible.

Below, based on the ECMM and EDMM process characteristics conception and design of prototype EC/EDMM machine has been presented. Analysis of electrochemical and electro discharge machine tools construction gives possibility to select similar functional units, what results in simplify machine design and construction.

2 EDMM AND ECMM PROCESSES CHARACTERISTICS

One can state that special place in group of micromanufacturing methods are connected with application of unconventional methods, such as electrochemical and electrodischarge machining, because of their high efficiency in shaping 3D structures. It is also worth to underline that this methods are not suitable to serial production and potential area of application is prototypes, technological tooling, MEMS parts and tools manufacturing.

In the Table 1 the comparison of main futures of both discussed methods has been presented. Characteristics of both methods indicate number essential complementary advantages. It is also worth to underline a lot of similarities in process (such as machining kinematics, tool shape and material, limitations of workpiece material etc.) which gives possibility to apply sort of identical technical solution in machine design for ECMM and EDMM process.

Because of above presented information the idea of combination of ECMM and EDMM process into sequential hybrid machining method (Figure 1) which will be carried on single machine tool looks as way to achieve effective micromanufacturing method. Proposed EC/EDMM process gives possibility to minimize disadvantages and strengthen the advantages of electrochemical and electrodischarge micromachining.

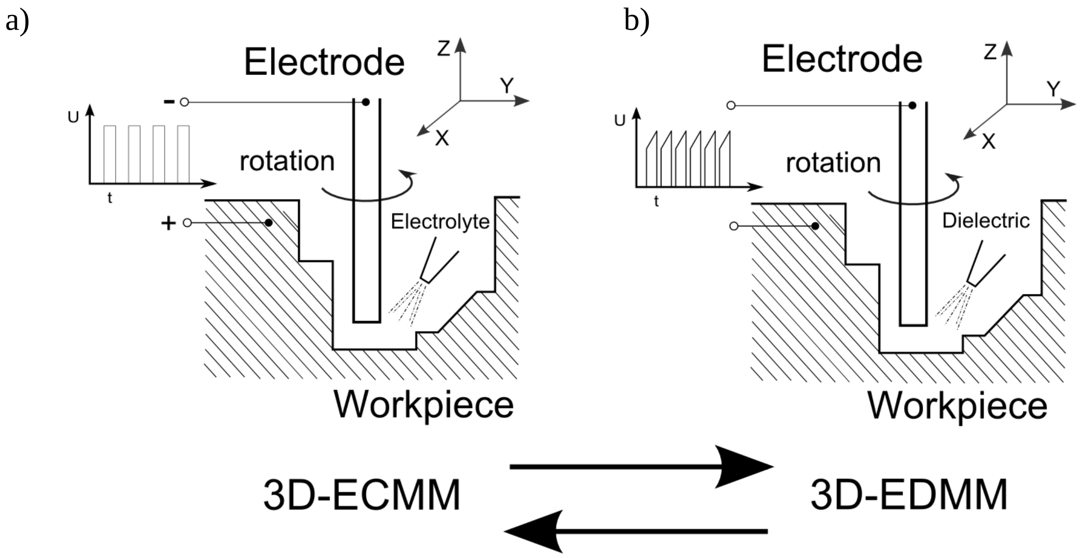
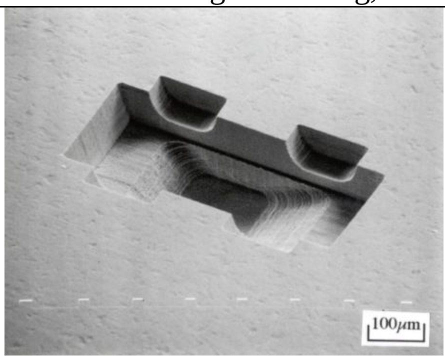
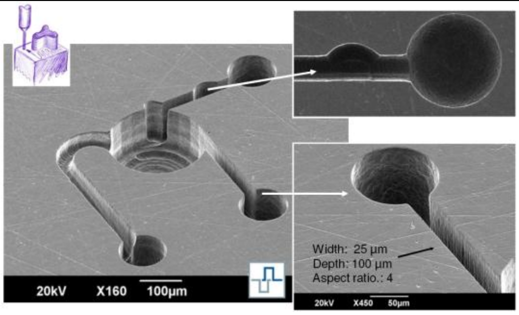


Figure 1. Scheme of the hybrid technology with application of EC/EDMM sequence, a) scheme of ElectroChemical MicroMachining (ECMM) with application of universal electrode, b) scheme of ElectroDischarge MicroMachining (EDMM) with application of universal electrode.

Table 1. The comparison of main features EDMM and ECMM technologies.

EDMM (Figure 1b)	ECMM (Figure 1a)
Process characteristics	
Material is removed thanks to micro electrical discharges between electrode tool and workpiece.	Material is removed thanks to anodic dissolution with application of ultra-short voltage pulses.
• Every current conducted material, despite of his mechanical properties can be machined. • Final shape of machined detail results from 3D trajectory of simple electrode tool reproduction (see Figure 1)	
Advantages	
• High accuracy (< 5 μm) of machining (high localisation of allowance removal)	• No tool wear. • High material removal rate. • Good surface layer quality
Disadvantages	
• Unsatisfactory material removal rate (machining time can reach several hours four machining complicated micro-parts). • High electrode tool wear rate (more than 30%) • High temperature during machining what decrease workpiece surface layer properties.	• Poor anodic dissolution process localisation • Irregularity of machined material structure has great influence on machining results (local shape inaccuracy, rounded edges).
Area of applications	
Manufacturing of 3D geometrical structures, tools (i.e. micro-molds), parts of technological tooling, MEMS parts prototypes – see below examples	
 Example of EDMM application [11]	 Example of ECMM application (machined by. ECMTEC GmbH)

3 ASSUMPTIONS FOR SEQUENTIAL HYBRID EC/EDMM PROCESSES

The EC/EDMM process can be carried on in the following sequences (Figure 1):

- ECMM→EDMM: about 80% of allowance is machined by electrochemical dissolution with accuracy about 20 μm. Remainder 20% of allowance thickness is removed with application of electrodischarge machining, what gives possibility to achieve final part with accuracy 1 to 5 μm and relative high material rate.

- EDMM→ECMM (or ECMM→EDMM→ECMM): sequence applied in case when minimal changes of surface layer quality is required (elimination of white layer after electrodischarge machining).

Presented conception gives possibility of essential reduction of both methods disadvantages what results in improvement of technological factors (especially decrease of machining time). Application of EC/EDMM sequence on single machine lead to efficient and accurate 3D surfaces micromachining method. However, it is worth to underline that integration of both technologies into single machine tool cause sort of technical problems connected with process realisation and lead to machine tool design complication.

4 DESIGN OF EC/EDMM PROTOTYPE MACHINE TOOL

Shaping of 3D microparts is connected with introduction sort of technical solutions which result in desired accuracy (high material removal localisation) with acceptable material removal rate. The main problems which have to be resolved to meet this requirement are as follows [8]:

- tool and workpiece handling,
- tool (before and during machining) and workpiece (before machining) preparation,
- choice of optimal machining parameters,
- identify and minimise source of errors,
- develop the effective CAM support,
- measurement of machining accuracy and surface layer quality.

Analysis of typical design of erosion machines gives possibility to identify similar functional units, what results in machine design simplify. Electrodischarge as well as electrochemical machines consist of following units (Figure 2):

- mechanical unit,
- process control and monitoring unit,
- power supply unit,
- working fluid unit,
- unit of electrode tool preparation/renew.

Characteristics of above listed units in aspect of EC/EDMM machine design have been presented in Table 2. One can state that main problem of both technologies integration on single machine tool is to achieve EC and ED machining with the same workpiece and tool handling. Therefore, the main technical problems which have to be solved are as follows:

- **exchange of working fluid** (electrolyte to dielectric and backwards). Because of quite different properties of working fluid in both processes, design of working fluid unit has to be developed independently. The main problem is exchange stage, which occurs in case of switch between EC and ED (and backwards) process. The same clamping of the workpiece for ECMM and EDMM needs to develop appropriate way of machining area flushing to avoid dielectric and electrolyte mixing, because it can make machining difficult for carrying out (or results in machining stop).
- **integration of the technology with the CAD/CAM system** to realise the machining sequence with single control programme (the same coordinates for both sequences).

The characteristic of the main units of the designed hybrid machine has been presented in Table 2.

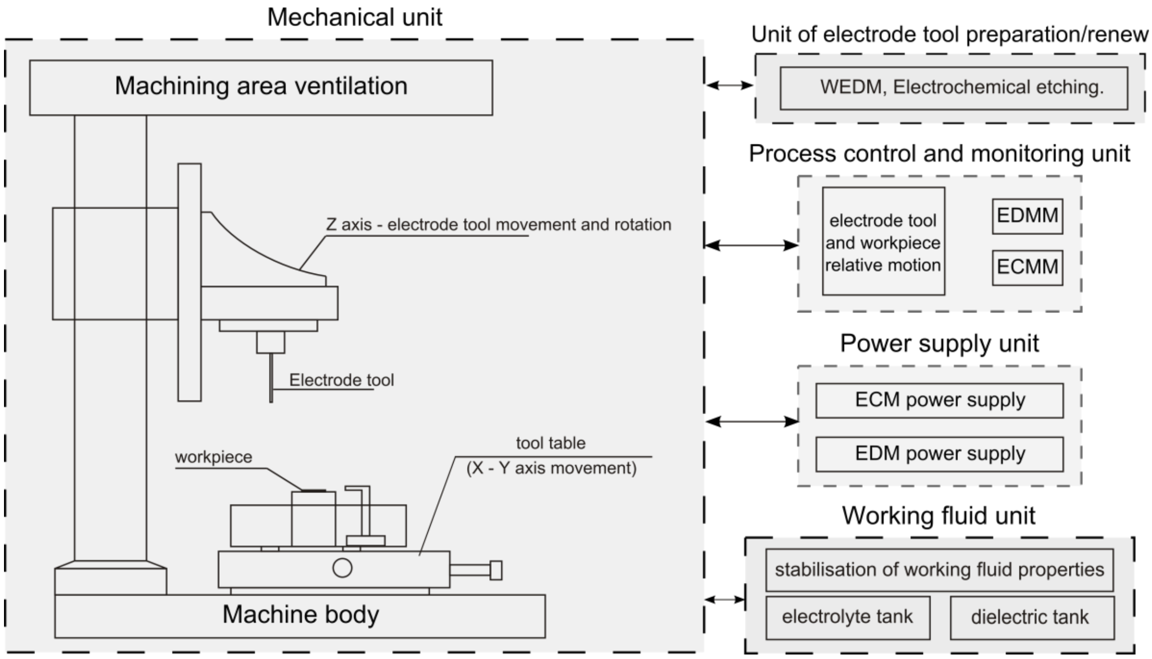


Figure 2. Functional scheme of hybrid sequence EC/EDMM machine-tool.

Based on this assumption machine has been designed in Institute of Production Engineering (Cracow University of Technology) – see Figures 3 and 4. Solution of the above presented problems gives possibility to take advantage from profs of ED and ECMM technologies.

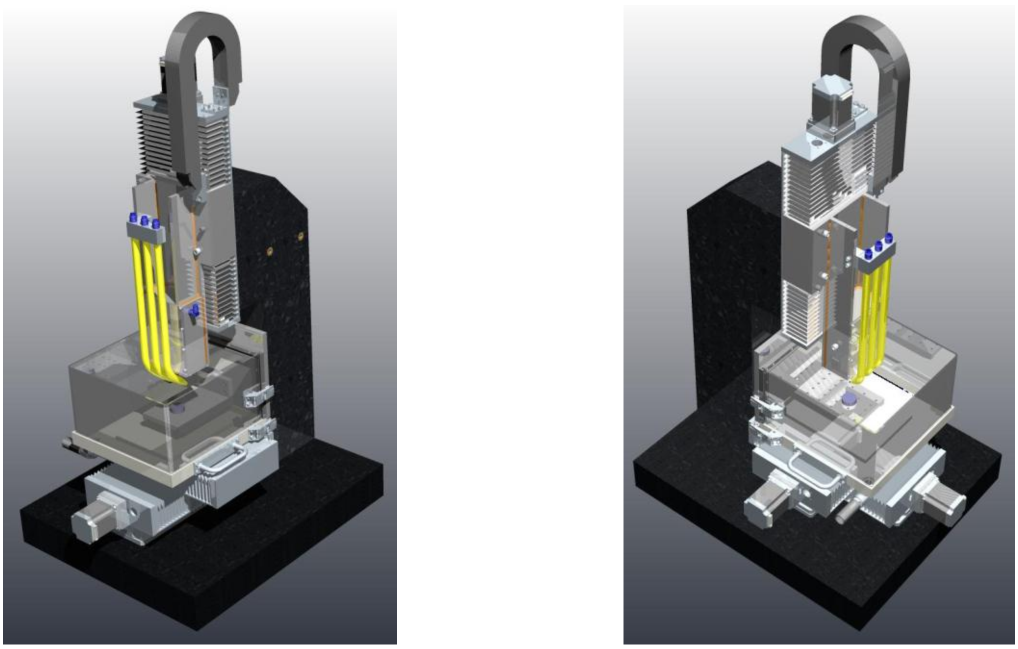


Figure 3. Design of the EC/EDMM hybrid sequential machine-tool developed in Cracow University of Technology.

Table. 2. Functional characteristics of 3D-EC/EDMM machine.

<table>
<tr><th>EDMM machine tool</th><th>ECMM machine tool</th></tr>
<tr><td colspan="2">Mechanical unit</td></tr>
<tr><td colspan="2">The mechanical part consist of machine body, tool table (movement along X-Y axis), Z axis unit (which include also rotation of electrode tool), elements of technological tooling (i.e. electrode tool and workpiece clamping). Because of lot of similarities in EC and ED process solutions applied in mechanical parts for both methods are almost the same and there is no obstacles to integrate it in single mechanical unit. Details of mechanical unit design are defined by dimensions of working space and accuracy of axis movement and positioning are connected with potential application.</td></tr>
<tr><td colspan="2">Process control and monitoring unit</td></tr>
<tr><td>• Control of electroerosion process (regulation of the interelectrode gap),
• Control of electrode movement in 3D space with consideration or electrode wear.</td><td>• Control based on current signal - the goal is to achieve constant dissolution conditions in interelectrode gap
• Control of electrode movement in 3D space</td></tr>
<tr><td colspan="2">Power supply unit</td></tr>
<tr><td>In EDM amount of removed material depends on single discharge energy, which is related to voltage and discharge current amplitude and pulse time. Limitations of the single discharge energy to $10^{-6} – 10^{-7}$ J gives possibility to shape mikroparts with high accuracy and relative good surface quality. In micro EDM application despite of low discharges frequency, the RC generators become popular, because it is possible to obtain the single pulse duration < 100 ns [1, 8, 10]. The parameters of the power supply unit for EDMM are as follows: pulse voltage 20 – 120 V, current amplitude: 0.1 – 10 mA, pulse duration $10^{-9} – 10^{-10}$ s.</td><td>To achieve high localisation of the electrochemical dissolution process, the pulse duration t_i should be less than 100 ns [2, 5], with interelectrode voltage $U < 15$ V and current amplitude range of 10^{-6} A.</td></tr>
<tr><td colspan="2">Working fluid unit</td></tr>
<tr><td>• The working fluid: dielectric (kerosene based dielectrics, water based dielectric), which is supplied to the machining are through the nozzle.
• Because of the machining area effective flushing after EDMM the water based dielectric should be applied.</td><td>The working fluid: electrolyte (i.e. water solution ofr $NaNO_3$, H_2SO_4, HCL) which is supplied to the machining area through the nozzle.</td></tr>
<tr><td colspan="2">The main functions of the unit are to filtrate of contaminations (dissolution and erosion products), measurement and stabilisation of electrolyte/dielectric properties (conductivity, pH and temperature).</td></tr>
<tr><td colspan="2">Unit of electrode tool preparation/renew.</td></tr>
<tr><td colspan="2">One of the conditions of high degree of machining parts miniaturisation is application of the electrode tool with the diameter as small as possible with adequate clamping system, stiffness and tool accuracy at the same time. Additionally the electrode tool wear in EDMM process is a reason to renew the electrode shape during machining from time to time. The most efficient way to fulfil this needs is to manufacture/renew the electrode tool on the machine (in the same clamping) and integrate special tooling in machine design and take into account additional software requirements connected with electrode renew during machining. There are two main methods which can be take into account: electrodischarge electrode shaping (WEDG, application of block etc [8]) and electrochemical etching. There should be possible to achieve electrode – tool diameter less than < 50 μm.</td></tr>
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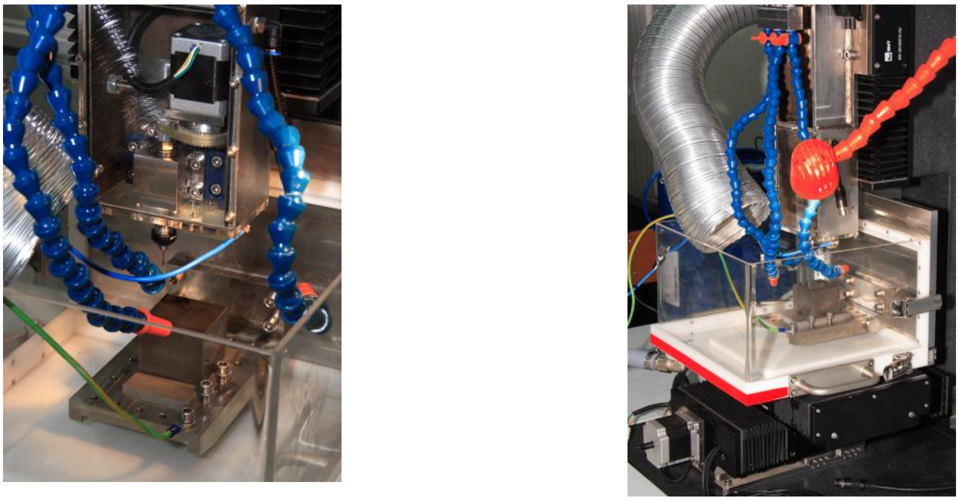

Figure 4. Photographs of the EC/EDMM hybrid sequential machine-tool developed in Cracow University of Technology.

5 CONCLUSIONS

In the paper the characteristics of the electrochemical and electrodischarge method with special attention paid to application for microelements machining have been presented. The area of application connected with manufacturing of sculptured surfaces (MEMS parts prototypes, technological tooling, microtools etc.) define the technological needs for achieving the desired accuracy with acceptable material removal rate.

Presented conception of EC and EDMM processes combination into single, sequential machining method gives possibility to obtain efficient technology which minimizes disadvantages and emphasizes advantages of electrochemical and electrodischarge micromachining processes.

Furthermore, based on the ECMM and EDMM process characteristics conception and design of prototype EC/EDMM machine has been presented. Analysis of electrochemical and electrodischarge machine tools construction gives possibility to select similar functional units, what results in simplify machine design and construction. The machine has been built in the Institute of Production Engineering (Cracow University of Technology), what gives possibility to carry out the EC/EDMM investigation and prove presented assumptions correctness.

6 ACKNOWLEDGEMENTS

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