Research on unconventional methods of cylindrical micro-tools manufacturing

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Abstract

In case of electrochemical and electrodischarge milling the minimal feature size depends on proper selection of machining parameters and electrode-tool size. Usually, as the electrode-tool the commercially available cylindrical rods are applied, so one of the main technical issues is to provide precise rotation and high tool stiffness. In the paper result of cylindrical tools in-situ manufacturing for EC and ED-micro milling process will be discussed. The special attention will be paid to electrochemical etching and electrodischarge turning application in the unconventional-milling process chain.

1 Introduction

Production of micro - details is dynamically developing area of production technology applications. In serial production the most popular methods are micro – cutting (turning, milling and drilling), micro - plastic forming and micro - laser beam machining. 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 for serial production and potential area of application is prototypes, technological tooling, MEMS parts and tools manufacturing. In aspect of 3D sculptured surfaces machining recommended solution is to apply machining with simple cylindrical electrode – tool and tool path design similar to milling (micro – electrochemical milling, micro – electrodischarge milling).

Shaping of 3D microparts is connected with introduction sort of technical solutions which result in desired accuracy (high material removal localization) with acceptable material removal rate. The minimal future size depends on proper selection of machining parameters and electrode-tool size (in case of EC and ED-milling it is shaft diameter). Usually, as the electrode-tool the commercially available cylindrical rods are applied, so one of the main technical issues is to provide precise rotation and high tool stiffness. In order to avoid handling difficulties and errors, the final tool shape and diameter should be achieved with application of specially design tooling on the machine, with the same tool holder as following milling.

Because of 3D-EDMM technology state of advancement and connected with this wider area of application and there is more electrodischarge methods of cylindrical tool shaping on the EDM machine [1, 4, 6, 8]. Usually the electrode – too is eroded against a sacrificial electrode in an operation known as EDM grinding. Different types of sacrificial electrodes are used. A problem is that the shape, dimension and roughness of the ground electrode is not easy to control.

The most popular method of cylindrical tools electrochemical shaping, which can be applied with the same tool holder as following milling, is electrochemical etching (called also deep immersion method) [2, 3] - see Figure 2. Shaft size, shape, and surface quality depends on proper selection of electrolyte concentration, applied voltage, etching time, etc.

Below result of cylindrical tools in-situ manufacturing for EC and ED-micro milling process will be discussed. The special attention will be paid to electrochemical etching and electrodischarge turning application in the unconventional-milling process chain.

2 Research methodology

The research has been carried out on test stand build in Cracow University of Technology Institute of Production Engineering. As was presented in [9] such solution gives possibility to carry out research on micro-electrodischarge, micro-electrochemical and sequences of this process on single machine tool.

Electrode-tool diameter change has been measured with application of CCD camera Motic 2300 and microscope unit. Measuring equipment has been mounted on the machine table (Figure 1), what gives possibility to make photos of the electrode between different stages of the machining, without any changes of the clamping etc. The CCD camera has been equipped with calibration plate, what makes electrode-tool diameter measuring possible.

Electrochemical shaping has been carried in the tank filled by electrolyte. The rotating with 100 rpm shaft has been immersed in the tank filled by electrolyte (Figure 2) in distance S_0 from steel block. The goal of this test has to find relation D(t) between electrode tool diameter D and machining time t.

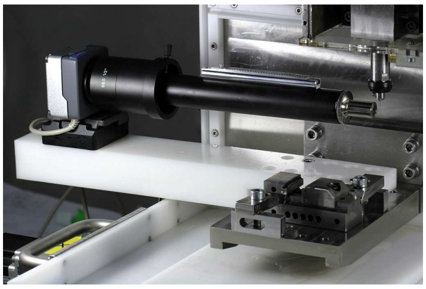


Figure 1 *Application of digital camera for tool diameter measuring.*

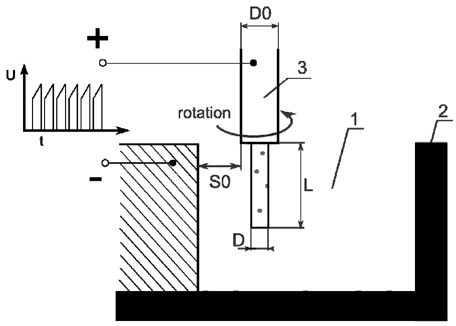


Figure. 2. *Scheme of electrochemical tool shaping applied during test with $NaNO_3$ electrolyte.*

The process can be modeled based on the following relation:

$$S(t) = \sqrt{2 \cdot \eta k_v \kappa (U - E) + S_0^2} \quad (1)$$

which describes the gap variation for the machining with stationary electrode tool. Taking into account condition:

$$S_0 + D_0/2 = S(t) + D(t)/2 \quad (2)$$

the electrode-tool diameter change in time can be calculated from following equation:

$$D(t)/2 = (S_0 + D_0/2) - \sqrt{2 \cdot \eta k_v \kappa (U - E) \cdot + S_0^2} \quad (3)$$

The research has been carried out for following parameters: interelectrode voltage: DC, U=5 V and U=15 V, electrolyte: $NaNO_3$ water solution with conductivity: 15 mS/cm, initial shaft diameter: D_0=0,4 mm, initial distance from steel block: S_0= 0,5 mm, block material: 304 steel.

Scheme of the EDM machining area has been presented in the Figure 3. The cylindrical tool has move into the metallic block. Due to electrode wear the electrode diameter D has decreased with distance L, so the main technological characteristic of this process is relation D(L). This process can be described with model presented in [5].

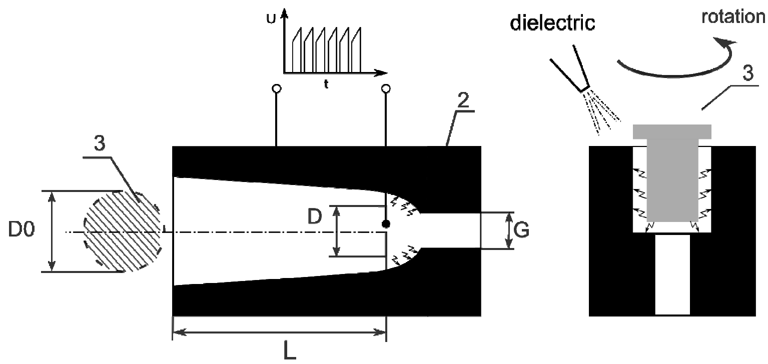


Figure 3. *Scheme of cylindrical tools electrodischarge machining method applied during tests, 2 – brass block , 3 – electrode-tool.*

The research has been carried out for two types of electrode material: copper and tungsten carbide with application of two EDM generators:

- isoenergetic, with following machining parameters: current amplitude I = 1 A, pulse time t_i=25 µs, pause t_p=5 µs and t_p=25 µs (for copper) and t_p=100 µs (for tungsten carbide),
- RC circuit, with following pulse settings: discharge voltage U=150 V, adjustment C1: W_e = 55,1 nJ, f_t=8,33 MHz (t_i ~ 120 ns); adjustment C5: W_e = 551 nJ, f_t =0,83 MHz, (t_i ~1,2 µs); adjustment C10: W_e = 18,2 µJ, f_t = 25,2 kHz, (t_i ~ 40 µs) where: W_e – theoretical discharge energy, f_t – theoretical discharge frequency, t_i – theoretical discharge time.

The others research constants have been as follows: initial shaft diameter: D_0=0,4 mm, dielectric: Exxsol D80, block material: 304 steel.

3 Results discussion

Below, in the Figures 4 and 5 comparison of simulation data (according to eq. 3) and empirical results for electrochemical etching are presented. In the Figures 6, 7 and 8 process characteristics and tool example have been presented.

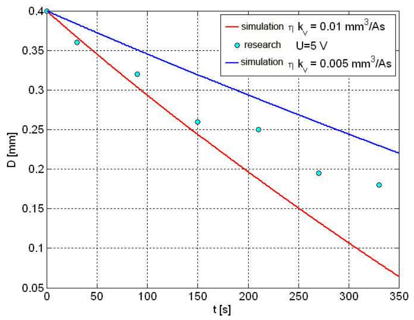


Figure 4. *Relations D(t) between shaft diameter D and machining time t: 1- research for interelectrode voltage U=5 V, 1 and 2 – simulation according to relation 3 for electrolyte conductivity* κ*=0,007 A/V,* D_0*=0,4 mm,* S_0*=0,5 mm, interelectrode potential drop E=1 V, electrochemical machinability* ηk_v*= 0.01 mm*^{3}*/As and* ηk_v*= 0.005 mm*^{3}*/As (*

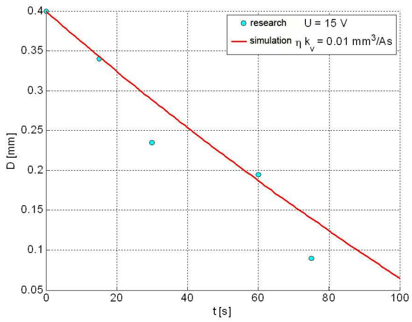
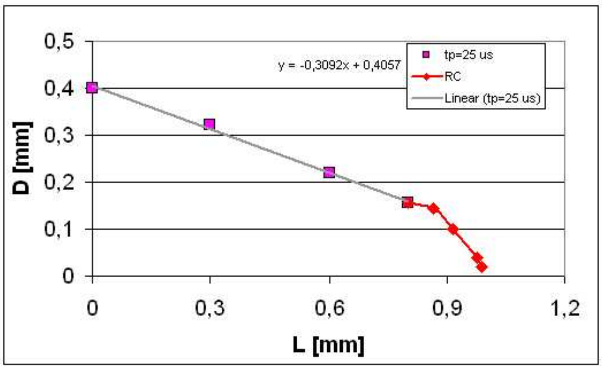
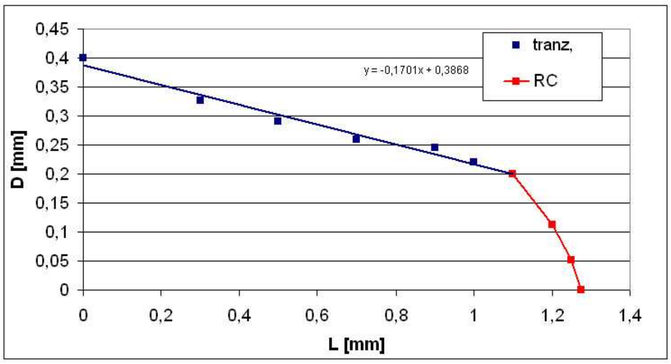


Figure 5. *Relations D(t) between shaft diameter D and machining time t: 1- research for interelectrode voltage U=15 V, 2 – simulation according to relation 3 for electrolyte conductivity* κ*=0,007 A/V,* D_0*=0,4 mm,* S_0*=0,5 mm, interelectrode potential drop E=1 V, electrochemical machinability* ηk_v*= 0.01 mm*^{3}*/As.*



L [mm]	W_e
0,865	*55,1 nJ*
0,915	*55,1 nJ*
0,978	*551 nJ*
0,990	*18,2 µJ*

Figure 6. *Relation between shaft diameter D and machining distance L (according to Fig 3) for:*
1 - isoenergetic generator (t_p *= 25 µs,* t_i*=25 µs I = 1 A), 2 - RC circuit generator (parameters in above table), electrode material: copper*



L [mm]	W_e
0,865	*55,1 nJ*
0,915	*55,1 nJ*

Figure 7. *Relation between shaft diameter D and machining distance L (according to Fig 3) for: 1 - isoenergetic generator (t_p = 100 μs, t_i=25 μs, I = 1 A), 2 - RC circuit generator (parameters in above table), electrode material: tungsten carbide.*

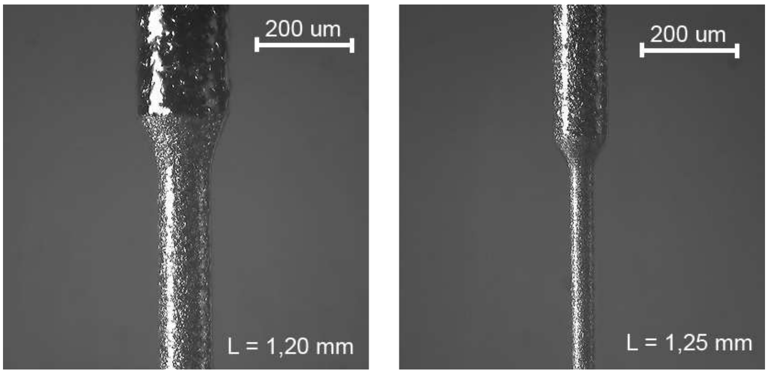


Figure 8. *Photographs of shaft tip for different distances L machined with RC circuit generator (parameters in Table 1), electrode material: tungsten carbide.*

Taking into account results presented in Figures 4 – 8 one can state that:

- for selected in experiment machining parameters the electrochemical tool shaping gives possibility to obtain shafts with minimal diameter in range of 150 - 200 µm. Further machining results in tool length decrease,
- electrochemical etching is much more efficient than electrodischarge machining,
- electrodischarge machining with application of isoenergetic generator limits the minimal shaft diameter only to 0,2 mm (below this diameter the electrode has been truncated),

- surface layer quality after machining with isoenergetic generator is poor (it is connected with quite big pulse energy),
- application of RC-circuit generator gives possibility to decrease the tool diameter below < 50 µm with significant improvement of surface layer quality,
- electrodischarge shaping with application of RC-circuit is slow – the average velocity of shaft diameter decrease is about 0,005 mm/min;
- in-situ tool manufacturing gives possibility to minimalize errors of tool clamping system and spindle rotation;
- the simulations results are close to empirical data, what gives possibility to apply described models for tool diameter changes prediction.

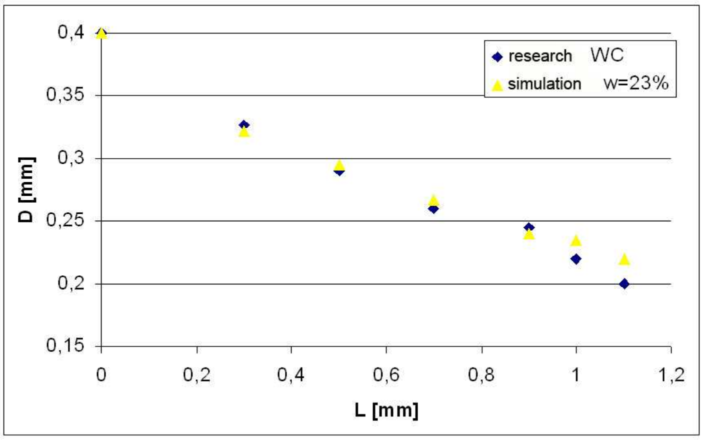


***Figure 9**. Comparison of relations D(L) for simulation for electrode wear assumption w = 23% (based on model presented in [5]) and empirical data for tungsten carbide electrode (isoenergetic generator, t_p = 100 µs, ti = 25 µs i I = 1 A).*

4 Conclusions

In the paper the characteristics of the selected unconventional methods of cylindrical micro-tools manufacturing has been presented. The main advantage of presented methods is possibility to shape the tool on the same machine-tool where the machining process is carried out. The machine has to be equipped with special tooling, software and database with process characteristics. Obtained during research relation D(t) (for ECM, Figures 4 and 5) and D(L) (for EDM, Figures 6 and 7) creates the process characteristics for investigated methods.

As results from above presented information, the technologist which design the EDMM or ECMM milling process can select one optimal tool-shaping process from sort of different methods. The electrochemical etching (deep immersion method) gives possibility to obtain quite simple cylindrical/conical tool shape while the electodischarge grinding is more flexible method (shaping of simple cylindrical tools, polygonal crosssection tools etc.)

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