Properties of Electro Discharge Machining with a Spinning Disc Tool System

Jan Hošek[1)] and Jan Drahokoupil[1)]

[1)] Czech Technical University in Prague, Faculty of Mechanical Engineering/ Department of Instrumentation and Control Engineering, Technická 4, 166 07 Prague 6, Czech Republic, e-mail: *Jan.Hosek@fs.cvut.cz*

Abstract — **We have developed a spinning disc tool system to test machining properties of such a tool to enhance the Electro Discharge Machining (EDM) process of hard and difficult to machine materials. We performed experimental machining tests with this disc tool system. We have measured and explained effects, which affect the stability of this electro discharge machining process with use of the spinning disc tool technique. We found out this system may speed up material removal rate of the EDM process, but its use for micromachining is limited by the tool wear.**

Keywords — Electro Discharge Machining, spinning disc tool, erosion, stability.

I. INTRODUCTION

Electro Discharge Machining technology is a well known technique used for hard and difficult to machine materials and structures. The EDM technique uses a series of electric sparks between the workpiece and tool electrode which gradually erode material from the workpiece electrode preferably. This principle was derived from the known wear of electric power contacts and this technique was developed up to commercial available machines during the 50th [1, 2]. The main advantage of this technique is its ability to machine any electro-conductive material and to produce geometrical shapes which are not possible to make with conventional machining technologies. Furthermore, the EDM is a non-contact technique where contact forces don't affect the workpiece shape. It makes this technique suitable for a very precise machining. These features make this technique indispensable for manufacturing of dies and moulds, prototyping, micro-machining etc. In contrary to the mentioned advantages the main drawback of the EDM technique is a relatively low material removal rate (MRR) and relative high tool wear rate (TWR) compared with other conventional techniques. Optimization of the MRR and elimination of the TWR for different combination of materials and sparking area size and shapes are still hot research problems. We tackle this problem in case of machining tool electrodes and small hard steel shafts. Our aim was to develop and test a system with the spinning disc tool electrode to increase the ratio of tool to workpiece sparking affected area, to increase the MRR and decrease the TWR during the machining process.

A. The Principle of EDM

The principle of the EDM process is based on controlled sparking between the tool and workpiece electrodes. Typically both tool and workpiece are submerged in a dielectric medium (dielectric oil or deionized water) what avoids electrolysis effects during the EDM process sparking. The process starts with increases of voltage between electrodes to cause a discharge over the gap of 10 – 100 µm width. It forms a channel of plasma and a control system has to control the machining current and voltage which heat the sparking spots on electrodes above the melting point and dielectric liquid in between above the evaporation point. As heating period is switched off the formed plasma bubble decreases its inner pressure and compressed molten material in the sparking spots on electrode surfaces is evaporated and splashed out by shock waves during the bubble collapse. Mixture of bubbles and debris in form of small condensed balls are flushed away during the OFF time process and by mechanical motion of the electrodes.

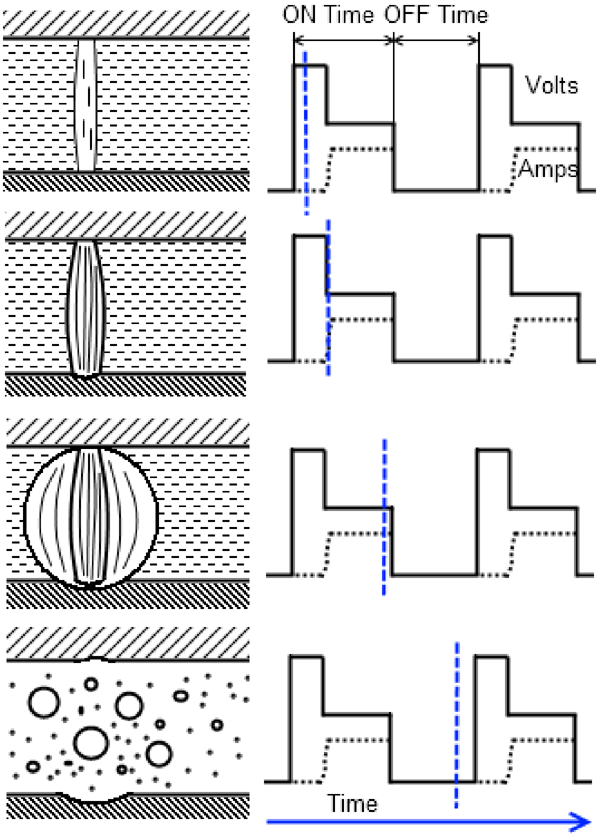

Fig. 1. Diagram of the spark material removal process.

A single event of the discharge process generates a very small crater on the electrodes surfaces, thus a series of repetitive discharges have to occur at high frequencies (kHz–MHz) to achieve an effective material removal rate. The discharges are initiated at surface positions with the highest intensity of electric fields in between the electrodes. Presence of bubbles and conductive debris in the gap between the electrodes cause statistical coverage of the electrode surfaces by merged craters. It leads to a typical cratered pattern of the EDM machined surfaces (see Figure 2).

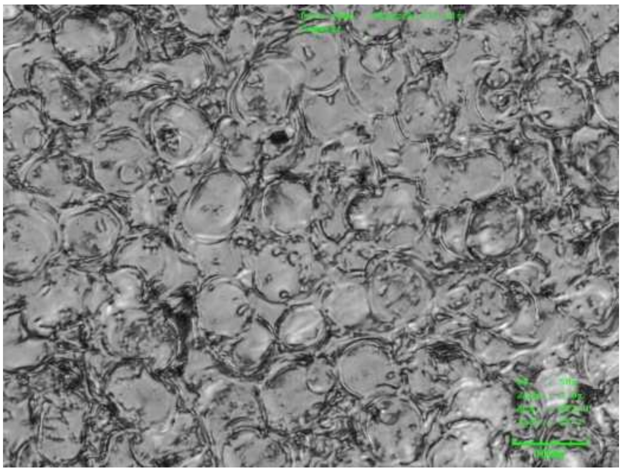

Fig. 2. Typical cratered pattern of EDM machined surface.

Machining using electric discharge phenomena is a very complex process involving heating, melting and evaporation of various materials with different thermodynamical properties within a very short time and in a limited space. Thus both experimental observation and theoretical analysis of the process are very difficult [3, 4, 5]. For practical reasons the optimization of the EDM process is studied as a function of adjustable process parameters [6, 7] or electrodes material [8] and geometrical combination [9, 10]. Our approach was to test a spinning disc tool electrode for the EDM hard steel shafts production and tungsten microelectrode dressing. The dressing of a raw electrode to an appropriate shape and dimension is a necessary step in the EDM production of fine structures [11, 12] such as in Figure 3.

Fig. 3. EDM grid with 83 apertures 0.4 x 0.4 mm^2 and struts width 60 µm in 0.16 mm thick molybdenum sheet [12].

II. DESIGN OF SPINNIG DISC TOOL SYSTEM

A. Aim of the System

Our aim was to develop and test a system, which enables to speed up production of rotating workpieces by means of the EDM technique. The most common method of rotational microelectrodes production is its EDM dressing by a precisely grinded AgW sacrificial block [10, 13]. The rotating electrode is pushed towards the sacrificial block by appropriate path and velocity till it erodes itself to a desired dimension, as it is schematically shown in Figure 4 left. This simple technique has few practical disadvantages. The first disadvantage is a compromise between the machining time and precision. The precise diameter can be reached under fine machining conditions, but these fine conditions extend the machining time. The second disadvantage is a local wear of the AgW sacrificial block. This local wear, see Figure 4 in the middle, affects the precision of the electrode final diameter. If a new electrode will be dressed at the same place as the previous, the electrode reaches other than desired diameter. This is a limiting factor affecting the sacrificial block lifetime.

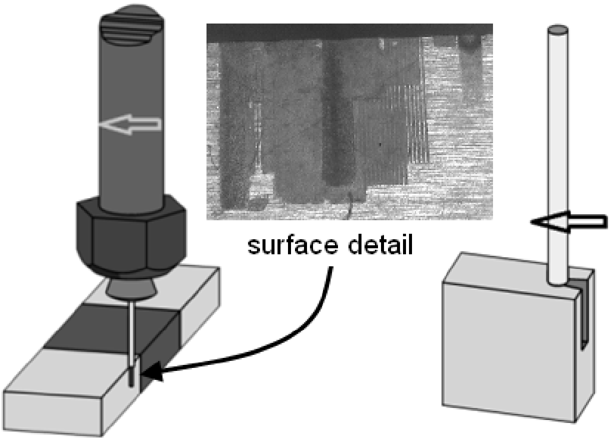

Fig. 4. Diagram of electrode dressing by sacrificial block – left; and sinking the electrode into the sacrificial block – right.

The worn area of the sacrificial block can be minimized by dressing the electrode by its sinking into the sacrificial block [9] (see Figure 4 – right). In this case the sacrificial block can be made of an easy EDM worn and cheap material, compared with the AgW sacrificial block.

Another known electrode dressing methods eliminate the local sacrificial block wear by using moving elements like a wire or disc. We decided to design and test a spinning disc tool system for the workpiece dressing, where the wear is applied along large area of the disc tool perimeter and the impact of the wear on the disc dimensions could be minimized.

B. Design of the Spinning Disc System

Our design of the spinning disc EDM tool had to fulfil few limiting constrains. Based on the previous experiments the optimal disc tool rotational speed is between 50 to 150 revolutions per minute for 90 mm disc diameter. A higher peripheral velocity leads to a decrease stability of the discharge due to high dielectric liquid flow. We provided the system with a planetary gear to reduce the drive motor rotational speed and to increase its torque. Another critical constrain is a restriction to the spinning disc wobbling. It has to be much smaller than the spark gap distance of the EDM process, typically 5–20 μm. The whole system was designed compact, possible to be fixed on a magnetic table of our EDM machine SODICK AP1L and be able to be submerged into dielectric oil. Minimum wobbling of the EDM spinning disc was achieved by use of precise ball bearings directly pressed on the spinning disc career vertical shaft. An electric contact was assured by a preloaded electric career bar. The tool disc is insulated by a ceramic wheel coaxially cemented to the shaft to prevent bearings from undesirable sparking among spinning bearing balls. A drive part of the system was designed separately and motion transmission is performed by a preloaded tooth belt to eliminate clearances and vibrations transfer to the tool shaft. We used a Black&Decker DC motor 400 W with a planetary gear as a drive. The design of the system is shown in Figure 5.

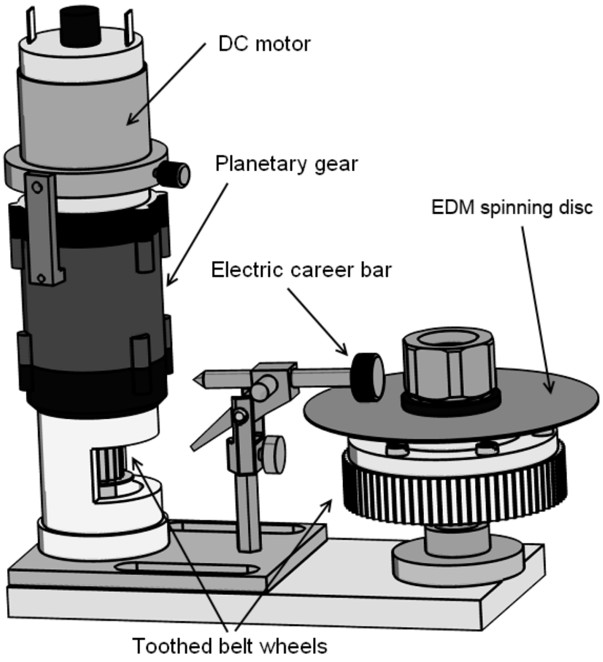

Fig. 5. Diagram of complete design of the EDM spinning disc tool system.

III. EXPERIMENTAL MACHINING TESTS

We performed series of EDM machining tests with this EDM spinning disc tool system. We used a slightly worn material (aluminium) as a spinning disc material for easy observation of the wear effects caused by the EDM process. We performed both radial and axial machining tests. Then we evaluated geometrical shape of the machined workpiece and tool disc wear.

A. Radial Machining Test

The radial machining uses radial feed of the tool electrode towards the spinning workpiece till the desired radial position in the workpiece is reached. If the length of the machined shoulder is longer then thickness of the tool disc, the spinning disc is shifted to a new axial position and radial machining is repeated. The discontinuity of such machining process with combination of the tool electrode wear leads to a relative high geometrical roughness of the workpiece. The highest wear of the tool electrode occurs at edges what forms ripples at the machined surface and disable to machine sharp inner corners (see Figure 6 – left). The ripples can be smoothed by a next radial machining, but it complicates and prolongs the whole machining process. Furthermore, the EDM process is very sensitive to keep a right spark gap distance, which is affected by the wheel wobble. It is necessary to keep low wobbling of the spinning disc with periodical disc dressing.

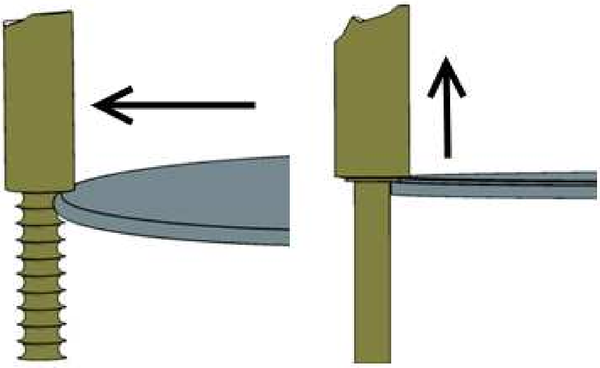

Fig. 6. Diagram of radial – left and axial – right machining with typical geometrical defects caused by tool electrode wear.

B. Axial Machining Test

The axial machining uses axial feed of the tool electrode along spinning workpiece (see Figure 6 – right). In case of the axial machining the total area of sparking is much greater than in case of the radial machining, where sparking occurs along single line at the disc perimeter only. It enables to use higher machining currents to increase process productivity. The tool electrode is worn at front side of the disc in this case. The spinning disc dressing can be done by dressing the whole front side of the disc or to use radial dressing to decrease the disc radius. Both these approaches remove large quantity of disc material which was not used for machining.

C. The Effect of Spinning Disc Wobbling and Bumps

Our experiments on real spinning disc system show the machining process is intensively affected by disc wobbling or presence of bumps at disc surface. Such effects change the spark gap distance and deteriorate sparking. We found out a positive feedback effect of the EDM process on bumps presented at the disc surface what leads to enlargement of bump dimensions during machining.

In case of a common grinding process the grains sticking out above others are loaded with the highest forces. These forces brake or release the highest bumps (grains) from the grinding wheel. It assures self-dressing of the grinding disc geometry and the grinding process behaves like a system with negative feedback. In contrary to the grinding process the EDM process uses no contact forces and the disc geometry change is mainly affected by the local sparking intensity. Presence of a bump at the spinning disc shortens the spark gap distance above the bump and the discharge affected area is larger than for a longer spark gap distance. The same amount of spark energy heats a larger electrode area than for a position with a longer spark gap distance, what decrease the depth of removed material of the bump compared with other parts of the disc. It causes the wear at the bump position is lower than the wear of flat parts of the disc. It can be described as a positive feedback of the EDM process on grow of the bulge above the other more worn parts of the disc surface.

We had to modify the EDM process control to eliminate problems caused by possible bulge defects of the spinning disc surface. We split continual feed motion of the spinning tool to discrete steps smaller than the spark gap distance. To keep even wear over the disc surface single feed step has to take time at least of one complete revolutin of the spinning disc. Under these conditions the positive feedback of the EDM process cannot enlarge potential bump at the disc surface to dimensions larger than the spark gap distance, what effectively stabilizes the EDM machining process.

IV. RESULTS

We performed few machining tests to confirm our discrete step machining method to eliminate positive feedback effect of the spinning disc EDM process on the spinning disc tool electrode geometry.

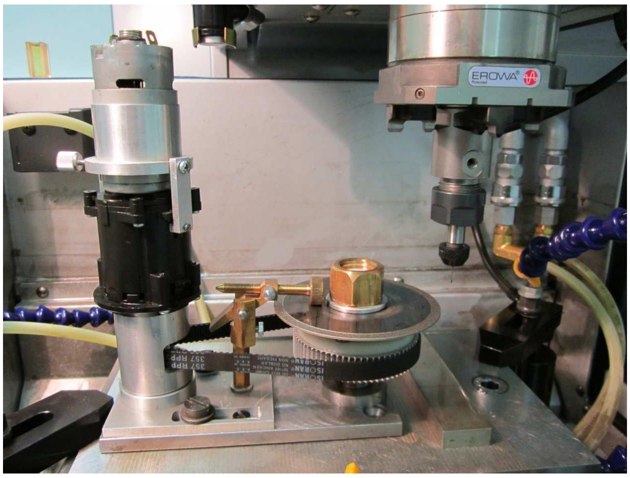

Fig. 7. Spinning disc tool system fixed in EDM machine SODICK AP1L machining tank ready to machine 1 mm diameter tungsten raw electrode clamped in the spindle.

We provided the spinning disc tool system with a hard steel spinning disc 1 mm thick. The disc was both axially and radially dressed with a turned copper electrode. The workpiece was fixed in a spindle collet of the EDM SODICK AP1L machine. The overall view on experimental configuration is in Figure 7.

We tested two methods of a discrete step feed set. As first we experimented a fixed feed step distance value as a fraction of the spark gap distance of given machining conditions. This approach is suitable for a fast material removal with a relatively higher tool electrode wear. The optimal feed step distance seems to be from 1/2 to 1/4 of the spark gap distance. The second method holds constant number of discrete steps, but decreases step distances down to 1/10 of the spark gap distance at the final machining stage. It restores geometry of the tool electrode at the end of machining and maintains the tool electrode geometry for longer time use. Typically we used combination of both approaches, the fixed steps at the beginning of machining and refine the feed step distances at the final stage of machining.

We experimented this approach in case of machining of a hard steel rod 2 mm in diameter machined at the axial distance 3 mm. Machining conditions of the EDM process used for combination of the hard steel tool electrode and hard steel and tungsten workpiece material are summarized in Table I.

TABLE I.
MACHINING CONDITION OF EDM PROCESS

	Machining condition	Steel / Steel	Steel / W
PL	Polarity (+ ↑; ground -)	-	+
ON	ON Time (μs)	90	2
OFF	OFF Time (μs)	5	66
IP	Current (A) (Dis/Main)	5.7/12	2.7/3
V	Voltage (V) (Dis/Main)	200/120	90/90
C	Capacitor (μF)	none	0.047

The feed step distance was set to 5 μm (1/2 of the spark gap distance) for the first 60 feed steps at the beginning of machining. Last 10 feed steps were gradually shortened. The total machining time was 18 minutes. We measured diameters of the machined rod at a regular distances L from the rod face with an electro-contact distance gauge. Results are shown in Table II.

TABLE II.
DIAMETERS OF MACHINED HARD STEEL ROD

Machined hard steel rod diameters at different positions						
L (mm)	0	0.5	1	1.5	2	2.5
D (μm)	1535	1570	1548	1580	1565	1620

Increase of the rod machined diameter from the face is caused by wear of the spinning disc electrode, but the EDM machining process remains stable without negative effects caused by the spinning disc irregularities grow.

We also tested the EDM machining of much resisting material with the hard steel spinning disc electrode. We machined a tungsten 1 mm diameter electrode at the axial distance 2 mm with our system. We had to use much finer machining conditions to prevent the tool electrode wear what decreases the spark gap distance to 5 μm. We used the 2.5 μm feed step distance for the first 120 feed steps of machining. The last 20 feed steps were gradually shortened. The total machining time of the tungsten electrode was 25 minutes. Measured diameters of the tungsten electrode are shown in Table III.

TABLE III.
DIAMETERS OF MACHINED TUNGSTEN ELECTRODE

Machined tungsten electrode diameters at different positions				
L (mm)	0	0.5	1	1.5
D (μm)	523	540	544	558

The measured diameter data clearly showed taper shape of machined tungsten electrode as a consequence of wear of the hard steel spinning disc electrode. Despite of this fact machining with the spinning disc was stable during whole process, although the spinning disc final geometrical tolerance reaches IT15 with the surface roughness $R_a = 12$. It gives good chance to get a stable and effective machining with the spinning disc tool system if we replace the easy worn spinning tool disc by more wear resist material as molybdenum, copper or tungsten.

V. CONCLUSIONS

We designed and tested a spinning disc tool system for the EDM electrode dressing. We found out a significant difference in the EDM spinning disc wear characteristics compared with the common grinding process. A positive feedback in the EDM spinning disc erosion can be overcome by discretization of the tool feed to single steps smaller than the spark gap distance and minimizing the spinning disc wobbling below the spark gap distance values. We tested this spinning disc tool EDM machining system provided with a hard steel disc for machining of a hard steel shaft and tungsten electrode. It shows possibility to achieve a stable and productive process despite of cheap and easy worn material was used as a tool electrode. We will continue in optimization of this system and we will test the EDM machining and tool wear properties by use of more wear resist tool disc materials as copper or tungsten.

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