Manufacturing and verification of tools for ECF

K. Hofmann\textsuperscript{a}, L. Staemmler\textsuperscript{b}, H. Kück\textsuperscript{a,c}

\textsuperscript{a} Institute of Micro- and Precision Engineering (IZFM), University of Stuttgart, 70569 Stuttgart, Germany
\textsuperscript{b} now: Greiner Bio-One GmbH, 72636 Frickenhausen, Germany
\textsuperscript{c} Hahn-Schickard-Institute for Micro Assembly Technology (HSG-IMAT), 70569 Stuttgart, Germany

Abstract

The electrochemical milling with ultra short voltage pulses (ECF) displays an important progress in micromachining of hard materials. Machining a workpiece with conventional milling the removal takes place by shape cutting. Therefore mechanical forces are applied to tool and workpiece. In contrast, using electrochemical milling, the material removal occurs by an electrochemical reaction. Therefore the workpiece as well as the tool are submersed into an electrolyte and the surface of the workpiece is etched by a galvanic current. Hereby the so called working distance is formed between tool and workpiece, which goes linear with the pulse amplitude and pulse on time in a first approximation. As a result, there are no mechanical forces applied to the tool. This allows the use of very thin tools. To achieve the highest precision with this technique, it is necessary to manufacture very precise tools and to verify the latter the exchange of electrolyte within the working distance is charged to a potential high enough for an electrochemical reaction only in close proximity around the tool, the so called working distance. Areas of the surface that are farther away are not affected by the ECF process.

However the latter the exchange of electrolyte within the working gap becomes more and more difficult. A promising strategy could therefore be the use of rotating tools to generate a flow of electrolyte around the tool. This will enhance the exchange of electrolyte in order to speed up the process and reduce the roughness. The rotation of the tool demands an extremely precise positioning of the tool on the rotational axis to avoid a run-out error. Thus the tool is manufactured in the ECF machine itself using the ECF-process. Therefore the electrochemical parameters have to be adapted to machine the tool instead of the workpiece.

To achieve the highest precision with this technique, it is not only necessary to manufacture very precise tools but also to verify their shape and dimensions. This allows to adapt the NC-data to the measured tool diameter.

For the dissolution process in addition to the constant potentials short voltage pulses in the range of 10 ns to 200 ns are applied between tool and workpiece. During these pulses the double layer capacitances are charged over the resistance of the electrolyte.

Because the value of this resistance depends on the length of the path of the electric current in the electrolyte a large distance between tool and workpiece leads to a slow charging of the double layer capacitance whereas a small separation leads to a fast charging (fig. 1). Due to the fact that charging takes place only during the short pulses the double layer capacitance is charged to a potential high enough for an electrochemical reaction only in close proximity around the tool, the so called working distance. Areas of the surface that are farther away are not affected by the ECF process.

Keywords: ECF, rotational symmetric tool, manufacturing, measuring

1. Introduction

Miniaturization proceeds not only in the semiconductor industry but also in other branches like medical engineering and automotive industry. The allocation of micro devices is getting more and more important. With electrochemical milling with ultra short voltage pulses (ECF), invented by Schuster et al. [1,2], a new technique is available to manufacture structures with micrometer feature size in conductive materials. Tool and workpiece are submerged into an electrolyte and the workpiece is electrochemically etched by a galvanic current. The so called working distance is formed between tool and workpiece. In a first approximation it varies linearly with pulse width and pulse amplitude. As a result, there is no contact between tool and workpiece and therefore no mechanical forces are applied to the tool and hence no tool wear occurs. This allows the use of very thin tools within the ECF process.

For smallest structures both the tool diameter and the working distance can be reduced. Nevertheless for the latter the exchange of electrolyte within the working gap becomes more and more difficult. A promising strategy could therefore be the use of rotating tools to generate a flow of electrolyte around the tool. This will enhance the exchange of electrolyte in order to speed up the process and reduce the roughness. The rotation of the tool demands an extremely precise positioning of the tool on the rotational axis to avoid a run-out error. Thus the tool is manufactured in the ECF machine itself using the ECF-process. Therefore the electrochemical parameters have to be adapted to machine the tool instead of the workpiece.

2. ECF Technique

ECF is a technique to produce structures with micrometer feature size into electrochemically active materials, even in very hard materials like stainless steel [3]. Therefore tool and workpiece are immersed into an electrolyte where they form a double layer capacitance on their surfaces. To prevent corrosion both tool and workpiece are hold at a constant cathodic potential. For the dissolution process in addition to the constant potentials short voltage pulses in the range of 10 ns to 200 ns are applied between tool and workpiece. During these pulses the double layer capacitances are charged over the resistance of the electrolyte.

The aim of the experiments shown here is to manufacture and verify rotation-symmetric tools for the ECF process.
3D-forming of the workpiece is achieved by moving the tool similar to conventional milling machines. If the feed rate is higher than the dissolution the tool comes in contact with the workpiece forming a short circuit. That is detected by the ECF machine. The motion of the tool stops and an evasion strategy starts to release the contact.

To achieve the aim of the work presented here it is necessary to machine the tool instead of the workpiece. For that only the electrochemical parameters have to be adapted. This is mainly done by inverting the pulse and shifting the constant tool potential.

3. Experiments

All ECF experiments shown here were carried out on an ECF machine developed by ECMTEC GmbH (Holzgerlingen, Germany). It consists of a xyz-stage with a traversing range of 100 mm in each direction. The stage is driven according to CAD/CAM-data files that are processed by a PC-software. The potentiostat and the pulse generator were especially developed for the ECF process. The pulse generator fits into the processing head of the ECF machine. This is necessary to keep the distance between pulse generation and tool as short as possible. The adjustment range for the pulse width is between 10 ns and 1600 ns and different duty cycles can be set. The pulse generator also detects the contacts between tool and workpiece by measuring the current through the tool. The potentiostat is equipped with an input that stops the potential control while the tool is in contact with the workpiece.

The electrochemical cell is a basin made of PTFE where a platinum-wire (Pt-wire) is horizontally spanned. The wire acts as counter electrode for the machining of the tool and has a diameter of 100 µm.

A high precision spindle was added to the ECF machine with a concentricity smaller than 2 µm. Figure 2 shows the schematic setup of a tool. It consists of a straight W-wire (purity: 99.9+%) with a diameter of 200 µm. The wire is held by a plastic cone that is tightened via a modified Allan screw. Although the use of the plastic cone is harmful for accuracy it is necessary for the insulation of the wire and therefore it limits the surface areas charged by the pulses. Nevertheless the plastic cone increases the run-out errors of the W-wire.

While it is rotating, the tool is moving from the start position into negative z direction until it gets in contact with the Pt-wire. Then the contact is released by moving the tool backwards. As soon as the contact is released the movement stops and short voltage pulses are applied to the tool for a period of 30 s. The constant tool potential is set to 100 mV, the pulse on-time is 100 ns and the duty cycle is 1:8. During this time the
electrochemical reaction takes place and the tungsten is dissolved until the distance between W-wire and Pt-wire is equal to the working distance. After this time the tool moves again into negative z direction until it gets in contact with the Pt-wire, releases the contact and the W-wire is machined for another 30 s and so on (fig. 4).

Due to this lathe-like technique used to reduce tool diameter the achieved tool stay precisely on the rotational axis of the spindle. Furthermore, since the trimming of the wire is done in situ, the tool can directly be used without any respanning, keeping the tool in its precise position.

All the results shown in this paper were made in aqueous electrolyte containing 2 M NaOH.

To verify the shape of the tools a commercial laser measuring system (Blum-Novotest GmbH, Germany) is used to measure the diameter of the tool. It starts by the tip and moves along tool axis measuring the tool diameter every 20 µm.

4. Results

4.1 Manufacturing of rotation-symmetric tools

To investigate the manufacturing of a rotation-symmetric tool a W-wire with a diameter of 200 µm was reduced down to 46 µm using a constant tool potential of 100 mV and 100 ns pulses with an amplitude of 2.4 V. The movement of the tool corresponds to the strategy described above. The counter electrode had a diameter of 100 µm. A SEM image of the resulting tool is shown in fig. 5 and fig. 6. Fig. 5 shows the tool in a side view. It can be clearly seen that the material removal does not take place symmetrically around the axis of the 200 µm W-wire but around the rotational axis of the spindle. Hence there is a shift between the centre axis of the W-wire and the thinner cylindrical part of the tool. This shift is the run-out error of the initial tool and in this case it is in the range of 50 µm. Mainly this large initial run-out error is caused by the use of the plastic cone to clamp the W-wire in the collet. It is difficult to manufacture this plastic part with an accuracy high enough for this application. Nevertheless it is necessary to manufacture this part out of a non-conductive material to insulate the W-wire from the other metallic parts of the tool to keep the surface areas charged by the pulses as small as possible.

The thinned part of the tool does not show a run-out error concerning the spindle axis anymore.

The surface of the machined part of the tool in fig. 5 and fig. 6 shows a high roughness, which is the consequence of the ECF process [4]. The roughness may be reduced be changing the process parameters. Using shorter pulses or pulses with lower amplitude the roughness of the tool should be decreased. In consequence this would reduce the material removal rate. On the other hand a rougher surface could have a positive influence on the exchange of electrolyte in the working gap using rotating tools.

4.2 Verification of tool shape and diameter

Fig. 7 shows the measured result of the tool diameter with the laser measuring system. The graph shows an xz-plot of the positions, where the tool interrupted the laser beam. The triangle data points represent the right side wall of the tool, the circles the left wall. Both give an impression of the tool shape. The squares show the tool diameter, i.e., the difference between the coordinates measured on the left and on the right side of the tool. Mark that to illustrate the tool’s shape the scale in fig. 7 starts at 40 µm (see abscissa at the top). In all three cases the ordinate shows the distance between tool tip and measuring point. Measurement of the diameter results in a repeatability of 0.27 µm which was derived from a set of 100 measurements (data not shown).
5. Conclusion

To manufacture very thin tools with low run-out error for the ECF process a spindle was installed to the ECF machine with a true running accuracy of the spindle of less than 2 µm. Using this spindle it could be shown that it is possible to manufacture rotation-symmetric tools using the ECF technique although the tool has an initial run-out error. A tungsten wire with a diameter of 200 µm could be processed so that a cylindrical tool with 46 µm diameter and no run-out error results.

Further it could be shown that these tools can be verified using a commercial laser measuring system. The repeatability for this system is below 0.5 µm.

In further experiments the influence of tool rotation on the ECF process including the influence of the roughness of the tool surface will be investigated.

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References