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ELECTROCHEMICAL MICROMILLING

BLEICHER, F[riedrich]; ZISSER - PFEIFER, R[einhard] & ZEMANN, R[ichard]

Abstract: *Many fields such as medicine, biomechanical technology, the automotive, and the aviation industry, etc, are searching for tools and methods to realize micro and nanostructures in varying materials. The micro-structuring of very hard materials like carbides or brittle-hard materials poses an especially major challenge for manufacturing technology. For these reasons the Institute for Production Engineering and Laser Technology (IFT) of the Vienna University of Technology is working in the field of electrochemical micromachining with ultra short pulses striving for the manufacturing of micro structures less than 100µm. The main targets are the development of pre-pulse technology to speed up the production rate and the elaboration and testing of new material-electrolyte-combinations.*
Key words: *electrochemical machining, micro milling, finishing*

1. INTRODUCTION

The machining technology of electrochemical micro milling *(ECM)* is based on the already well-established fundamentals of common electrochemical manufacturing technologies. The enormous advantage of the highest manufacturing precision underlies the fact of the extremely small working gaps achievable through ultra short voltage pulses.

Another big advantage of the electrochemical micro milling technology is that the treatment of the work piece takes place without any mechanical forces or thermal influences. Therefore with no abrasive wear of the tool, the basis for extremely sharpe-edged geometries is set. There is no unintentional rounding of edges and no burring on the part.

At the moment for several nonferrous metals like nickel, tungsten, gold etc., as well as alloys like non-corroding steel 1.4301, appropriate electrolytes have already been found. Nevertheless a main focus of research for the IFT in cooperation with the company ECMTEC (Germany) will be the search for new material-electrolyte-combinations to expand the field of application for this technology and to enhance its manufacturing productivity. This needs to be accomplished in order to fulfill the requirements of industrial production because in industries such as the automotive sector, the rate of production is very important. At the IFT an excellent assortment of measuring devices like for example a Zeiss F25 coordinate measuring machine, high end optical measuring devices like the Alicona Infinite Focus 4G and the Nikon Nexiv VMR-3020, and an JEOL JCM-5000 scanning electron microscope are available. Based on the technology of ECM and by the use of high end measuring devices, specimen and parts in the micrometer range and smaller are to be manufactured and analyzed in order to investigate material removal rates and accuracy of resulting work piece geometries.

Due to the multidisciplinary nature of this technology, intensified cooperation with other Institutes of the Vienna University of Technology in the fields of electro technical engineering, high frequency technology and electrochemistry are established. The goal of research will be to bring this technology to an appropriate level for possible industrial use by enhancing current component´s manufacturing accuracy and the process efficiency. Therefore a profound knowledge of material science, electrochemistry and production technology for extremely small dimensions will be required. The necessary expertise in these fields will be provided by the cooperating Institutes and partners.

To accomplish these improvements in ECM technology it will be necessary to merge several research subjects, which are already dealing with topics of piezo driven nano-positioning devices or development of high precision machine structures for measuring machines.

2. ELECTROCHEMICAL MICROMILLING

Similar to conventional electrochemical manufacturing methods the ECM process with ultra short voltage pulses uses an oppositional electric voltage for the work piece and the tool. At the phase boundaries between tool and electrolyte and also between work piece and electrolyte, an electrochemical double layer is formed whose functionality can be understood principally as a kind of a double condenser. In addition to the proper choice of the electrical process parameters like the amplitude of the pulses, the pulse width, the voltages at the tool, the work piece, and the backing electrode, the right choice of the electrolyte is probably the most important aspect for this process. The whole machining process takes place in a basin filled with an electrolyte solution which has to be adapted adequately to the work piece material used.

Even during filling of the basin the greatest caution is appropriate due to the fact that once in contact with the electrolyte, the surface of the material immediately begins to corrode. To prevent the work piece surface from the influence of the electrolyte-solution, a cathodic protection-current is applied.

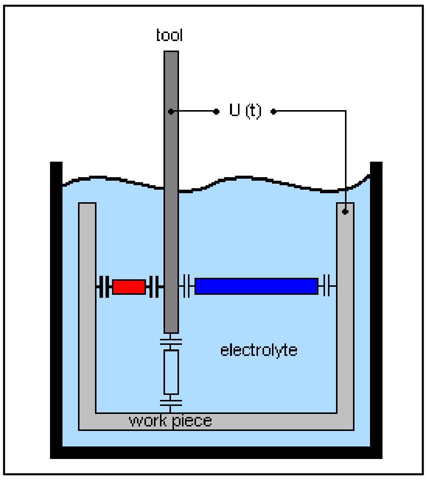

Fig. 1. Electrochemical double layers and schematic illustration of the electrolyte as electrical resistor between tool and work piece

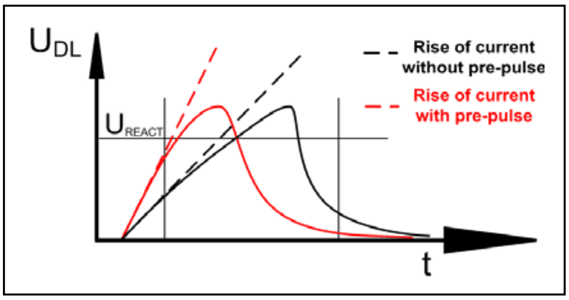

Fig. 2. Time variable voltage curve in the electrochemical double layer without (red) and with (black) pre-pulse

With the basin filled as needed, the process of work piece calibration can be done directly with the tool. This is an advantageous aspect of this technology because neither the tool nor the work piece has to be unclamped.

Then the manufacturing program, which conforms to a standard CNC-program, is started. The tool moves along the pre-programmed paths and selectively ablates material due to the effect of the voltage transfer in the electric double layer triggered by the ultra short pulses. Figure 1 shows the schematic illustration of the tool and the work piece in the electrolytic reservoir and the electrochemical double layer. If the voltage pulse width is very short, the erosion takes place very close to the tool (red part in Figure 1), since the ohmic resistance of the electrolyte prevents ablation at areas further away of the tool (blue part) due to the double layer capacitor cannot be sufficiently recharged. The pulse width depends on the choice of electrolyte.

A pulse width of about 400 nanoseconds is used for rough machining and a pulse width of about 150 nanoseconds is used for the finishing procedure.Even more accurate machining can be achieved with pulse widths in the range of picoseconds, and by separating the processing pulse in a pre-pulse and a main pulse. In particular, the investigation of the influence of targeted pre-pulses is one of the main research topics to be elaborated at the IFT. In order to elaborate on the research work concerning the technology of using ultra short voltage pulses, the relevant demands of industry; basically increasing the material removal rate, has to be considered as a main goal. Subsequently, an increase in the already excellent machining accuracy is regarded as a main target.

Another big advantage (cp. Tab. 1) of this technology is the possibility to reverse the process electrically. This means that not only the work piece can be machined, but also the tool itself can be defined as work piece and be machined to its ideal geometry without any further set-up.

	Structure-size	Aspect-ratio	Dimen-sions	Materials
EC Micromilling	Limit 10nm	> 10	2.5D	electrochemical active materials
Litho-graphy	> 10 nm	~ 1	2.5D	etchable and evaporatable mat.
Focused Ion Beam Milling	~ 30 nm	~ 10	2.5D	galvanically separable materials
Laser-Ablation	~ 0.5 µm – 1 µm	~ 10	2.5D	metals and dielectric fluids
Mechanical Milling	~ 1 µm	~ 1	2.5D	metals and polymers
EDM	~ 1 µm	~ 10	2.5D	metals

Tab. 1. Comparison of micro- and nano-machining methods

The existing technical installations also admit a high precision calibrating process. Regarding all these functionalities the requirements for a precise micro-machining are met. Possible tasks that can be performed with this machining centre include: tooling, milling, turning, sinking and measuring.

Characteristics of the ECM-process:

- Production of smallest geometries and products
- High aspect-ratio (>10)
- No thermal load
- No mechanical process forces
- High precision
- No tool wear
- Small working gaps between tool and workpiece (<1µ)
- Very small edge-rounding
- No burring
- High quality measuring function
- Electric pulse width range between pico- and microseconds

Besides the research work on the basics of ECM machining itself, and the development of the pre-pulse technology, several application-like experiments will be explored. One of the main objectives of these experiments will be for example the specific processing of the surface of cutting plates to manipulate the chip formation for milling and turning operations. This surface structuring method will also be analyzed; on the one hand considering the application for micro injection moulding tools and on the other hand for the production of special surfaces with similar behavior like the lotus flower- and sharkskin- effects

Another challenge is the manufacturing of micro geometries less than 100µm, for example the first measuring caliper with a ball diameter less then 80µm.

3. CONCLUSION

The use of pre-pulse technology and the applicable effects on process accuracy and material removal rate of difficult to machine materials offers a wide range of possible applications for ECM technologies. The research work needs an interdisciplinary approach covering the topics of chemistry, electronics and production engineering. Due to the combination of existing metrology systems and ECM technology the machining of nano- and micro-structures in high precision applications will be developed. The pre-pulse technology offers possibilities to realize innovative products which up to now could not be machined adequately.

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