Analysis of strategies for gap control in jet electrochemical machining

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Abstract

Electrochemical Machining (ECM) is a promising micro-production technique for the creation of complex and highly accurate three-dimensional geometries in electrically conductive materials. As the electrochemical dissolution behavior is independent from the material's mechanical characteristics like hardness and ductility, ECM is an alternative processing technique to create micro-structures even in mechanically hard to machine alloys.

The basic principle of ECM is the anodic dissolution of work piece material by electric charge transport. As a special procedure electrochemical machining with continuous electrolytic free jet (Jet-ECM) offers the possibility to machine work pieces at extremely high current densities up to 1000 A/cm² [1,2]. In Jet-ECM the electrolyte is pumped continuously through a micro nozzle and ejected with an average speed of approximately 20 m/s perpendicularly to the work piece surface. Thus, a free jet is formed on the surrounding atmospheric air, which leads to a high localization of the current density and therefore to a highly localized machining area around the impinging jet. From the previous work on Jet-ECM the working gap was detected as a significant process variable, which needs an adequate control or adjustment. In this study, an analysis of potential strategies to control this variable is summarized.

1. Introduction

In Jet-ECM, micro structures are machined by moving a nozzle horizontally over a work piece surface and switching the process voltage in dependence of the nozzle's position. The principle of Jet-ECM is shown on the left picture of figure 1.

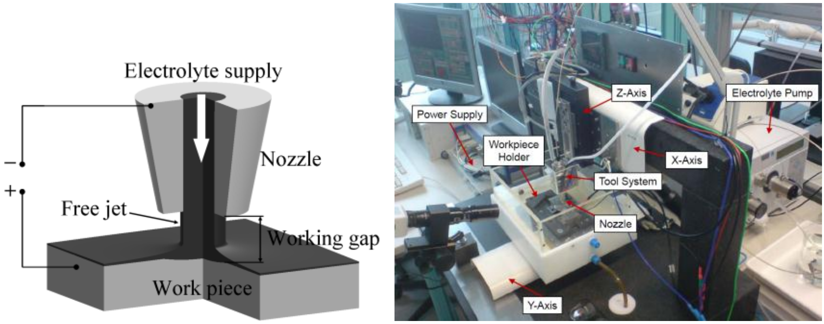

Figure 1: principle of Jet-ECM [3] and photograph of the prototype facility [2]

The initial working gap is the distance between the nozzle's front and the work piece surface. To realize Jet-ECM a prototype was designed. A photograph of the system is shown on the right picture of figure 1. A three-axes positioning system was built up, which consists of a granite frame in portal design to guarantee the requested thermal and mechanical stiffness. With high precision linear stages a repeatability of 1µm over the whole positioning range of 150mm x 150mm x 50 mm (X/Y/Z) is realized.
The positioning speed is limited to 5mm/s by the control software. The software itself was programmed individually based on LabVIEW from National Instruments Germany GmbH, Munich, Germany.
Up to now the adjustment of the working gap is realized by detecting three points of the plane work piece surface through measuring the electrical contact. From these coordinates the normal vector of the detected surface is calculated and used to control the instantaneous height position of the nozzle. With this method it is possible to control the working gap corresponding to the work piece inclination. However, complex geometries of the sample surface are not yet detected. Therefore this study summarizes an analysis of potential strategies to control the working gap.

2. Strategies for Gap Control

From previous studies in Jet-ECM the working gap was derived as a significant process variable, which needs to be controlled or adjusted accurately to obtain a reproducible result. Furthermore, processing with a wide working gap is less resource-efficient. Hence, two cases have to be distinguished. The first is the determination of the working gap before Jet-ECM and the second is the determination of the working gap during the process.

2.1 Adjusting the working gap before Jet-ECM

To determine the working gap before the Jet-ECM process, the following three strategies are possible.

AN – adjusting by normal vector

Up to now the adjustment of the working gap is based on an electrical probing. Three points of the sample surface are touched by measuring the voltage drop between the tool nozzle and the work piece. These contact positions are used to calculate the normal vector of the surface. With this method the adjustment of the working gap according to the work piece inclination is realized, whereat a planar surface is postulated.

AG – adjusting by grid

For detecting more complicated shape deviations, multiple points can be detected according to an individually chosen grid layout. The normal vectors of the corresponding areas can be calculated from the determined values. The working gap is adjusted during the process by using a plurality of normal vectors.

AR – adjusting by reference points

In this case an individual number of points along the removal geometry are detected. For example the start and stop position of the respective contour and a certain number of reference points within the contour can be chosen. The working gap is then calculated according to the results and precisely controlled during the process.

2.2 Controlling the working gap during Jet-ECM

To control the working gap during the process, the following strategy is possible.

CD – control dynamical

The working gap is controlled dynamically during the process. The present working gap is determined and adjusted when differing from a defined tolerance. For the dynamic control different types of measurement signals, e.g. electrical, mechanical, acoustical or optical signals can be applied.

2.3 Combination of adjusting and controlling the working gap

A combination of adjusting and controlling is also a possible strategy. Before processing the working gap is adjusted, according to one of the strategies mentioned in chapter 2.1 (AN, AG, AR) and during the Jet-ECM the working gap is controlled dynamically (CD). The most relevant example is the combination

AR+CD – adjusting by reference points and control dynamically.

On the basis of reference points the working gap is adjusted first and then controlled during the process.

3. Summary

In this study strategies for gap control in Jet-ECM are shown. The working gap can be adjusted before or controlled during the process. Furthermore, it is possible to set up a combination of adjusting and controlling. The preferred strategy is a combination of adjusting and controlling the working gap because it is a suitable compromise of a fast feed speed before and an accurate gap control during the process.

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