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Characterization of an Electrochemical Machining Process for Precise Internal Geometries by Multiphysics Simulation

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Abstract

In several fields of mechanical engineering internal precision geometries are applied. For this, application requirements like high shape accuracy, sufficient stability, high wear resistance or an increase of life time have to be fulfilled. However, there is also a demand on quick and precise manufacturing processes that are flexible in machining various internal geometries. Electrochemical machining (ECM) is a process which meets these requirements. This process allows surface structuring and shaping of metal components with high shape accuracy independently of the materials strength and hardness [1].
This study presents investigations on a developed process design for manufacturing internal precision geometries by pulsed electrochemical machining (PECM) with help of multiphysics simulations. The peculiarity of this process is the shaping of the workpiece by the lateral working gap. Multiphysics simulations were carried out to understand the respective interactions between several physical phenomena. Especially, fluid dynamical effects are described in detail within the developed model. Furthermore, Joule heating and cathodic hydrogen formation are included. The fluid flow ensures the removal of heat and hydrogen and a continual supply with fresh electrolyte, respectively. The electrical conductivity of the electrolyte is modeled as a function of hydrogen volume concentration and temperature. Hence, both effects, Joule heating and hydrogen formation, influence the current density distribution which in turn determines the material removal.

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Keywords: Electrochemical machining (ECM), Finite element method (FEM), Multiphysics Simulation

1. Introduction

Various shapes like involute splines or feather key grooves are needed for example for shaft-hub connections. In this case a precise manufacturing of internal precision geometries with small tolerance ranges has to be realized. In some areas of application high stresses occur in such parts, wherefore wear resistant materials with high hardness are applied. Hence, the processing by cutting technologies can be very difficult. In the case of internal precision geometries broaching can be used. Here, the broaching tool is complex, sophisticated to manufacture and therefore expensive. Furthermore, the geometries which can be machined are limited. So there is a demand on quick and precise manufacturing processes that are flexible in machining various internal geometries and independent of the strength and hardness of the workpiece [1]. Electrochemical machining (ECM) is a process which meets these requirements.

For the manufacturing of internal precision geometries pulsed electrochemical machining (PECM) was chosen. This process is a further development of EC-lowering and is characterized by a moving cathode and pulsed electric direct current [2, 3]. Figure 1 schematically shows the principle of a pulsed electrochemical machining process. The workpiece, marked in gray, is connected to the positive electrical pole of a power supply. The cathode which is marked in yellow is connected to the negative pole and is moved with a defined feed rate towards the workpiece.

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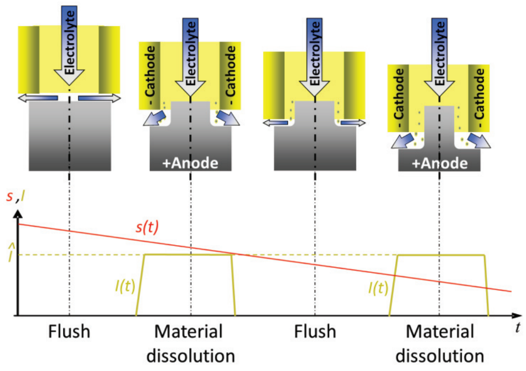

Fig. 1. Principle of a pulsed ECM process [4]

During the process a sufficiently conductive electrolyte is flushed through the working gap between workpiece and cathode. The material dissolution occurs during the electric current pulse in the pulse-on time. After that the electric current is paused, which is referred as pulse-off time. Within this time reaction products like hydrogen, dissolved material as well as process heat are transported out of the machining area, before a new electric current pulse is triggered. This strategy leads to enhanced accuracy of the production process.

In contemporary praxis, the design of the manufacturing process is a time-consuming and cost-intensive empirical procedure. As shown in a former study especially the process design of machining internal geometries is difficult, because the shaping of the workpiece is effected perpendicular to the feed direction [5]. Therefore, the peripheral working distance has to be determined, which is dependent on various process parameters. This study presents investigations on a developed process design by the help of multiphysics simulations. Due to the process design and the spatial dimensions of the working gap, fluid-dynamical quantities are experimentally hardly accessible. Hence, the main focus of the present study is on the investigation of the turbulent fluid flow during the machining process.

2. Model Description

2.1. Geometry and Materials

For machining internal precision geometries using PECM a design concept was developed. The basic structure of this concept is shown in figure 2.

For reasons of usefulness an axisymmetric geometry is regarded in this study. The main components are the workpiece, a laterally insulated cathode body on which a replaceable disk with the functional surface of the cathode is mounted, as well as various clamping elements. The replaceable disk has a thickness of 1 mm. The front working gap between disk and workpiece measures 59 µm. The cylindrical workpiece is pre-drilled. It has an outer diameter of 44 mm and a bore diameter of 25 mm. The edge of the bore features a chamfer. The aspired diameter of the bore which is to be machined by PECM is 32 mm. To realize this diameter investigations are to be performed using a cylindrical cathode disk with 31.6 mm in diameter and a constant cathode feed rate of $v_f = 1$ mm/min. The flushing concept exhibits an upward directed electrolyte flow from the predrilled bore of the workpiece through the working gap into a flushing chamber above. This chamber is not illustrated in the figure for reasons of clarity. The flushing concept guarantees a permanent exchange of electrolyte in the working gap and the removal of reaction products and heat.

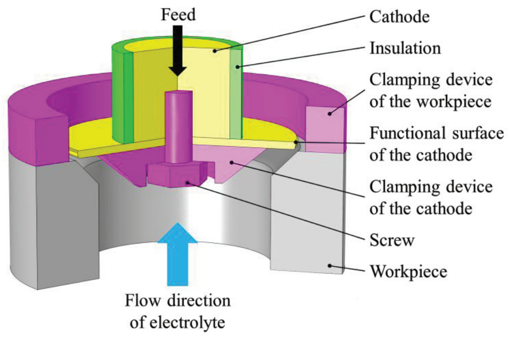

Fig. 2. Design concept for machining internal precision geometries with pulsed electrochemical machining [5]

The presented design concept of the machining process is the basis for the derivation of a 2D-axisymmetric model. Figure 3 shows the respective model geometry containing the numbering of domains and boundaries.

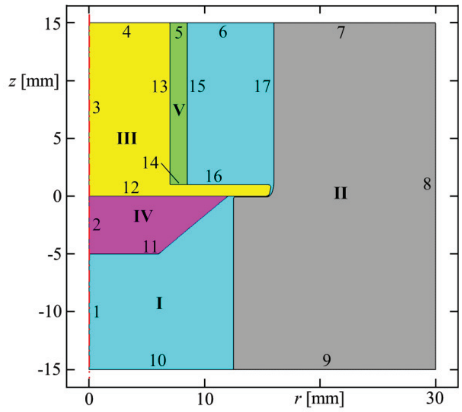

Fig. 3. 2D-axisymmetric geometry of the model containing the numbering of domains and boundaries

This predefined fixed geometry represents a model of an ongoing stationary machining process. The coordinate system is fixed at the cathode. Hence, on the workpiece the surface-normal components of the material dissolution velocity and the relative workpiece motion are in equilibrium. The predefined geometry was determined in preliminary simulations considering constant electric conductivity of the electrolyte. Due to the utilization of a predefined fixed geometry and the negligence of geometry deformation, this model is referred to as a pseudo-stationary model of PECM. The model geometry consists of five domains with the material parameters defined in table 1.