Journal of Materials Processing Tech. 258 (2018) 89–96

Contents lists available at ScienceDirect

Journal of Materials Processing Tech.

journal homepage: www.elsevier.com/locate/jmatprotec

Large allowance electrochemical turning of revolving parts using a universal cylindrical electrode

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ARTICLE INFO

Keywords:
Electrochemical machining
Material removal rate
Revolving parts
Flow field
Machining allowance

ABSTRACT

There are many large-scale revolving parts in aerospace engines, which usually require relatively large machining allowances to ensure production of the necessary shapes and sizes. Efficient removal of the machining allowances from such large-scale revolving parts, especially for hard-to-cut materials, represents a challenge for traditional mechanical processing. In this research, electrochemical turning with a universal cylindrical electrode is proposed as an efficient method to remove the large machining allowance of revolving parts. Lateral flow and internal flow patterns are exploited to ensure timely removal of electrolysis products and Joule heat. The electric field distribution shows that the current in the machining area increases significantly for the method. The flow field distribution shows that a more uniform flow velocity distribution can be obtained using an internal flow pattern. Experiments were performed to verify the proposed method. The results show that the internal flow pattern allows for faster feed rates and more stable processing, and the material removal rate may be improved significantly through use of an optimized flow pattern, especially for work-pieces with a large machining allowance. To demonstrate application, three differently shaped revolving structures were machined successfully with a radial removal allowance of 10 mm.

1. Introduction

Revolving parts are widely used in many industrial applications (Schilder et al., 2008), and these parts usually have the necessary allowance to ensure that they are of high quality to obtain the necessary shapes and sizes (Sysoev, 2001). In traditional mechanical processing, it is very challenging to efficiently remove the machining allowances of revolving part blanks (Zhang et al., 2015), especially for large-scale revolving parts in the aerospace industry, which are usually made of hard-to-cut materials (Klocke et al., 2014). Therefore, it is desirable to use an alternative manufacturing technology.

Electrochemical machining (ECM) is a non-conventional machining process in which materials are removed based on electrochemical anodic dissolution (Rajurkar et al., 1999). Compared with conventional machining, the ECM process has many unique advantages, such as high machining efficiency, no tool wear, the ability to machine heat-resistant and high-strength materials without heat-affected zones and internal stresses (Hewidy et al., 2007). The ECM is a very cost-effective and highly efficient production method, especially suitable for work-pieces of difficult-to-machine material and with large machining allowances.

Electrochemical turning (ECT) has been used to process revolving parts or surface features, whereby a shaped tool is fed into a rotating workpiece so that axially symmetrical turned parts can be manufactured (Hofstede et al., 1970). This approach simplifies many turning operations in traditional and copying lathes, and the revolving parts, especially ones having high slenderness ratios or small wall thicknesses, which would be difficult to machine in traditional mechanical processing because of the distortion effects of the cutting forces, can be machined readily. Dietz et al. (1979) investigated the ECT process using an electrode consisting of two surfaces inclined to each other at an angle. They derived a theoretical model that gave a relationship between the minimum inter-electrode gap, the feed rate, and the electrode geometry. To simplify the cathode design and save on manufacturing and time costs in ECT, a wire served as the cathode tool and the work-piece acted as the anode. The work-piece could be shaped by the relative motion between the wire and the work piece itself. To improve the stability, performance, sensitivity, and productivity of the wire ECT (WECT) process, Haridy et al. (2011) proposed an integrated framework for statistical process control and designed experiments to implement the experimental procedures and to investigate a reliable mathematical model for optimizing the WECT process. Recently, ECT has gained attention as a finishing process. Hocheng and Pa (2003)

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https://doi.org/10.1016/j.jmatprotec.2018.03.013
Received 7 October 2017; Received in revised form 12 February 2018; Accepted 18 March 2018
Available online 19 March 2018
0924-0136/

designed various types of electrode shape for electro-polishing of an external cylindrical surface. Geometric parameters for the cathode tool were optimized by measurement of surface roughness and the cathode feed rate. Surface roughness was significantly improved by using an optimized cathode geometry during the electro-polishing process, but the processing efficiency was insufficient. To improve the polishing performance of ECT for revolving parts, hybrid machining processes which can integrate several processes, and can make use of combined or mutually advantageous features, and at the same time avoid or reduce some adverse effects, have been studied by many scholars. El-Taweel (2008) integrated ECT and magnetic abrasive finishing (MAF) to produce a combined process that improved the material removal rate (MRR) and reduced the surface roughness (SR). The MRR was increased to $0.82\,g\,min^{-1}$ by using optimal machining parameters, which represents an improvement of some 148% over traditional ECT. Nonetheless, for a work-piece requiring a large allowance removal, optimization of the polishing process is difficult to attain.

In all of the above studies, the processing of the anode work-piece is a slow process in terms of removing material along the radial direction, in which the anode work-piece rotates at high speed while the cathode tool is fed progressively. Different from the above studies, a method of large allowance ECT, is proposed in this study, whereby the cathode tool first cuts into the anode work-piece to a required depth, and then the anode work-piece rotates slowly to remove the machining allowance in one go. Thus, the aims of achieving an improved removal rate for the anode work-piece, and at the same time realizing an efficient machining of the large machining allowance for difficult-to-cut materials can be achieved. A cylindrical part replaces the shaped cathode to be used as the universal cathode tool, which effectively avoids a time-consuming electrode design process (Westley et al., 2004). In the machining process, the cathode tool maintains a high rotation speed to facilitate removal of the electrolysis products. The electrolyte flow pattern, which often affects the processing stability, accuracy and surface quality, is another key factor in ECM (Xu et al., 2014). Therefore, the lateral flow pattern and the internal flow pattern were designed particularly to ensure efficient removal of electrolysis products and to achieve stable sample processing. Numerical simulations and experiments were conducted to illustrate the flow field patterns and the scope of the proposed method. The results show that the proposed method can effectively improve the removal rate of the anode work-piece using the appropriate flow field pattern. Also the removal rate can be enhanced significantly with an increase of the cathode cutting depth. The proposed method is also suitable for removing the internal allowance of revolving parts.

2. Principle and analysis

The method of large allowance ECT of a revolving part with a universal cylindrical cathode tool is shown in Fig. 1. There are two steps involved in the method. The first step is radial cut processing, in which the anode work-piece is held stationary and the cathode tool rotates at high speed with the aim of driving out the electrolysis products in an efficient manner. Simultaneously, the cathode tool keeps moving towards the work-piece at a constant feed rate. With the electrolyte being flushed through the narrow gap between the work-piece and the cathode tool, the work-piece is dissolved gradually and the required radial machining allowance is fed into place.

The second step is circumferential removal processing, in which the anode work-piece and the cathode tool rotate with a large relative speed difference. For the cathode tool, the rotation speed is the same as the first step. For the anode work-piece, however, the rotation speed is very slow given that it is fed under motion in the circumferential material removal process. With sufficient flushing of electrolyte through the machining area, the material in the circumferential direction of the work-piece is removed gradually.

It should be noted that the rotational speed of the anode work-piece in the second step needs to be precisely controlled because control of the feed motion is a key parameter during the ECM process. It is assumed that the ECM is in a balanced state with the corrosion rate being equal to the anode linear velocity. Thereby, the anode rotation speed can be calculated as follows:

$$n_a = {}^{300\eta\omega i}\!/_{\pi r} \quad (1)$$

where n_a is the anode rotatation speed (rpm), η is the current efficiency, ω is the volume electrochemical equivalent ($cm^3\,A^{-1}\,s^{-1}$), i is the current density ($A\,cm^{-2}$) and r is the initial anode radius (mm).

From Fig. 1, it can be seen that the machining gap between the anode and cathode is always kept at a small constant value in the process, which is quite different from the periodic variation of the machining gap during the conventional ECT process. According to Faraday's law, the total amount of material removed from the anode can be expressed as follows:

$$M_{theory} = \eta k Q \quad (2)$$

where k is the mass electrochemical equivalent ($g\,A^{-1}\,s^{-1}$) and Q is the integral of the current flowing through the anode surface (C).

The current density in the machining area of the anode work-piece in the proposed method was obtained numerically by using COMSOL software (version 5.1). The experimental parameters are listed in Table 1. To facilitate a comparison of the current density distribution of the anode surface, the zero position of the arc length are all set at the O point in this study, as shown in shown in Fig. 2(a) and (c), where the Y-axis coordinates are zero. From Fig. 2, it can be seen that a stable and high current density in the machining area of the anode is found, both for the radial cut and for circumferential removal. The arc lengths of the

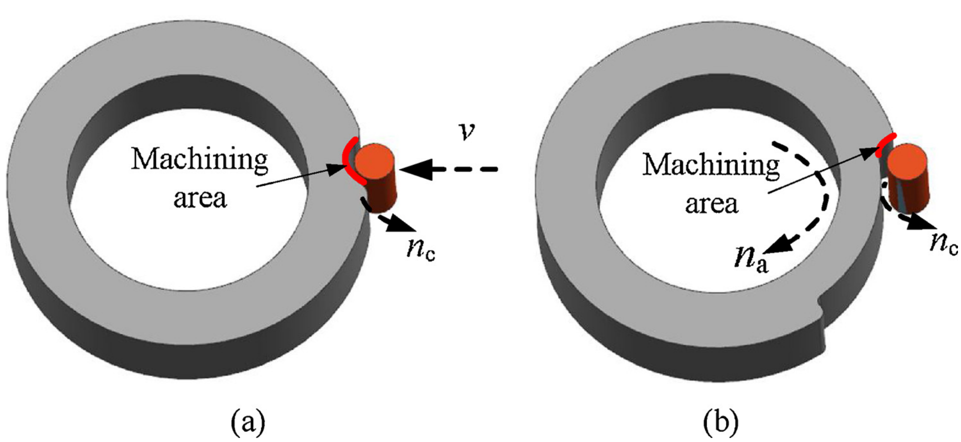

Fig. 1. Principle of large allowance electrochemical turning: (a) radial cut and (b) circumferential removal.