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# Electrochemical machining of a convex strips structure on a revolving part by using site directed power interruption

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**Abstract** Revolving parts with complex surface structures are widely used in machinery and mechanical equipment. The ECM process provides its adequacy to cut hard materials with different shapes, and its applications are widely increased, due to its outstanding advantages. In this paper, a new method for machining a convex strips structure on a cylinder by using site directed power interruption (SDPI) in the ECM process is presented. A variable correction value of the power-off time was defined and optimized to obtain the ideal interval for better machining accuracy and stability. The electric field distribution and the simulated convex profiles show that the stray current density can be reduced effectively by using the proposed method. The correction value has an important influence on the machining accuracy. A suitable correction value in the range of 0.6–1.2 s can effectively improve the machining accuracy of the convex strips structure. Experiments were also conducted to verify the proposed method. Results have confirmed that the stray corrosion on the convex strips surface is significantly reduced and the machining accuracy of convex strips structure is remarkably improved by using the proposed method with a suitable correction value in the ECM process. Finally, a convex strip with a height of 2 mm on a thin-wall revolving part was also produced successfully using a correction value of 0.9.

## 1. Introduction

Revolving parts are widely used in machinery and mechanical equipment, such as shaft components which are commonly used to transmit power and rotational motion in mechanical equipment.[1] In order to successfully implement these functions, the surfaces of revolving parts are usually accompanied by many features, such as the characteristics of key, groove, gear and thread.[2,3] In the aerospace industry, there are also

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many revolving parts with complex surface structures involved in aerospace engines, which are usually made of difficult-to-cut materials such as nickel-based super alloys and titanium alloys.[4,5] This will lead to a high-cost and time-consuming manufacturing process by using conventional mechanical machining.[6]

Electrochemical machining (ECM) is a non-traditional machining technology based on electrochemical anodic dissolution at the atomic level, which is suitable for machining difficult-to-cut materials due to advantages such as a comparable high material removal rate,[7–10] theoretically no tool wear, and its applicability for machining of complex-shaped components and structures with stress-free and crack-free surfaces.[11] Therefore, ECM is an effective method to process structures on revolving parts. Hofstede and Brekel used box-shaped and plate tool electrodes in an electrochemical turning process to obtain shaft components with a small roundness error.[12] Hocheng and Pa investigated the use of different electrode geometries on electro-polishing of cylindrical surfaces.[13] The feed rate, machining stability, and surface quality were significantly improved by optimizing geometric parameters and machining parameters. El-Taweel and Gouda used a wire cathode tool to process grooves on a cylindrical surface.[14] A wire tool constitutes frequently a cheap alternative to a full-form tool, allowing cutting of intricate shapes without the need of large power supplies. Wang, et al. utilized a shaped cathode to process a spiral turbulated hole.[15,16] The shaped cathode was prepared by means of an ultraviolet curing mask method considering the shape of the expected spiral turbulator. Chen and Zhu studied ECM for an inner ratchet wheel with a slice cathode.[17] A better machining quality was obtained by optimizing the cathode design and machining parameters. The surface roughness reached about 1.6 μm, and the process precision especially the repeat precision was improved significantly.

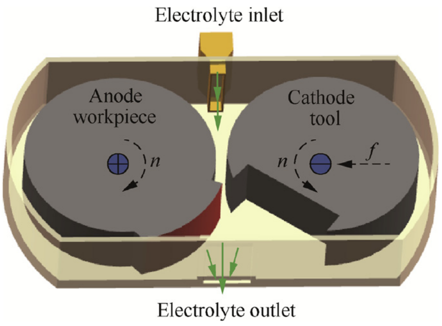

**Fig. 1** ECM process for convex strips.

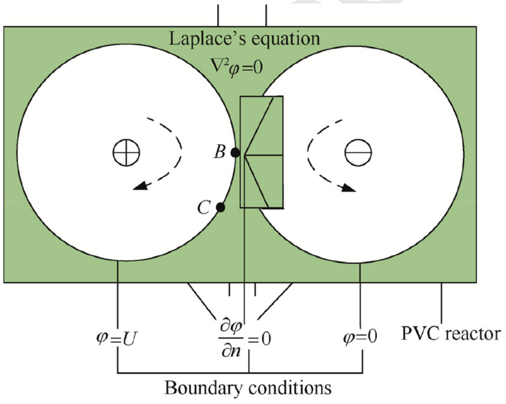

**Fig. 2** Analysis of the physical model and boundary conditions.

Zhu et al. used a revolving cathode tool with hollow windows to fabricate convex structures on a thin-walled revolving part in the counter-rotating electrochemical machining (CRECM) process.[18,19] A revolving part with complex convex structures was successfully machined without any flow tracks or residual ribs. In this paper, based on the CRECM process, a new method of site directed power interruption (SDPI) is applied for machining of a convex strips structure on a cylinder. During the SDPI process, the $T_{\text{off}}$ time is closely related to the rotation speed, the radius of the work-piece, and the width of the convex strips. A variable $a$ is used to adjust the $T_{\text{off}}$ time to ensure better machining accuracy and stability. Numerical simulations and experiments were conducted to illustrate the proposed method. Results showed that the non-machined area on the top surface of the convex strips on the anode work-piece could be obviously protected by using SDPI, and the machined quality of the convex strips structure was significantly improved. The proposed method is also a promising way for machining other structures on revolving parts such as stiffener, groove, keyway, spline and gear.

## 2. Principle and analysis

### 2.1. Stray corrosion of the convex strips structure in the ECM process

Fig. 1 shows a schematic of the ECM process for convex strips on the anode work-piece. A cylindrical electrode with a groove is designed to be a cathode tool. During the ECM process, the cylindrical anode work-piece and the cathode tool rotate relative to each other at the same rotation speed $n$. Meanwhile, the cathode tool keeps moving towards the workpiece at a constant feed rate $f$. With sufficient electrolyte flow through the working area, the redundant materials on the anode surface are gradually removed under electrolysis. As a result, a convex strips structure is fabricated on the corresponding area of the cathode groove. However, due to the poor localization effects of anodic dissolution in ECM, the top surface of the convex strips structure on the anode (the red[1] area in Fig. 1) will inevitably suffer serious stray corrosion when both the anode work-piece and the cathode tool are immersed in the electrolyte.

The current distribution during the ECM process was numerically simulated. As the whole process takes place in a reactor that is made of a PVC material, the sidewall and bottom face of the groove on the cathode are electrically insulated from the electrolyte. With some assumptions,[20] the distribution of the electric potential $\varphi$ in the electrolyte domain $\Omega$ and the boundary conditions are shown in Fig. 2, where $B$ and $C$ are two sample points that represent the midpoint and edge point of the non-machining area, respectively. The relative conditions of electric field simulation are shown in Table 1.

The current density $i$ can be described by Ohm's law as

$$i=\kappa\nabla\varphi \tag{1}$$

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[1] For interpretation of color in Fig. 1, the reader is referred to the web version of this article.

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