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Reduction of stray currents in counter-rotating electrochemical machining by using a flexible auxiliary electrode mechanism

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ABSTRACT

Counter-rotating electrochemical machining (CRECM) is a new ECM technique which can be used to fabricate convex structures on thin-walled revolving parts. During the CRECM process, the non-machined top surface of the convex structure inevitably suffers from stray current attack, resulting in poor machining quality. To reduce the stray currents in CRECM, a flexible auxiliary electrode mechanism has been developed. A positive potential difference is applied between the auxiliary electrode and the anode workpiece. The electric field distribution and the simulated convex profiles show that the stray current density can be reduced effectively by using an auxiliary electrode. The magnitudes of the stray current densities on the non-machined area decrease with increasing potential difference. A suitable positive potential difference of 10 V is able to completely eliminate the stray currents from the entire non-machined surface of the convex structure. Experiments have also been conducted to verify the proposed method. It was confirmed that the stray corrosion on the convex surface is significantly reduced and the machining quality is remarkably improved by using a flexible auxiliary electrode mechanism.

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1. Introduction

Aero-engine casings are thin-walled revolving parts composed of many convex structures distributed over the outer surface, and have become some of the most important components in the aerospace industry. The revolving casing part is usually made of difficult-to-cut materials such as nickel-based super alloys, titanium and inter-metallic compounds. Due to the complexity of the structures and their weak rigidity, many difficulties and challenges remain for conventional mechanical machining (Zhang et al., 2015). Electrochemical machining (ECM) is cost-effective in processing difficult-to-cut materials, and has numerous advantages, such as a high material removal rate, no tool wear, a good surface integrity and the ability to fabricate components with complex geometries (Klocke et al., 2014). To fabricate complex convex structures on the thin-walled revolving part, a new ECM technology, counter-rotating ECM (CRECM), was used by Wang et al. (2015a,b). A revolving cathode tool with hollow windows was employed to rotate relative to the anode workpiece at the same rotational speed. All the convex structures could be machined by using a single tool electrode, and the machining efficiency was significantly improved.

The machining accuracy, however, in ECM is affected to a great extent by stray corrosion. As reported by Rajurkar et al. (1999), stray corrosion usually occurs at the surface adjacent to the machining area which is exposed to the electrolyte flow and electric field, resulting in undesirable dissolution and inferior accuracy control. In the CRECM process, the anode workpiece and cathode tool are immersed in the electrolytes, and the side gap is expanded during the rotation of the electrodes. As a result, the non-machined top surface of the convex structure will inevitably suffer stray current attack.

In conventional sinking ECM, various attempts have been made to improve the machining accuracy. DeSilva et al. (2003) used low electrolyte concentrations to obtain better accuracy. The influence of electrolyte concentration on the ECM accuracy was derived empirically. A greater degree of localization and higher accuracy can be achieved with low concentration than with high concentrations. Pulsed power has been successfully used by Wang et al. (2004) to localize the anodic dissolution and decrease the gap width. Experimental results for industrial applications using high-precision pulses indicate that higher frequency and shorter pulse width can yield better accuracy and surface quality. Recently, hybridization techniques have been applied to ECM to achieve better performance. Hewidy et al. (2007) used a tool electrode with low frequency vibration in ECM to produce a flushing action and provide a positive effect by changing the physical conditions in

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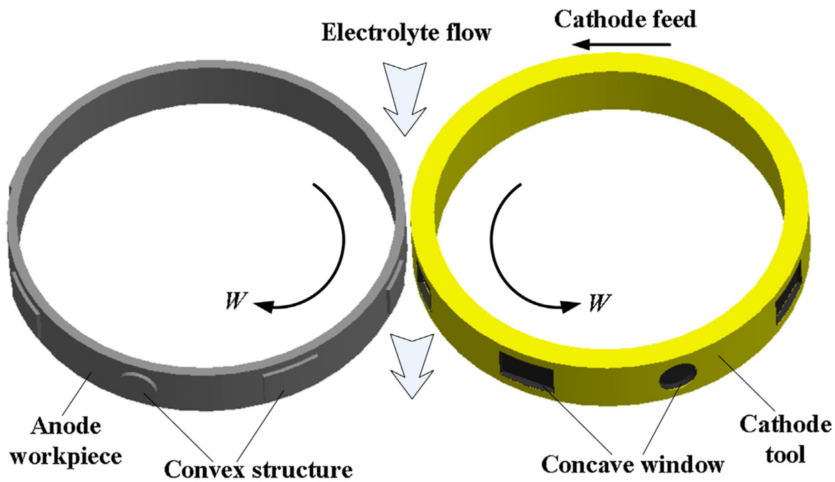

Fig. 1. Schematic diagram of the CRECM process.

the inter-electrode gap. Nguyen et al. (2012) combined micro-EDM (electrical discharge machining) and micro-ECM to mitigate the adverse effects. The quality of both surface finish and machining accuracy was improved by the use of a hybrid machining process. The micro-holes drilled using a combined EDM-ECM process had much better machining and shape accuracy than conventional micro-ECM-fabricated holes (He et al., 2013). Furthermore, laser-assisted ECM as proposed by Pajak et al. (2006) can significantly limit stray corrosion as the laser beam is able to direct the dissolution to specifically targeted areas.

Auxiliary electrodes in particular have been successfully used to change the electric field distribution in the inter-electrode domain to reduce stray current attack. In the electrochemical drilling process, Fang et al. (2014) applied a potential difference between the auxiliary electrode and the anode to improve the hole exit accuracy. The currents could be concentrated at the tool tip using a suitable value of the potential difference and the current direction was reversed on the workpiece surface. A dual-pole tool with a metallic bush outside the insulated coating of a cathode tool was invented by Zhu and Xu (2002) to bring down the current density at the side gap of the machined hole. As a result, removal of the stray material there was significantly reduced. With a thief anode fixed at the side wall of the cathode tool, the distribution of the current lines changed and hence the magnitude of the stray current attack came under control (Jain et al., 2005).

A review of the literature on auxiliary electrodes revealed that most auxiliary electrodes used in previous studies were either stationary or fixed on the cathode tool. A fixed auxiliary electrode can significantly reduce the magnitude of stray currents. However, as the fixed auxiliary electrode usually has some distance from the non-machined area, it is therefore sometimes difficult to eliminate the stray currents.

In this study, a flexible auxiliary electrode was used instead of a fixed auxiliary electrode inside the concave window in the CRECM process. The insulating sheets on the auxiliary electrode could then immediately make contact with the non-machined top surface of the convex structure as soon as it rotated into the machining area, which is better for reducing stray currents. An equal potential and a positive potential difference between the auxiliary electrode and the anode workpiece were employed respectively. Numerical simulations and experiments were conducted to illustrate the proposed method. The results showed that the stray currents on the non-machined top surface of the convex structure could be dramatically reduced by using a flexible auxiliary electrode mechanism. In particular, with an appropriate applied positive potential difference, the stray currents could be completely eliminated and the machined quality of the convex structure was significantly improved. A flexible auxiliary electrode can also be used in some other ECM schemes such as conventional sinking ECM.

2. Principle of a flexible auxiliary electrode mechanism

Fig. 1 shows a schematic diagram of the CRECM process. A revolving cathode tool with concave windows of various shapes was designed. During the CRECM process, the cathode tool rotates relative to the anode workpiece at the same rotational speed, and simultaneously moves towards the anode workpiece at a constant feed rate. With sufficient flushing of electrolyte through the working area, the materials on the anode surface are gradually dissolved, and convex structures are formed on the corresponding areas of the concave windows. Here, the cathode tool is made of 304 stainless steel, and the material of the anode workpiece is a type of nickel-based super alloy, Inconel 718, which is widely employed in the aerospace industry.

As the anode workpiece and cathode tool are counter-rotating during the CRECM process, the only alternative installation location for the auxiliary electrode is inside the concave window on the cathode tool. Fig. 2 shows a schematic diagram of a flexible auxiliary electrode mechanism in three different positions. An auxiliary electrode is mounted on a flexible spring mechanism fixed at the cathode tool. The auxiliary electrode is made of titanium with a platinum coating on the surface. Titanium has a relatively high decomposition potential, and the platinum coating is made of an inert metal which that is almost insoluble. Thus, the auxiliary electrode is insoluble during ECM, and in theory can be reused indefinitely. The inner surfaces of the concave window are insulated. Two thin insulating sheets are embedded in the grooves of the auxiliary electrode (Fig. 3). The insulating sheets protrude slightly from the top surface of the auxiliary electrode so that there is a small gap between the auxiliary electrode and the non-machined top surface during rotation.

The auxiliary electrode initially protrudes a certain distance above the surface of the cathode tool. When rotating into the machining area, the insulating sheets on the auxiliary electrode can immediately make contact with the non-machined top surface of the convex structure. Owing to the elastic effect of the spring, the insulating sheets on the auxiliary electrode can keep in touch with the top surface of the convex structure until it rotates out of the machining area.

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