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Flow Field Design in Electrochemical Machining of Diffuser

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Abstract

The diffuser which is usually made from hard-to-machine nickel-based and titanium-based alloys is a key component in the aero engine. In the electrochemical machining, the electrolyte flow mode has great effect on the machining stability and efficiency. This paper presents several flow modes for an aero engine diffuser on which the blades are long and thin. Then the flow field distributions of these flow modes are simulated by using the computational fluid dynamics software. The simulation results show that the mode in which the electrolyte flows from leading edge to trailing edge is appropriate. Furthermore, the fixture for this optimal flow mode is designed and fabricated, and the corresponding experiment is carried out. There is no flow mark on the diffuser sample surface and the process is stable. The experimental results show that this flow mode is appropriate and can be also used in other similar aero engine components.

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Keywords: Electrochemical machining; flow field; diffuser; electrolyte; design

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1. Introduction

Electrochemical machining (ECM) is an unconventional manufacturing technology, and its major advantages are high material removal rate, no tool wear, and good surface quality without any white layer as well as no mechanically affected zones. Therefore, it is an economical and effective approach to manufacturing aero craft components such as diffuser [1-2].

In ECM processes, electrolyte flow mode has great effect on the process stability and efficiency. Several new flow mode, such as W-shape mode, Π-shape mode, and dynamic additional flow [3], were proposed. Various innovative measures as progressive pressure [4], and pulse electrolyte were adopted [5]. Many scholars have analyzed distribution of characteristic parameter on flow field in the inter electrode gap, Dabrowski researched on the two-dimensional electrolyte flow in ECM [6]. Fujisawa et al. [7], Van Damme et al. [8], Klocke et al. [9, 10], Westley et al. [11], and Tang et al. [12] already proposed numerical models and then delivered their findings in literature.

The above researches reflected that an appropriate flow mode and even flow field distribution was very crucial in ECM. This paper proposes an ECM manufacturing method for diffuser with cathode axial feeding, and presents several flow modes to find a suitable one for processing. The flow field distribution in flow channel is then simulated and the characteristic parameter in inter electrode gap is analyzed to obtain the best flow mode. Finally, experiments were carried out to verify the effectiveness of the flow mode.

Nomenclature

U_i	*i*th components of the mean electrolyte velocity vector
x_i	*i*th Cartesian coordinate
ρ	electrolyte density
P	mean electrolyte pressure
u_i'	*i*th fluctuation of the electrolyte velocity component around its mean value
v	kinematic viscosity
$\overline{u_i'u_j'}$	Reynolds-stress tensor
k	turbulent kinetic energy
ε	dissipation rate
V	velocity variance
n	sampled point number

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2. Flow mode description for ECM of diffuser

An ECM manufacturing method for diffuser with cathode axial feeding is proposed for machining the channels between radial blades. The sketch of this method is shown in Fig.1. In the process, tool cathode moves towards diffuser workpiece with a certain feed rate. The metallic material dissolves when a power supply is applied on the cathode and workpiece. Meanwhile, electrolyte is continuously pumped through the inter-electrode gap with high-speed to carry away the dissolved metal and remove the Joule heat. The channel between two blades is then forming to the final profile gradually. As one channel is manufactured, diffuser is rotated by control system into a definite angle for machining another channel. The process continues until all of the channels are fabricated.

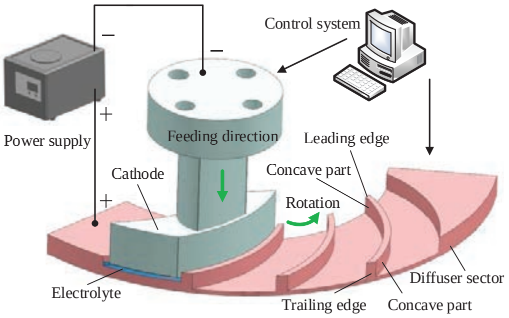
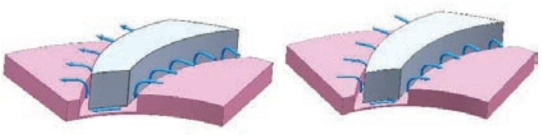
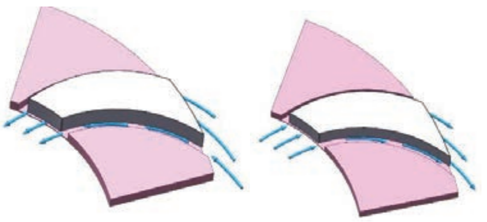


Fig.1 Sketch of the diffuser ECM process with cathode feeding in the axial direction

In ECM process for diffuser, a suitable flow mode is very significant to acquire uniform flow field. While an improper flow mode may produce area with bad flushing conditions, leading to instability of the process even shortcut phenomenon. Therefore, this paper aims to obtain an appropriate flow mode. Because the blade is twisted and the channel between two blades is large, it is difficult for electrolyte to flow through the whole inter-electrode gap evenly and it is crucial to design a good flow mode in diffuser ECM. This study presents four different flow modes combining with the diffuser structure which are described in Fig.2. The electrolyte motion direction of these four flow modes are defined as below. (1) Mode 1, electrolyte inlet is at the side of convex part (VP) while electrolyte outlet is at the other side of concave part (CP). The fluid flows through VP channel, inter-electrode gap, CP channel, and goes to the electrolyte cell from the outlet (Fig.2 (a)). (2) Mode 2, electrolyte flows from CP channel to VP channel and its main motion direction is opposite to Mode 1 (Fig.2 (b)). (3) Mode 3, electrolyte inlet is at the trailing edge (TE) side while electrolyte outlet is at the leading edge (LE) side. The fluid passes through the machining gap from TE to LE (Fig.2 (c)). (4) Mode 4, the direction of electrolyte motion is from LE to TE which is contrary to Mode 3 (Fig.2 (d)).



(a) Mode 1 (VP to CP) (b) Mode 2 (CP to VP)



(c) Mode 3 (TE to LE) (d) Mode 4 (LE to TE)

Fig.2 Electrolyte flow modes

The motion structure of these flow modes is entirely different, so the flow field distribution in the machining gap is diverse. In order to observe the characteristics of the flow field to choose the best mode, simulation is going to be conducted in the following part.

3. Simulation and discussion

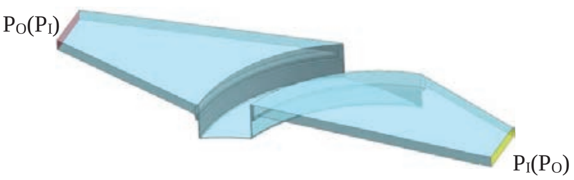
3.1. Simulation process

To simplify the proposed model, several assumptions are made as follows. First, the electrolyte flow is continuous and incompressible. Second, the ECM process is in the equilibrium state. The momentum conservation and mass conservation equations, which are generally used for the turbulent flow in ECM, are described as follows [3]:

$$\frac{\partial U_i}{\partial x_i} = 0 \tag{1}$$

$$U_j \frac{\partial U_i}{\partial x_j} = -\frac{1}{\rho}\frac{\partial P}{\partial x_i} + \frac{\partial}{\partial x_j}\left(\nu\left(\frac{\partial U_i}{\partial x_j} + \frac{\partial U_j}{\partial x_i}\right) - \overline{u_i' u_j'}\right) \tag{2}$$

There are many experimental results indicating that the turbulent flow is necessary for the stability of ECM process [4]. The renormalization group (RNG) k–ε turbulent model, which is suitable for curved wall flow, is then introduced to simulate the flow field in the channel with the above equations. The simulation models of presented flow modes are established when the process is in the equilibrium state (Fig.3). As described in Fig.3, simulation models of Mode 1 and Mode 2 is the same while electrolyte inlet and outlet planes are different. Plane P_I represents electrolyte inlet and plane P_O is the electrolyte outlet. Simulation models of Mode 3 and Mode 4 is the same, yet electrolyte inlet and outlet planes are just opposite. The boundary conditions for simulation will be determined by setting pressure values on inlet and outlet planes, and the specific values are that P_I=0.8 MPa and P_O=0.1 MPa according to the preliminary work. The inter-electrode gap is the electrochemical dissolution region, in which the flow field distribution is of most interest in this study. Plane P, whose position is in the middle of the inter-electrode gap, is then chosen to observe flow field distribution in the following article.



(a) Mode 1 (Mode 2)