

# Flow Field Simulation and Experiment Study of ECM Variable Cross-Sectional Hole

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**Abstract**—In order to solve the problem that ECM (electrochemical machining) of variable cross-sectional hole is easy to short circuit and the flow pattern is large, a rotating flow field electrochemical machining method is proposed. In this paper, the gap flow field model of variable cross-sectional hole is established, the flow field with different oblique angle of liquid hole is simulated and analyzed. The simulation results show that designing rotating flow field with the outlet hole oblique angle of 45° can improve the electrolyte distribution in machining gap and greatly reduce the low speed zone. Under the conditions of processing voltage 10V, electrolyte inlet pressure 1.6MPa, electrolyte temperature 30°C and cathode feed speed 5mm/min, the electrochemical machining of variable cross-sectional hole was carried out by using the optimized cathode. The results show that the gap flow field simulation can optimize the cathode structure, shorten cathode design cycle and reduce experiment cost.

**Keywords**-Variable Cross-Sectional Hole; ECM; Flow Field; Technological Experiment

## I. INTRODUCTION

Variable cross-sectional hole parts are widely used in the field of mechanical equipment. This kind of parts have the

characteristics of high material hardness, non-equal gap distribution of hole inner diameter and so on. Due to the limitation of tool cutting, it is difficult to use traditional machining. Electrochemical machining has the advantages of once forming, high machining efficiency, good surface quality, no cathode loss and so on. It is widely used in the equipment manufacturing[1].

Scholars at home and abroad have made great efforts to improve the forming accuracy and application range of electrochemical machining. For the application of the intractable material, Holstein et al. used to study the tungsten alloy material by the electrochemical processing technology[2]. Tang et al. studied the application of electrolytic machining in special stainless steel materials, which improved the material removal rate and surface accuracy of electrochemical machining[3]. Burger et al., realized the finishing of conical micropores in LEK94 materials[4]. Qu et al. proposed the electrochemical machining of Ti6Al4V material with pulsating electrolyte, and the surface roughness after the machining reached 0.53μm[5]. Schubert et al. studied on the anodic dissolution behavior of tungsten carbide in alkaline electrolyte by electrochemical machining[6]. Electrochemistry, electric

field, flow field and other factors that interact with each other exist in the electrochemical machining gap, and various physical fields can be simulated by finite element analysis[7-8]. Some scholars have carried on the simulation analysis to the electrochemical machining flow field [9-11]. Many scholars have carried out amount of research work on electrolyte [12-13]. The technology of hole electrochemical machining will be developed in the direction of high efficiency, high surface quality and high precision [14-17]. Sathish et al. carried out the optimization of micro drilling process in stainless steel [18]. Leese et al. Described the important influencing parameters in micro electrochemical machining [19]. Mi realized the machining of the tapered hole with a diameter of 7.8mm with a rotating cathode[20].

In this paper, a rotating electrolyte flow mode is proposed. Through the simulation of gap flow field in electrochemical machining, the optimal design of cathode structure of variable cross-sectional hole is realized. The parts are finally processed after verification by experiment.

## II. DESIGN OF ELECTROCHEMICAL MACHINING VARIABLE CROSS-SECTIONAL HOLE

The variable cross-sectional hole part is mainly composed of two sections of intersecting conical surfaces. The material is 30CrNi2MoVE and the hardness is 255HBS10/3000,The chemical composition is shown in Table 1.

TABLE I. CHEMICAL COMPOSITION OF 30CrNi2MoVE

element	Content/%
C	0.3
Si	0.27
Mn	0.45
Cr	0.75
Ni	2.2
Mo	0.25
V	0.23
Fe	The rest

In this paper, the mobile electrochemical machining method is used to realize the one-time machining of the parts. The cathode model of electrochemical machining is shown in Fig 1.

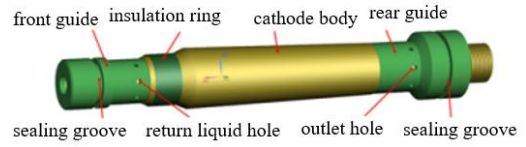


Figure 1. The cathode model

By establishing the machining gap model of different cathode outlet hole oblique angle, and using COMSOL to analyze the flow field of machining gap.

## III. MODELING AND SIMULATION OF ELECTROCHEMICAL MACHINING GAP

### A. Mathematical model

In order to facilitate research, it is assumed that the machining gap is an ideal state and the electrolyte is an incompressible fluid. The influence of solid particles in the gap is ignored, and its dynamic viscosity does not change with the change of speed. Meanwhile, the influence of temperature change is ignored, and the machining process is steady. The processing conditions were set as follows: the electrolyte was 15% NaCl solution, and the kinetic viscosity coefficient  $\mu$  was  $1.0 \times 10^{-3} Pa \cdot s$ , density  $\rho$  is  $1.1 \times 10^3 kg/m^3$ .

The distance of electrolyte flow in the processing area is not big, and its flow is constrained by mass conservation law and momentum conservation law. The flow model meets the *Navier – Stokes* equation:

$$\rho(u \cdot \nabla) = \nabla \cdot [-\rho I + K] + F \quad (1)$$

$$\rho \nabla(u) = 0 \quad (2)$$

where,  $\rho$  is the electrolyte density,  $u$  is the electrolyte flow velocity,  $I$  is the unit tensor,  $F$  is the volume force of the unit mass fluid, and the volume force  $F$  of the electrolyte is very small in the machining gap, which can be ignored.

The transmission equation of  $K$  is as follows:

$$\rho \frac{\partial k}{\partial t} + \rho u \cdot \nabla k = \nabla \cdot \left( \left( \mu + \frac{\mu_T}{\sigma_k} \right) \nabla k \right) + P_k - \rho \varepsilon \quad (3)$$

The transmission equation of  $\varepsilon$  is as follows:

$$\rho \frac{\partial \varepsilon}{\partial t} + \rho u \cdot \nabla \varepsilon = \nabla \cdot \left( \left( \mu + \frac{\mu_t}{\sigma_\varepsilon} \right) \nabla \varepsilon \right) + C_{\varepsilon 1} \frac{\varepsilon}{k} P_k - C_{\varepsilon 2} \rho \frac{\varepsilon^2}{k} \quad (4)$$

Where, the turbulent generation term,

$$P_k = \mu_t (\nabla u : (\nabla u + (\nabla u)^T)) - \frac{2}{3} (\nabla \cdot u)^2 - \frac{2}{3} \rho k \nabla \cdot u \quad (5)$$

The model constant values in the formula are shown in table 2 [21].

TABLE II. CONSTANTS IN THE STANDARD K- EPSILON MODEL

constant	value
$C_{\varepsilon 1}$	1.44
$C_{\varepsilon 2}$	1.92
$C_\mu$	0.09
$\sigma_K$	1.0
$\sigma_\varepsilon$	1.3
K	0.41

### B. Physical model

The physical model of variable cross-sectional hole electrochemical machining in this paper is shown in Fig 2. The cathode adopts push feed. During machining, the electrolyte flows in from the exit hole on the rear guide, and then flows out from the past hole on the front guide. There are liquid exit holes distributed along the radial direction on the rear guide, and liquid return holes on the front guide, to ensure sufficient machining clearance pressure. The flow direction of electrolyte in the machining gap is consistent with the cathode feed direction, make the flow field more convergent and the machining effect better.



Figure 2. Physical model of variable cross-sectional hole electrochemical machining

### C. Geometric models and mesh division

The region through which the electrolyte flows is the geometric model of the electrolytic machining flow field. The geometric model of the flow field based on UG is shown in Fig.3.



Figure 3. Geometric model profile of flow field

The flow field was simulated by COMSOL. In order to get accurate results and fast calculation speed, the geometric model is meshed. The electrolyte outlet, inlet and boundary layer are divided in detail and corner is encrypted. Selected conventional free tetrahedral mesh for the rest of the areas. The mesh generation results are shown in Fig. 4.



(a) OVERALL MESH DIVISION (b) ELECTROLYTE INLET MESH

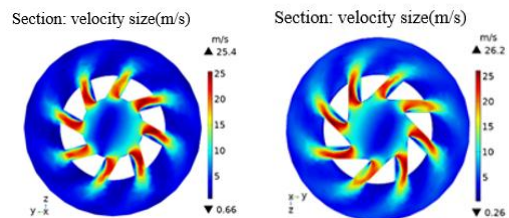
Figure 4. Results of mesh generation

## IV. ANALYSIS OF SIMULATION RESULTS

The outlet hole and radial inclination Angle  $\alpha$  were set as  $0^\circ$  and  $45^\circ$  respectively. The flow field simulation was carried out under the conditions of inlet pressure of electrolyte 1.6MPa, outlet pressure of standard atmosphere and electrolyte temperature of  $30^\circ\text{C}$ .

### A. Electrolyte inlet flow field distribution

As shown in Fig. 5, we can clearly see that The inlet velocity of oblique outlet hole at  $45^\circ$  angle is maximum and more uniform.



(a)  $0^\circ$  OUTLET HOLE (b)  $45^\circ$  OUTLET HOLE

Figure 5. Flow field distribution of electrolyte inlet with different Angle

### B. Gap flow field distribution

As shown in Fig. 6 the electrolyte flow line of the 45° angle outlet hole flows from the second taper end to the small end, the electrolyte flow line on the cathode and the workpiece surface is more sufficient, and the flow field low velocity area is greatly reduced.

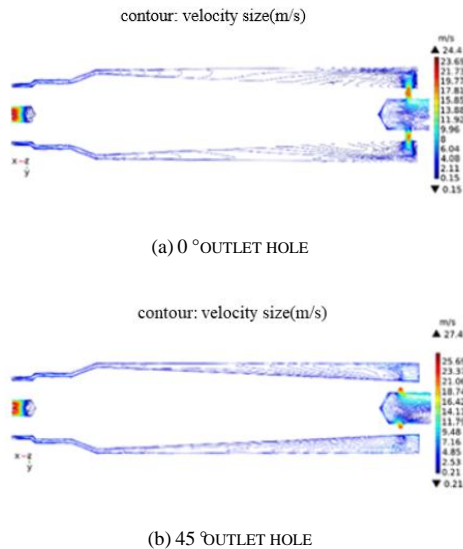


Figure 6. Distribution of gap velocity with different Angle

To sum up, when the Angle of exit hole is 45°, the overall effect of machining gap flow field is better, which is conducive to eliminating the phenomenon of fluidity on the inner surface of the workpiece after processing, and can timely take away the products and heat generated by machining gap erosion, so as to meet the requirements of mobile electrochemical machining.

### V. PROCESS EXPERIMENT

According to the simulation results, the experiment was carried out under the following conditions: the cathode with 0° and 45° oblique angle of liquid hole is used, the material is H62 brass. The insulation part is epoxy resin. The electrolyte is 15%wt NaCl solution. Under the 10V processing voltage, 1.6MPa inlet pressure of electrolyte, 30°C electrolyte temperature and 5mm/min cathode feeding speed, the variable cross-sectional hole electrochemical machining experiment was conducted. Samples of different cathode processing were shown in Fig.7.

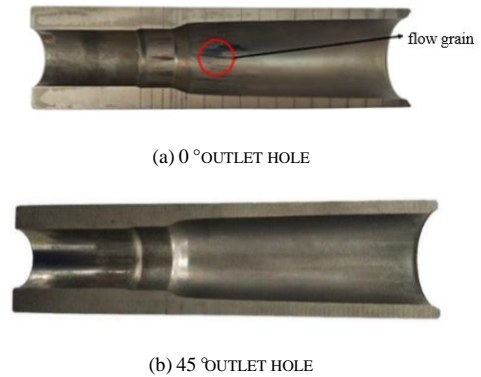


Figure 7. Samples processed by different cathodes

Under the same parameters, the internal surface of the workpiece processed by cathode with 45° slant liquid hole was free of fluidity, and the surface roughness was up to Ra0.8μm. Experimental indicated that the designed rotating flow field can effectively improve the clearance flow field and eliminate the phenomenon of flow grain on the workpiece surface after machining.

### VI. CONCLUSION

This paper proposed a rotating flow field electrochemical machining method. Through the simulation of gap flow field in electrochemical machining, the optimal design of cathode structure of variable cross-sectional hole is realized, and the process experiment is carried out. The following conclusions were obtained:

1) When the angle of exit hole is 45°, the overall effect of rotating flow field is better, which can effectively improve the uniformity of electrolyte distribution in machining gap and greatly reduce the low-speed zone of flow field on cathode and workpiece surface.

2) Under the conditions of 10V machining voltage, 30°C electrolyte temperature, 1.6MPa electrolyte pressure and 5mm/min cathode feeding speed, the electrolyte was 15%wt NaCl solution. The optimized cathode was used to conduct the electrochemical machining experiment of variable cross-sectional hole. After machining, the internal surface was free from the phenomenon of fluidization and the surface roughness was up to Ra0.8μm.

3) Through simulation, the gap flow field of electrochemical machining can be optimized and the cathode

structure can be modified, which can effectively shorten the design cycle of cathode and reduce the experimental cost.

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