

Study on Numerical Simulation of Electrochemical Machining Ring Narrow Groove

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Abstract—For annular narrow slot structure of electrochemical machining process test cycle is long, type face the problem of difficult to predict, establish mask electrochemical machining process of the electric field, flow field and temperature field coupling mathematical model, using COMSOL Multiphysics to numerical simulation of multiple physical fields, get the machining gap in electrolyte, current density, velocity and pressure distribution. The results show that the multi-physical field coupling simulation technology can correctly budget the electrochemical machining process, provide a theoretical basis for the actual machining process parameters, and is of great significance to improve the quality and efficiency of electrochemical machining with narrow groove structure.

Keywords—Annular Narrow Slot; Mask Electrolytic Machining; Multi-physical Field Coupling; Numerical Simulation

I. INTRODUCTION

Due to the deep groove shape and high hardness of materials, the traditional processing technology has problems such as difficulty in chip removal, severe tool wear, internal stress on the workpiece surface, poor machining accuracy and surface quality [1]-[2].

In order to ensure the processing efficiency, the stability of the electrolytic machining process of the trough-like workpiece is the content of the study [3]-[6]. In this paper, a mathematical model of electric field, flow field and temperature field coupling is established by means of mask electrochemical machining the above model is numerically simulated based on COMSOL Multiphysics, and the variation law of each parameter in the machining process is analyzed. According to the simulation result, the feasibility of the mask electrolytic machining of the annular narrow groove is verified, the optimal ring groove process parameters are obtained, the slotting precision and the surface quality are improved, and a new method and a theoretical foundation are provided for the in-depth study of

the electrolytic processing of the complex special-shaped cavity.

II. THEORETICAL ANALYSIS OF MASK ELECTROCHEMICAL MACHINING

A. The Principle of Mask Electrolysis

The principle of mask electrolytic machining ring cell is shown in Fig.1. Mask insulation, anodic workpiece exposed area and electrolyte contact follow Faraday's law, continue to dissolve until etched to meet the requirements of the shape [7]-[8].

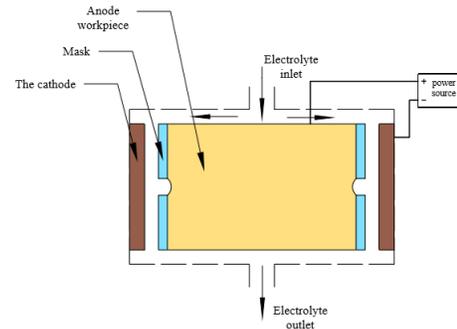


Figure 1. Schematic diagram of electrolytic machining of annular narrow cell mask

B. Analysis of Forming Law of Mask Electrochemical Machining

In the process of mask electrolytic machining, the surface shape and size of the cathode will not change when the cathode is fixed. As shown in Fig.2, the initial gap between the anode workpiece and the cathode is Δ_0 . After t time, the depth of the machining slot is H .

After calculation, the depth of the ring groove H after the mask electrochemical machining time t is [9]:

$$H = \sqrt{2\eta\omega\kappa(U - \delta E)t + C} - \Delta_0 \quad (1)$$

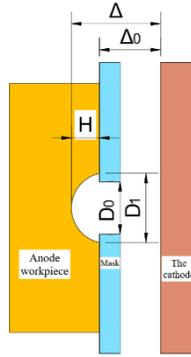


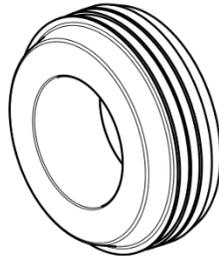
Figure 2. Analysis Diagram of Mask Electrolytic Localization

In the process of electrochemical reaction, the distribution of electric field, flow field and temperature field in the gap between electrodes is very complex, and its parameters interact with each other and change at all times, which makes it difficult to predict the anodic dissolution characteristics accurately. Therefore, it is necessary to simulate the multi-physical field coupling numerical simulation of mask electrolytic machining process.

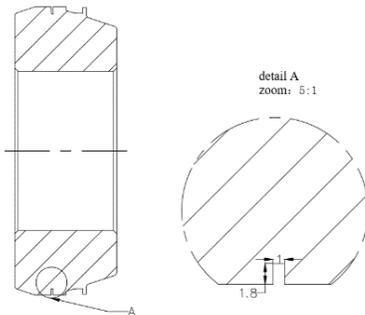
III. MULTI-PHYSICAL FIELD COUPLING MATHEMATICAL MODEL

A. Establishment of Geometric Model

The object of processing in this paper is the circular groove in the winding wheel, the overall structure of which is shown in Fig.3(a) below, and the narrow groove structure and enlarged figure are shown in Fig.3(b) below.



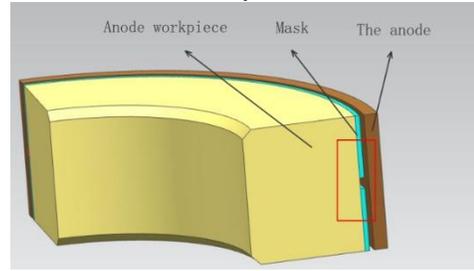
(a) Integral structure of winding wheel



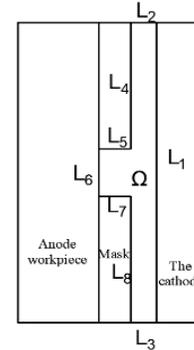
(b) Narrow slot structure and magnification diagram

Figure 3. Annular narrow slot geometric model

The three-dimensional section view of the electrochemical machining model of the ring groove mask is shown in Fig.4(a). Since the whole model is annular, it is assumed that the coupling field in each section is the same. In order to facilitate analysis and calculation, the model is simplified in two dimensions. The red border of interpolar gap in Fig.4(a) is taken for analysis. The two-dimensional mathematical model is shown in Fig.4(b), where L_2 , L_3 is the free boundary of machining gap, L_1 is the cathode boundary, L_6 is the anode workpiece boundary, L_4 , L_5 , L_7 , L_8 is the insulation boundary.



(a) Three-dimensional model of ring groove machining



(b) two-dimensional mathematical model

Figure 4. Machining area Model of Ring Groove

B. Multi-physical field coupling analysis

The electrochemical machining process of ring cell and its complexity involve flow field, electric field, temperature field and structural field, which vary and affect each other at any time [10].

The flow field and electric field affect the conductivity and current efficiency, and the conductivity increases with the increase of temperature, which leads to the change of workpiece erosion rate and then affects the distribution of electric field and flow field [11]-[12]. The electric field model (2) and the flow field model (3) are substituted into the current density formula (4) to obtain the coupling equation (5) of the flow field and the electric field [13]-[15]:

$$\nabla^2 \phi = \frac{\partial^2 \phi}{\partial x^2} + \frac{\partial^2 \phi}{\partial y^2} = 0 \quad (2)$$

$$\begin{cases} \rho \frac{\partial v}{\partial t} + \rho(v \cdot \nabla)v = -\nabla p + (\nu + \nu_r) [\Delta v + (\Delta v)^T] \\ \rho \nabla \cdot v = 0 \end{cases} \quad (3)$$

$$i = -\sigma \cdot \nabla \phi \quad (4)$$

$$\rho C_p \left(\frac{\partial T}{\partial t} + v \cdot \nabla T \right) - \nabla \cdot (\sigma_i \nabla T) = -\sigma \cdot \nabla^2 \phi^2 \quad (5)$$

IV. NUMERICAL SIMULATION ANALYSIS

The parameters of the processing area are, the groove width is 1mm, the depth of the groove is 1.8mm, the thickness of the mask is 0.1mm, the selection quality of the electrolyte is 10% NaNO₃ solution [16].

Add current density, turbulence, fluid heat transfer, moving grid physical field to COMSOL Multiphysics, In the current density field, and the grid is divided, and the single-field and the coupling field are simulated and simulated by changing the different processing parameters.

A. Analysis on the influence law of process parameters at the initial moment

Under different electrolyte inlet pressure, the flow velocity distribution cloud diagram at the machining gap is as shown in Fig.5. With the increase of electrolyte flow rate, the streamline distribution is similar, but the flow rate increases gradually. The flow rate at the slot can reach 11m/s, the streamline is stable without liquid shortage, and the inter-polar products can be taken away in time to ensure the stable processing. As shown in Fig.6, the temperature distribution in the machining gap under different inlet pressures. The joule heat generated by the current heats up the electrolyte, the inlet pressure increases, and the interelectrode velocity increases. In order to ensure the uniformity of the flow field, a large electrolyte inlet pressure is used in the machining, but too much pressure makes the flow rate too large, resulting in tremor affecting the machining accuracy. When the inlet pressure of electrolyte is 0.23Mpa, the flow rate between electrodes is 10.27m/s, which can meet the processing requirements.

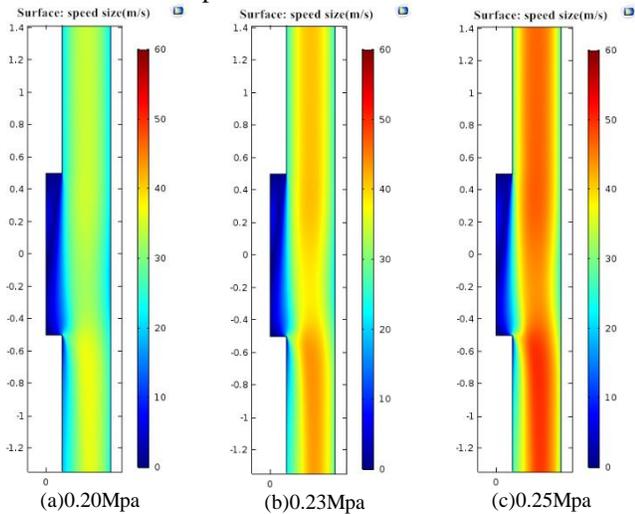


Figure 5. Velocity between poles under different inlet pressures

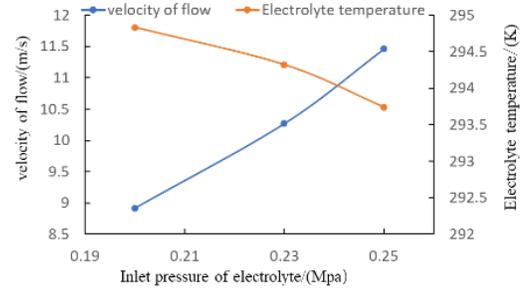


Figure 6. Variation trend of Inter-polar flow rate and electrolyte temperature

As shown in Fig.7, the initial current density around the machining area increases with the decrease of the machining gap, while the current density of slotted part is basically the same distribution of unit current density under different gaps. Therefore, different machining gaps mainly affect the initial current density distribution at the gap between anode and cathode, with little difference in the influence on the slotted area. But too much machining gap can affect the current distribution, weaken the interelectrode electric field, small clearance machining electrode current density distribution of the uniform, can in order to promote ring groove shape precision on the basis of the machining efficiency, but the gap is too small easy to cause short-circuit bumps the cathode electrolytic product discharge difficulties, so this article chooses the initial machining gap of 0.2mm.

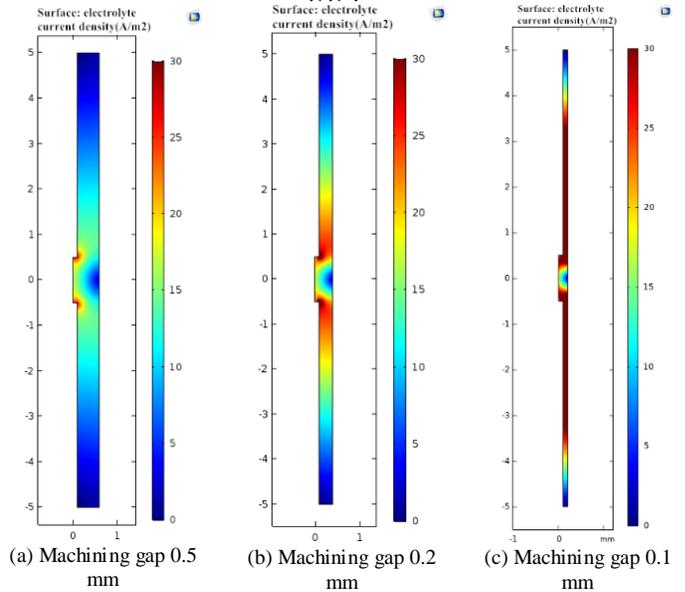


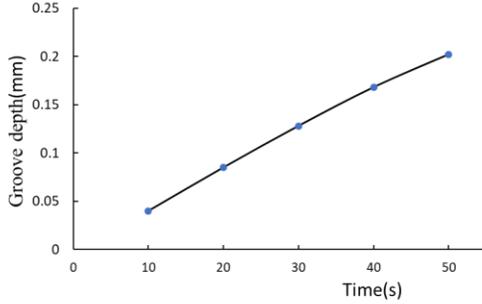
Figure 7. Current density cloud map corresponding to different processing gaps

B. Simulation analysis of ring groove forming process

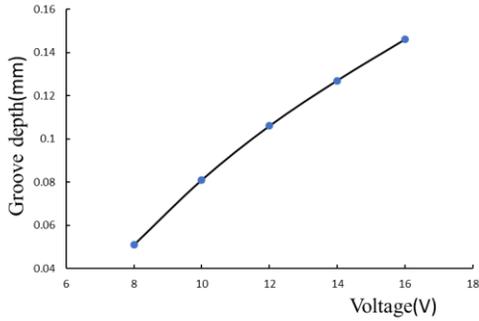
1) Effect of machining time and voltage on groove depth:

On the basis of the above electric field and the coupling simulation of the flow field, the physical field of the moving mesh is added, and the change of the depth of the groove under different machining voltage and processing time is

solved by the transient solver, and the variation rule shown in Fig.8 is obtained by numerical fitting.



(a) The relationship between the depth of the slot and the processing time at the voltage of 15 V



(b) The relationship between the depth of the slot and the processing time at the voltage of 30 V

Figure 8. Slot depth variation diagram

As shown in Fig.8(a), as the processing time increases, the depth of the groove deepens, but the growth rate decreases. Mainly due to the anodic material removal, the interelectrode machining gap becomes larger, and the interelectrode current density decreases under the condition that the processing voltage remains unchanged, leading to the decrease of processing efficiency. As shown in Fig.8 (b), due to the increase of voltage and conductivity, the depth of the slot increases, but the increase of the current density of the machining gap is limited, which leads to the slow growth rate of the slot depth. It is found from the trend diagram that the growth rate of slot depth is mainly related to processing time and inter-pole gap, and the voltage has little effect on it. The processing voltage of 12V can provide a large inter-pole current density to complete the machining of ring slot and the stray corrosion of slot width can ensure the machining accuracy. Therefore, the processing voltage of 12V is selected in this paper.

2) *Study on parameter distribution between poles:* In that electrolytic process, the constant variation of the profile of the workpiece result in a change in the electric field structure and the electrical conductivity of the electrolyte. Through the multi-physical field coupling simulation, the current density distribution in the machining gap after processing 120s is obtained, as shown in Fig.9(a), the current density of the surface of the workpiece is gradually reduced as the processing is carried out, and the dissolution rate of the anode is reduced, and the processing erosion

amount in the same time is reduced, The erosion rate in the deep direction of the groove becomes slow. Fig.9(b) electrolyte potential distribution, The anode potential was higher and showed a uniform trend of decline. With the progress of processing, the potential at the ring groove was higher and evenly distributed.

In order to ensure the smooth progress of mask electrolytic machining and timely discharge of electrolytic products and heat, large electrolyte pressure and flow rate are needed at the machining gap. As shown in Fig.9(c) and (d), the flow rate of the small electrolyte between the two poles is faster at the initial time of machining. With the removal of the anode workpiece, the gap between the large electrodes becomes larger with the removal of the anode workpiece, because the constant inlet flow rate leads to the decrease of pressure and flow rate. Due to the continuous etching process, the gap between the anode and the cathode will become larger, the flow of the electrolyte in the deep groove will be blocked, the speed of the electrolyte will be slow, and the processing stability will be affected.

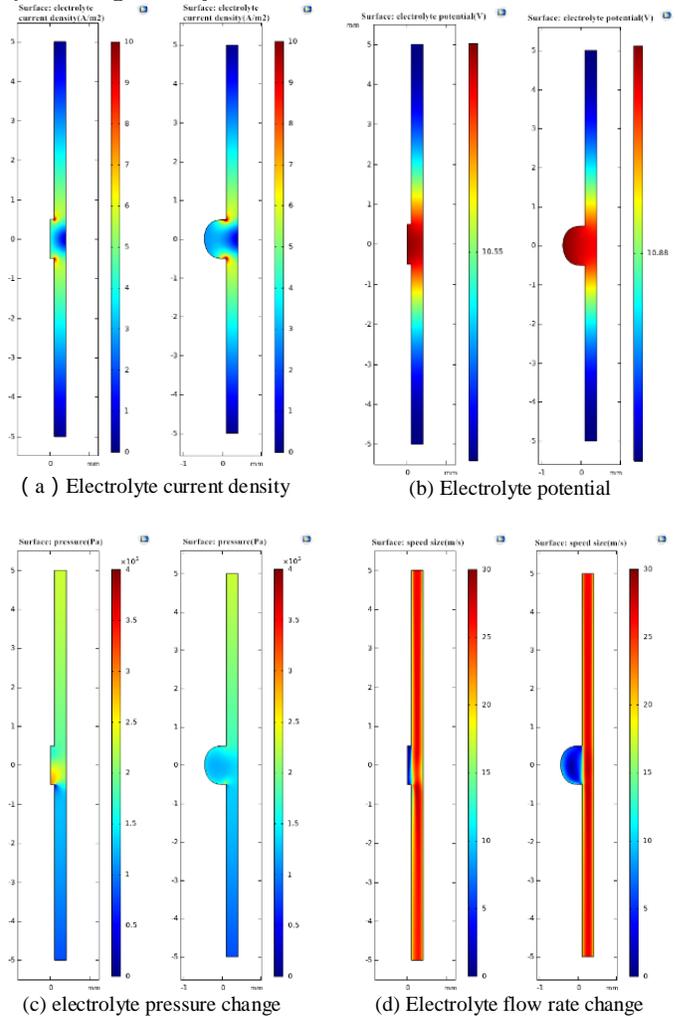


Figure 9. Simulation comparison of different processing time

Above, the COMSOL simulation software is used to simulate and study the variation rules of each physical field

in the process of circular narrow groove machining under the condition of multi-physical field coupling of electrochemical machining. According to the simulation results, the machining accuracy can be predicted and the actual electrochemical machining process of circular groove can be guided to provide guarantee for mass production of workpiece.

V. CONCLUSION

In view of the problems of traditional milling such as difficulty in chip removal and internal stress on the surface of the workpiece, this paper proposes the processing method of mask electrochemical machining. By establishing the two-dimensional structure diagram of the ring and groove, the mathematical model of each physical field was constructed, and the multi-physical field model was numerically simulated by COMSOL Multiphysics software, and the variation rule of each parameter in the processing process was obtained. The results show that the multi-physical field coupling simulation is carried out on the mask electrolysis process of the annular narrow groove, and the variation rule of the interelectrode parameters can be obtained, and the machining process can be effectively predicted and the test period can be shortened. According to the law of parameter change in the simulation process, it is known that the distribution of current density can be uniform with small initial machining gap, and the product between electrodes can be taken away in time with large inlet pressure, which can improve the machining efficiency and ensure the accuracy of ring slot at the same time; In the process of electrolytic machining of ring cell, the current density between electrodes is always evenly distributed, but with the decrease of the depth current density of the ring slot, the erosion rate decreases and the machining efficiency decreases; the high electrolyte pressure and the flow rate can discharge the electrolytic product and heat in time, and as the inter-electrode gap of the etching is increased, the pressure and the speed of the electrolyte are reduced, and the processing stability can be affected; Through the multi-physical field coupling simulation analysis of annular narrow cell mask electrolytic machining, the optimum process parameters are obtained as follows: initial machining gap 0.1mm, electrolyte inlet pressure 0.23Mpa, machining voltage 12V.

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