Simulation Analysis of Flow Field Based on Horizontal Electrolytic Machine Tool

Tian Tian
School of Mechatronic Engineering
Xi'an Technological University
Xi'an, China
E-mail: 15929779361@163.com

Jia Feng
School of Mechatronic Engineering
Xi'an Technological University
Xi'an, China
E-mail: jiafeng@xatu.edu.cn

Cao Yan
School of Mechatronic Engineering
Xi'an Technological University
Xi'an, China
E-mail: caoyan@xatu.edu.cn

Zhang Leiyan
Tool structure manufacturing
Xi'an KunLun Industry (Group) Company with Limited Liability
Xi'an, China
E-mail: bqzb_zly@sina.com

***Abstract*—In order to solve the problem that the stability of flow field affects the machining accuracy of aero-engine blade in EDM, according to the structure of EDM horizontal machine tool, the corresponding fixture is designed in this paper. Based on the flow field of machining gap, the finite element simulation of different sizes of electrolyte inlet is carried out respectively. Through the simulation, it can be seen that when the electrolyte inlet is larger than the machining gap, the pressure distribution in the gap flow field is uniform. The electrolyte flow rate in the gap is increased from 13m/s to 45 m/s, thus ensuring the stability of the flow field.**

Keywords-Engine Blade; ECM; Gap Flow Field; Finite Element Simulation

I. INTRODUCTION

Blade is the core part in aero-engine manufacturing, and its processing quality directly affects the performance of aero-engine [1]. With the increasing requirements for the strength, hardness, toughness and thermal stability of blade materials, high temperature nickel-based alloy materials began to be widely used in aerospace, and high-temperature nickel-based alloy materials have many machining difficulties, such as large cutting force, serious tool wear, easy to produce thermal deformation and so on [2]. Electrolytic machining (EDM) has become the main method of aero-engine blade manufacturing because of its non-contact machining method, high machining efficiency, no limitation of mechanical properties of metal materials, good surface quality, tools without loss and so on [3]. The flow field design of electrolyte is an important link in electrolytic machining. To provide sufficient and uniform electrolyte in the flow channel processing area is not only related to the machining quality of the workpiece, but also determines the stability of the electrolytic machining process. Reasonable and stable flow field has become the key factor to the stability of electrolytic machining [4].

The design of the flow field of electrolytic machining has been a hot topic in the field of electrolytic machining. For example, Xu Zhengyang et al. [5], put forward a new active control electrolyte flow mode in the electrolytic machining test of engine blade profile, which flows in from both sides of the edge plate and flows through the blade basin and back flow channel respectively. Compared with the traditional side flow, the numerical simulation shows that the active control flow mode is helpful to the uniform stability of the flow field, and is verified by experiments. Sun Lunye [6] designed controllable symmetrical electrolyte flow field for electrolytic machining of integral cascade passage of cascade. Compared with the previous electrolyte flow mode, the accuracy of impeller hub is improved, which shows that the design of controllable flow field is reasonable, which is beneficial to improve the machining quality of wheel hub, and can obtain better machining stability and consistency. Jain [7] uses one-dimensional bubble single-phase flow model to calculate the variation of air bubble rate, temperature and pressure in the machining gap. Fluerenbrock et al. [8] established a one-dimensional two-phase flow model to solve the bubble rate, temperature and gap distribution in the processing zone. The heat flow characteristics of the electrolytic drilling are studied by using the one-dimensional two-phase flow model by Hourng and Chang et al. [9]. The results show that the influence of the air bubbles on the conductivity and the equilibrium gap is very large. In the study of electrolytic machining, the design of the flow field of the electrolyte has been the core of the process research and the uniform and stable electrolyte flow field, which not only can improve the stability in the processing, but also can process the gap uniformly and improve the processing precision [10]. The structure of the blade of the aero-engine is complicated, and different tool holders need to be designed when the different machine tools are used, and the flow field state of the electrolyte in the area of different inlet and outlet cross section is not fully taken into account in the original flow field design, and the optimal flow field stability cannot be guaranteed.

In view of the difficulty of machinability of high temperature nickel-based alloy materials, this paper adopts electrolytic machining method, takes an aero-engine blade as the object, establishes the relevant fixture model for the horizontal electrolytic machining machine tool, designs the electrolyte flow channel, simulates and compares the gap flow field from the gap pressure and the gap electrolyte flow rate by changing the inlet caliber, and selects the optimal structure and optimizes the gap flow field.

II. ESTABLISHMENT OF FLOW FIELD MODEL

A. Selection of electrolyte flow mode

According to the relationship between cathode and electrolyte flow, the flow form of electrolyte in machining gap can be divided into three flow forms: positive flow, side flow and reverse flow [11], as shown in figure 1.

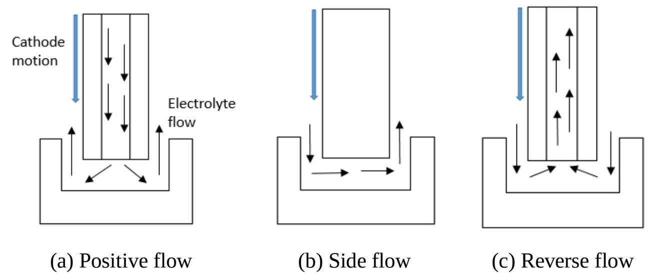


Figure 1. Flow form of electrolyte

In the process of traditional blade electrolytic machining, the side-flow flow from the inlet and exhaust edge is usually used [12], figure 2 is the schematic diagram of the machining.

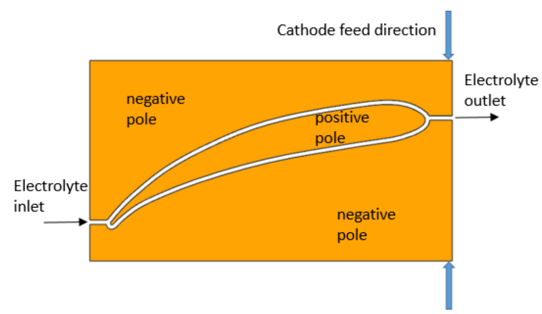


Figure 2. Schematic diagram of traditional side flow blade machining

For the blade with less distortion, this kind of liquid supply mode has certain advantages, but there will be some problems for the blade with higher curvature, such as the electrolyte will be rebounded separately when it passes through the side of the blank, which will cause the flow field there to be very disordered and cause the processing process to be unstable, and this flow mode is a kind of passive separation, the flow through the blade basin and the back of the blade can not be controlled, and the distribution of the flow field is not controllable. As shown in figure 3. Therefore, the side flow mode of liquid intake from the inlet and exhaust side can not meet the needs of blade processing.

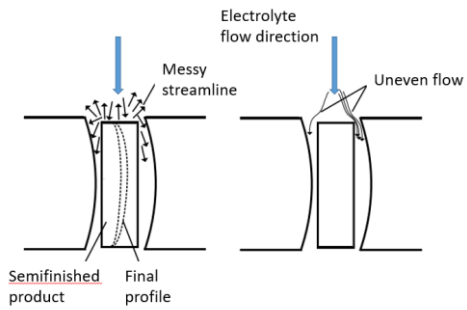


Figure 3. The problems with the traditional side flow mode

In order to solve the above problems, to ensure that the electrolyte flows through the machining area stably with a certain pressure and flow rate, combined with the structure of the horizontal electrolytic machining machine tool, the electrolyte flows in from one side of the edge plate, flows through the edge plate, the blade body, and finally flows out of the blade tip, as shown in Fig. 4, which actively separates the back passage of the blade and eliminates the disorder of the flow field caused by the impact of liquid flow on the inlet edge of the blade. At the same time, the flow rate of the blade basin and the back of the blade can be controlled respectively, and the flow field distribution is well controllable, so it is called the active control electrolyte flow mode.

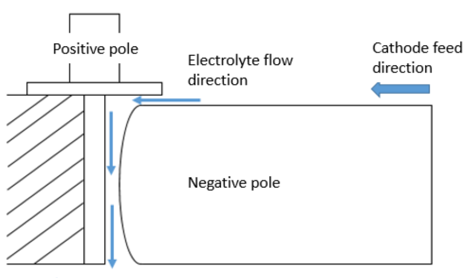


Figure 4. Schematic diagram of electrolyte flow

B. *Tool fixture design*

The factors to be considered in the design of fixture are as follows:

1) The designed fixture should be able to ensure the stable operation of the electrode;

2) The designed fixture can ensure the smooth and stable flow of electrolyte and can be transported to the machining area at a certain pressure and velocity;

3) The fixture should have enough stiffness to ensure that it does not deform in the process of machining;

4) The fixture should have good insulation and sealing performance.

Considering that the fixture is impacted by electrolyte and the electrolyte is corrosive in the process of machining, there are certain requirements for fixture body material. In this paper, ABS plastic was selected as the bulk material of fixture because of its high strength, good wear resistance, low water absorption, good machining, good corrosion resistance, long-term corrosion resistance of electrolyte, and good insulation performance. As shown in figure 5.

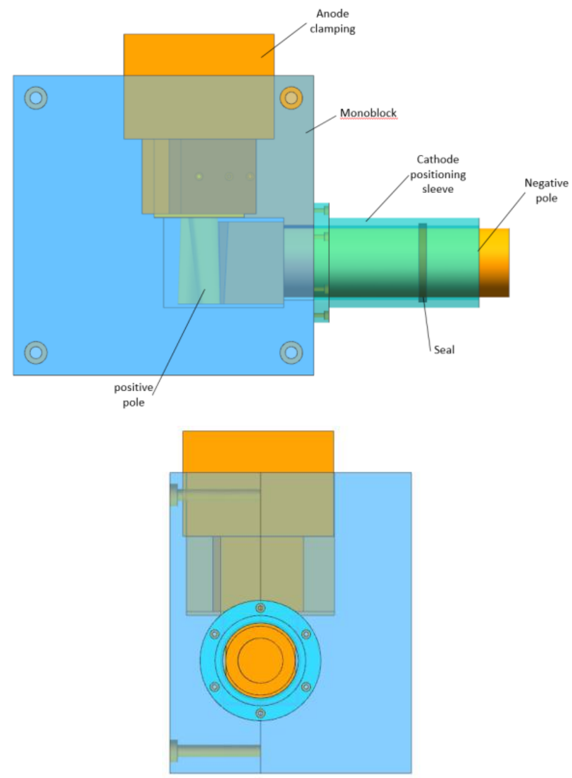


Figure 5. Fixture

III. ANALYSIS OF FLOW FIELD CHARACTERISTICS

A. *Mechanism of flow field*

The flow field parameter, which plays an important role in the flow field, is the velocity, and the inlet pressure is the necessary condition to ensure the high velocity. The flow rate of electrolyte is mainly based on the double criterion.

Criterion I: Control the temperature rise to determine the inlet velocity u_0 of the gap, which is obtained by formula (1):

$$u_0 = \frac{i^2}{\rho_l \kappa_0 C_l \Delta T} L \quad (1)$$

In the formula, i is the current density, u_0 is the inlet flow rate of the electrolyte, κ_0 is the initial conductivity of the electrolyte, L is the length of the electrolyte process, ΔT is the temperature rise of the electrolyte, ρ_l is the density of the electrolyte and C_l is the heat capacity of the electrolyte.

Criterion II: To ensure that the electrolyte is in a turbulent state, the flow rate corresponding to the turbulent state should meet the following formula:

$$u_{R_e} > 2300 \frac{\nu}{D_h} \quad (2)$$

In the formula, R_e is the Reynolds number, D_h is the hydraulic diameter, and ν is the kinematic viscosity.

The velocity of flow can be determined by combining the criterion of double determination:

$$u \geq \max\{u_{R_e}, u_0\} \quad (3)$$

To ensure that the electrolyte in the gap has enough flow rate, it is necessary to add a certain pressure at the entrance of the gap. The value should be the sum of dynamic pressure, viscous friction and outlet back pressure of fluid motion. According to the Bernoulli equation of the actual fluid, the energy conservation of the fluid flowing through the cross sections of the two flow tubes in a unit time is as follows:

$$P_A + \frac{a_A \rho_l u_0^2}{2g} + \rho_l Z_A = P_B + \frac{a_B \rho_l u^2}{2g} + \rho_l Z_B + \rho_l \sum H \quad (4)$$

In the formula, a_A and a_B are the flow parameters at the inlet and outlet of the gap, $a_A = a_B$, $\sum H$ is the head loss of the fluid per unit weight. It is assumed that the water level at the inlet of the gap is the same as that at the outlet, that is, $Z_A = Z_B$; The velocity varies little along the flow process, approximately $u = u_0$; In addition, it is assumed that there is no back pressure at the exit of the gap, that is, P_B=0. So the Bernoulli equation can be written as follows:

$$P_A = \rho_l \sum H = \rho_l \left(\lambda \frac{L}{D_h} + \zeta\right) \frac{u_0^2}{2g} \quad (5)$$

The values of the relevant parameters in the formula are shown in Table 1.

TABLE I. VALUES OF PARAMETERS

Parameter	κ_0**(S m^{-1})**	i_0**(A/cm^2)**	ρ_l**(kg m^{-3})**	C_l**(J kg^{-1} K^{-1})**
Value	6.72	30	1100	4125

B. *Theory model*

In this paper, the standard $k-\varepsilon$ turbulence model is used to solve the problem. For the steady state flow of incompressible fluid, regardless of the influence of gravity, the standard $k-\varepsilon$ two-equation model is as follows:

$$\rho(u\nabla)k = \nabla\left[\left(\mu + \frac{\mu_T}{\sigma_k}\right)\nabla k\right] + \rho_k - \rho\varepsilon \quad (6)$$

$$\rho(u\nabla)\varepsilon = \nabla\left[\left(\mu + \frac{\mu_T}{\sigma_\varepsilon}\right)\nabla \varepsilon\right] + C_{C_1}\frac{\varepsilon}{K}\rho_k - C_{C_2}\rho\frac{\varepsilon^2}{K} \quad (7)$$

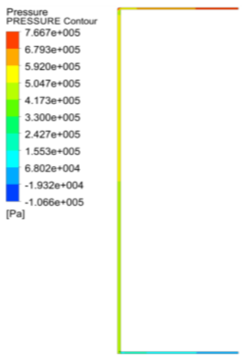
In the formula, $\varepsilon = ep$, $\mu_T = \rho C_\mu \frac{K^2}{\varepsilon}$, $\rho_k = \mu_T[\nabla u: (\nabla u + \nabla u)^T]$, μ_T is the turbulent viscosity, ρ_k is the generating term of turbulent kinetic energy k caused by the average velocity, ε is the turbulent dissipation rate, and the values of other constant terms are shown in Table 2.

TABLE II. VALUES OF CONSTANT ITEMS

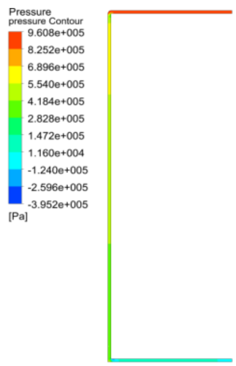
Constant	C_{C_1}	C_{C_2}	C_μ	σ_k	σ_ε	K
Value	1.44	1.92	0.09	1.0	1.3	0.41

IV. SIMULATION AND ANALYSIS

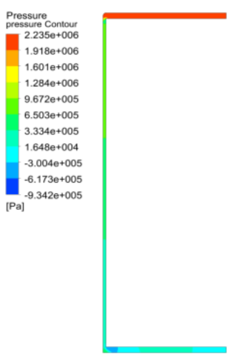
In this paper, the flow field simulation of electrolyte flow channel model is carried out by ANSYS CFX to optimize the model structure. The flow field of inlet and outlet caliber smaller than machining gap (0.3mm), equal and machining gap (0.5mm) and larger than machining gap (1.0mm, 1.5mm) is simulated by using ANSYS CFX software and the boundary condition value in Table 2, respectively, as shown in figure. 6.



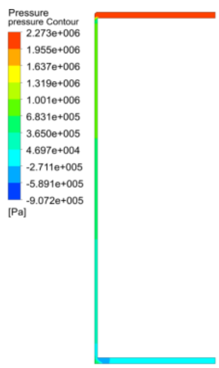
(a) 0.3mm Pressure



(b) 0.5mm Pressure



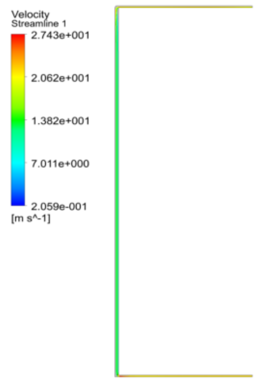
(c) 1.0mm Pressure



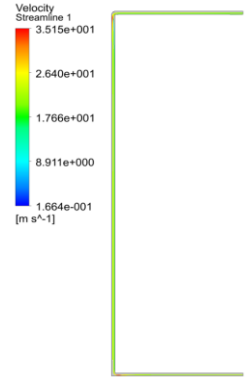
(d) 1.5mm Pressure

Figure 6. Cloud diagram of pressure distribution in gap flow field

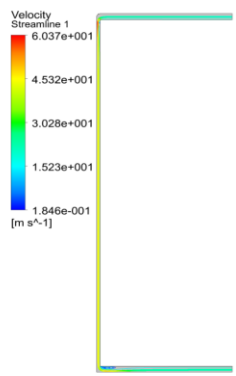
In figure. 6, (a) (b) (c) (d) is a cloud picture of gap flow field pressure distribution when electrolyte flow rate is 20m/s, 0.5mm, 1.0mm and 1.5mm respectively, in which the equilibrium gap is 0.5mm. Through the pressure cloud diagram, it can be seen that when the inlet and outlet width of electrolyte is smaller than the machining gap and equal to the machining gap, when the electrolyte first enters the machining part, the pressure value is lower than the pressure value in the machining clearance. Because of the sudden pressure drop, it is easy to cause holes, vortex and other phenomena, which is not conducive to the stable flow of the electrolyte. When the electrolyte pressure is greater than the balanced machining gap, the clearance pressure is about t, and the pressure drop of the whole machining part is small and uniform.



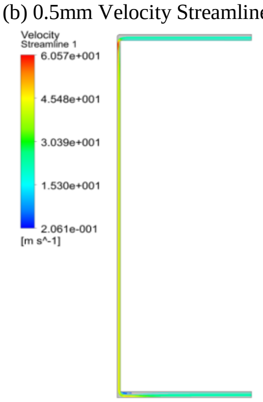
(a) 0.3mm Velocity Streamline



(b) 0.5mm Velocity Streamline



(c) 1.0mm Velocity Streamline



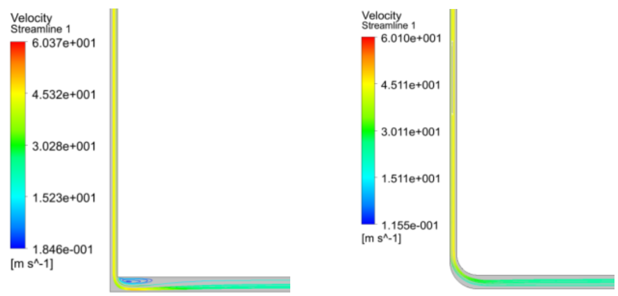
(d) 1.5mm Velocity Streamline

Figure 7. Velocity flow chart of gap flow field

In figure. 7, (a) (b) (c) (d) is the velocity diagram of the gap flow field when the electrolyte inlet and outlet are 0.3mm, 0.5mm, 1.0mm and 1.5mm, respectively. When the electrolyte inlet and outlet width is less than the balanced machining gap, the electrolyte flow rate in the machining gap is about 13 m/s, and when the electrolyte inlet and outlet width is equal to the machining gap, the electrolyte flow rate in the machining gap is about 17 m/s, which is lower than the electrolyte inlet velocity. When the width of the electrolyte inlet and outlet is larger than the machining gap, the flow rate in the machining gap is about 45 m/s, which is larger than the electrolyte flow rate at the inlet and outlet of 0.3mm and 0.5mm, which is beneficial to the discharge of electrolytic products and the reduction of temperature rise.

By analyzing the simulation results of the above four cases, it can be found that the stable flow state of electrolyte is satisfied only when the inlet and outlet width of electrolyte is larger than the machining gap. It can be seen that the simulation results of width 1.0mm are close to those of 1.5mm. Because the width of electrolyte inlet affects the structure of blade edge, the channel structure with 1.0mm inlet and outlet width of electrolyte is selected for processing. Figure 7(c), electrolyte has a vortex after the machining gap will cause holes, so it is necessary to optimize the outlet of the flow channel, as shown in figure 8.

Because the velocity loss of electrolyte in machining gap is small, this paper optimizes the right angle of liquid outlet to round angle by prolonging the electrolyte flow process, so as to improve the distribution of electrolyte streamline and make it evenly distributed.



(a) Velocity streamline before optimize

(b) Velocity streamline after optimize

Figure 8. Comparison diagram of electrolyte streamline

V. CONCLUSION

In the process of electrolytic machining, the reasonable design of electrolyte flow channel can ensure the stability and uniformity of electrolyte flow in the process of machining, and at the same time, it can ensure the requirements of machining accuracy. For the design of electrolyte flow channel, the simulation results show that when the inlet diameter is less than or equal to the balanced machining gap, a period of pressure drop occurs when the electrolyte first enters the machining gap, which will cause holes, which is not conducive to electrolyte flow, and when the inlet diameter is larger than the balanced machining gap, the pressure drop of the whole machining gap is uniform. When the inlet diameter is less than the balanced machining gap, the electrolyte flow rate in the gap is about 13 m/s, and when the inlet diameter is equal to the balanced machining gap, the electrolyte flow rate in the gap is about 17 m/s. When the inlet diameter of the electrolyte is larger than the equilibrium gap, the electrolyte flow rate in the gap is increased to about 45 m/s. The high speed flow electrolyte is beneficial to the discharge of electrolytic products, reduces the temperature rise, and improves the flow field in the machining gap.

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