Design and Simulation Analysis of Flow Field in Turbine Blades ECM Process

Zhao Han
School Of Mechatronic Engineering
Xi'an Technological University
Xi'an, China
E-mail: 1206532804@qq.com

Fan Qingming
School Of Mechatronic Engineering
Xi'an Technological University
Xi'an, China
E-mail: fanqingming@xatu.edu.cn

***Abstract*—Turbine blades play an important role as important parts in aero engines. One of the main methods of machining is electrochemical machining (ECM). In this paper, based on the flow field theory of electrochemical machining, the flow field analysis of machining gap was taken as the main research content When machining turbine blades. And the gap flow field model of blade electrochemical machining was established. Then based on COMSOL Multiphysics software, the distribution and characteristics of flow field were studied by numerical simulation of machining gap. Finally, the effects of different machining gaps and electrolyte pressure on turbine blade machining were analyzed, and the effects of electrolyte velocity and pressure on distribution were summarized.**

Keywords-Electrochemical Machining(ECM); Turbine Blade; Flow Field; Simulation

I. INTRODUCTION

As a key component in aviation turbine engines, aero-engine blades have the disadvantages of complex shape, difficult processing and frequent failures. They have always been the research hotspot in the world of engine manufacturing. National aero-engine industry has adopted CAD technology while breaking through aero-engine design technology, material science technology and manufacturing technology, and gradually developed towards the complexity of structure, low-cost and high-efficiency processing methods[1-2]. Electrochemical machining (ECM) is a kind of non-contact machining based on the principle of electrochemical anode dissolution. There is no tool loss, suitable for hard cutting materials[3-5]. A series of researches have been carried out on it at home and abroad. Jia Minghao et al[6]. studied the flow field design of electrochemical machining. Xu Zhengyang and Zhu Di[7] designed the flow form of "two-way feed liquid" by adopting the three-head feed electrochemical machining blade mode to conduct the test. It can be seen that the uniformity design of the flow field is an important part of electrochemical machining, which not only has a significant influence on the distribution of the electric field, but also largely determines the quality of electrochemical machining.

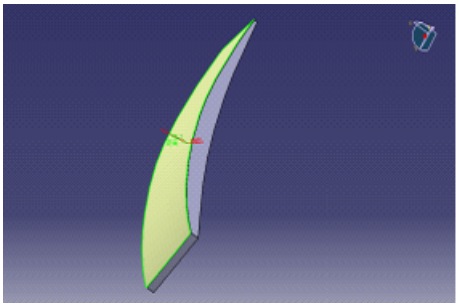
In this paper, the turbine blade was taken as the research object just like Fig.1.The general process of the flow field analysis of the blade cathode surface based on COMSOL was described.

Figure 1. Aero-engine turbine blades

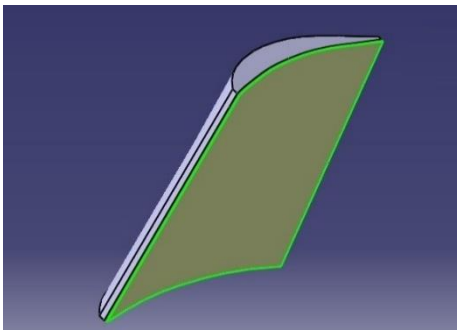
II. ESTABLISHING A RUNNER MODEL

Opened the three-dimensional blade model in CATIA, and established the cathode surface of blade basin with machining gap of 0.3mm (as shown in Fig.2), 0.4mm and 0.5mm, as well as the blade back. Four cross sections and five longitudinal sections were drawn on the blade surface in

the established closed flow path so as to intersect at 20 points, so that 20 control points and coordinate values of each point were listed in Fig.3.

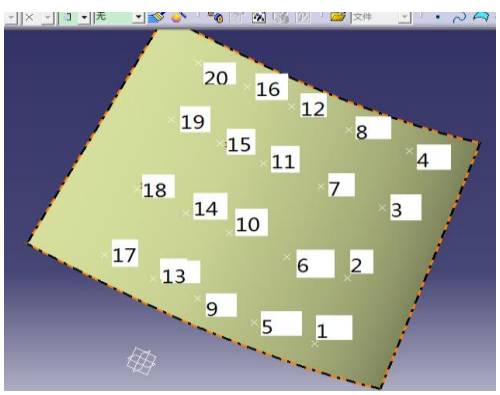


a) Cathode profile model of blade back



b) Cathode profile model of leaf basin

Figure 2. The blade cathode profile model with a machining gap of 0.3 mm



Distribution of control points

Figure 3. Control point number and its coordinates

III. Flow Field Analysis of Blade Cathode Surface Based on COMSOL

In the process of flow field simulation, the geometric model of the electrolyte flow region was first established by using 3D modeling software. Secondly, the calculation format of the COMSOL Multiphysics solver was output. Then the solution was calculated in the COMSOL Multiphysics. Finally, the simulation results were post-processed.

A. Select physics and define boundary conditions

Modeling the flow field of electrochemical machining had the following assumptions: ① The fluid was an incompressible and constant Newtonian fluid, that was, when the velocity gradient changes, the dynamic viscosity remained unchanged. ② In electrochemical machining, in order to facilitate uniform flow field and eliminate polarization concentration, the electrolyte should be in a turbulent state, and the change of electrolyte temperature and the effect of energy loss caused by temperature were ignored during processing[8].

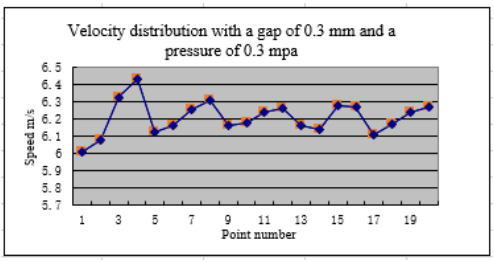
In the COMSOL, the “turbulence k-ε(spf)” was selected for the physical field, and the solver type was "steady state". Flow patterns of fluids were roughly divided into two types: laminar and turbulent. Only when the flow state of the electrolyte was turbulent, the electrolyte with higher flow rate can take the electrolysis products away from the gap flow field in time, which was beneficial to eliminate the concentration polarization and uniform flow field. The closed area of the different machining gaps composed of the blade and the cathode surface was numerically simulated for the research object, and the inlet/outlet pressure was determined according to the boundary condition, and the results were represented by the contour cloud map and the streamline diagram to visualize the flow field characteristics.

B. Flow field simulation analysis process

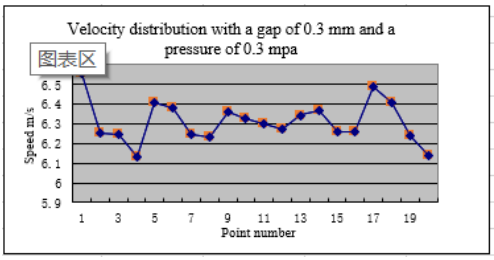
There were many factors affecting the uniformity of the flow field during the electrochemical machining, among which different machining gaps in the flow field and electrolyte pressure had the most important influence on the stability of flow field in the process of electrochemical machining. Based on the flow field theory of electrochemical machining, the flow field of different machining gaps was analyzed by COMSOL, and the velocity and pressure distribution of the flow field in the machining gap were obtained.

1) Flow field analysis of a 0.3mm gap model

When the machining gap was 0.3mm and the electrolyte pressure was 0.30MPa, The data of the electrolyte flow rate was obtained from the flow rates corresponding to the 20 control points on the blade basin and back, as shown in Fig.4, the flow rate map was shown in Fig.5, and the pressure map was shown in Fig.6 At this point, the velocity of electrolyte fluctuated between 6m/s and 6.6m/s, and there was no low-speed region lower than 5m/s and the distribution was relatively uniform.

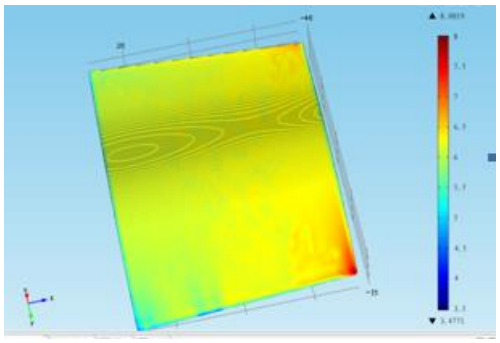


(a) Velocity at each point on the blade back

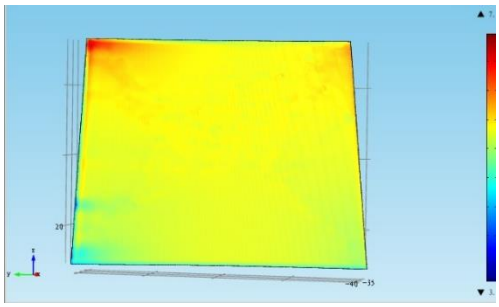


(b) Velocity at each point on the blade basin

Figure 4. Flow velocity distribution of 0.3mm gap and 0.30MPa electrolyte pressure

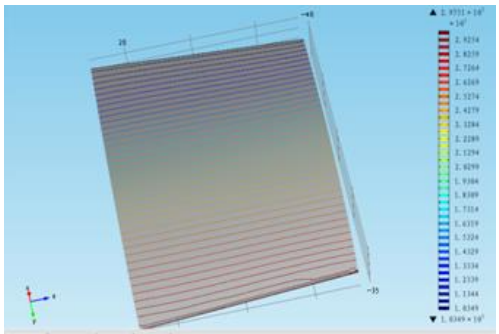


(a) Velocity image of blade back

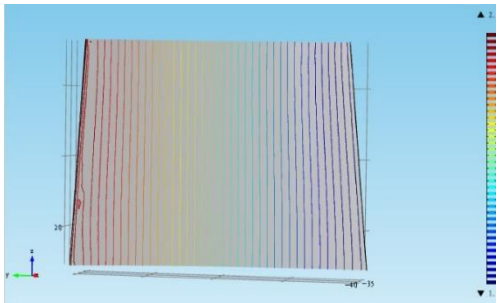


(b) Velocity image of blade basin

Figure 5. Velocity image with electrolyte pressure of 0.30 MPa



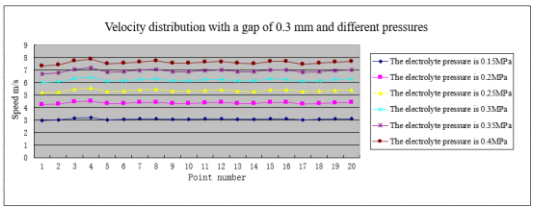
(a) Pressure image of blade back



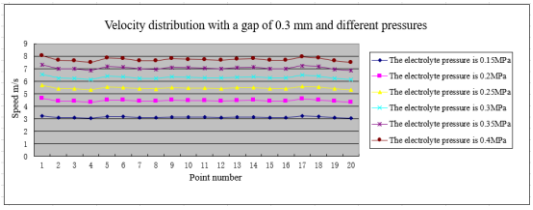
(b) Pressure image of blade basin

Figure 6. Pressure image with electrolyte pressure of 0.30 MPa

Considering changing the inlet pressure of electrolyte, when the electrolyte pressure was 0.40MPa or other values, the corresponding velocity data distribution of each control point on the blade can be plotted. In order to compare the trend of flow velocity under the condition of the same machining gap and different electrolyte pressure, multiple data distribution curves were drawn in the same line graph (as shown in Fig.7).



(a) The velocity of each control point on the blade back under different pressures



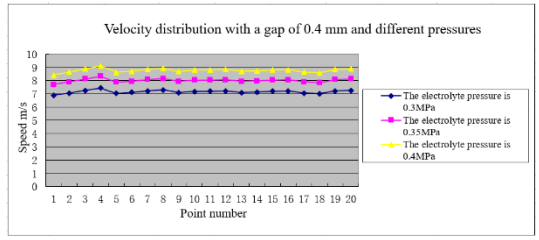
(b) The velocity of each control point on the blade basin under different pressures

Figure 7. Flow velocity distribution at different electrolyte pressures with a gap of 0.3 mm

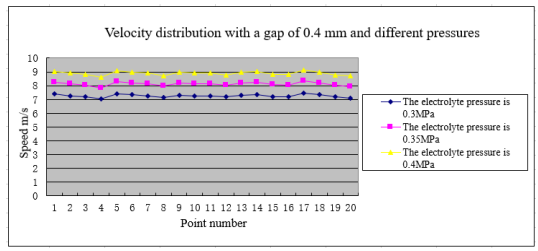
As can be seen from the flow velocity distribution map corresponding to each set of points above that the electrolyte flow velocity changes were basically uniform under a certain machining gap and different electrolyte pressures, and the higher the electrolyte pressure was, the higher the velocity will be. When the pressure of electrolyte increased by 0.05mpa, the electrolyte flow velocity will increase by about 1m/s. According to the control points division in the model establishment process, the flow velocity of several groups of points on different sections tended to be basically the same. On the back of the blade, among the four control points of the same section, the flow rate at the low point was smaller than that at the high point, and it increased slowly. On the blade basin, the opposite was true, the low point flow rate was higher than the high point flow rate.

2) Flow field analysis of a 0.4mm gap model

The machining gap was changed to 0.4 mm, and the electrolyte pressures were 0.30 MPa, 0.35 MPa, and 0.40 MPa, respectively. The flow rate data of 20 control points on the blade basin and back were measured, and the data distribution map was plotted as shown in Fig.8.



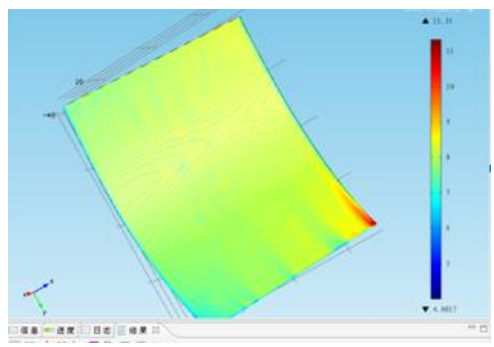
(a) The velocity of each control point on the blade back under different pressures



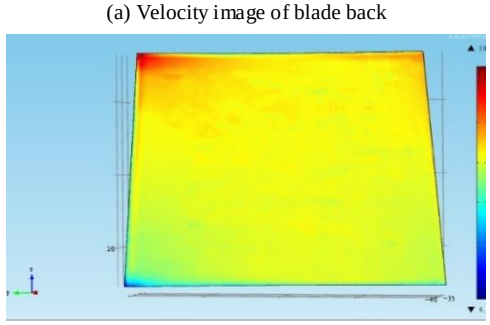
(b) The velocity of each control point on the blade basin under different pressures

Figure 8. Flow velocity distribution at different electrolyte pressures with a gap of 0.4 mm

When the gap was 04.mm and the electrolyte pressure was 0.35MPa, the flow rate of the blade was shown in Fig.9 and the pressure was shown in Fig.10.

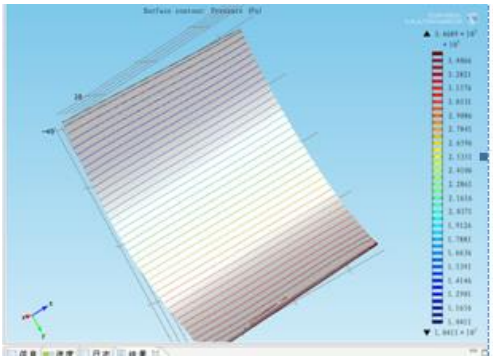


(a) Velocity image of blade back

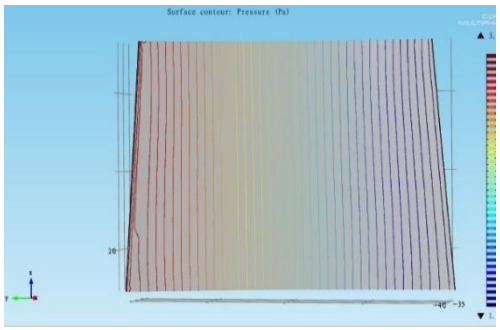


(b) Velocity image of blade basin

Figure 9. Velocity image with a gap of 0.4mm and electrolyte pressure of 0.30 MPa



(a) Pressure image of blade back



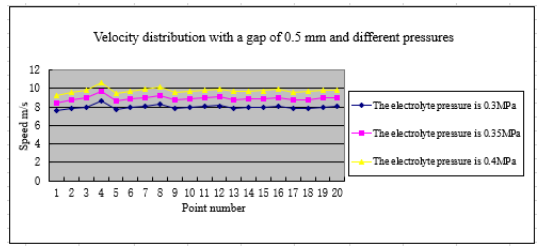
(b) Pressure image of blade basin

Figure 10. Pressure image with a gap of 0.4mm and electrolyte pressure of 0.30 MPa

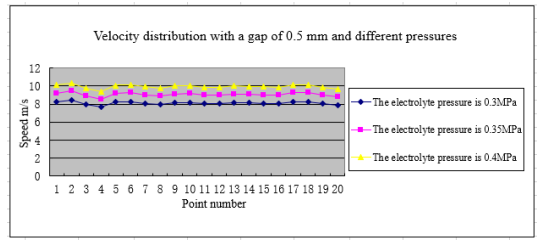
When the machining clearance was changed, the flow velocity variation trend under different electrolyte pressure was basically the same as when the gap was 0.3 mm. Observing each control point, the machining gap was increased from 0.3 mm to 0.4 mm, and the electrolyte flow rate was increased by about 1 m/s.

3) Flow field analysis of a 0.5mm gap model

Changed the machining clearance to 0.5mm, and took the electrolyte pressure to 0.30MPa, 0.35MPa and 0.40MPa respectively. The flow velocity data of 20 control points in blade basin and back were detected, and the data distribution diagram was drawn as shown in Fig.11.



(a) The velocity of each control point on the blade back under different pressures



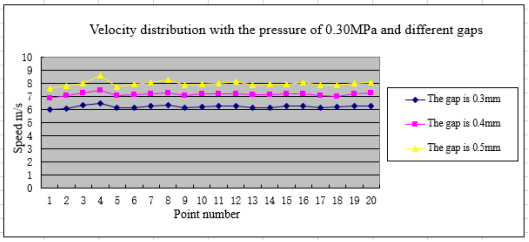
(b) The velocity of each control point on the blade basin under different pressures

Figure 11. Flow velocity distribution at different electrolyte pressures with a gap of 0.5 mm

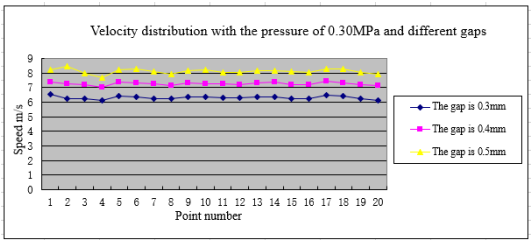
The processing gap was increased from 0.4 mm to 0.5 mm, and the flow rate of the electrolyte was stably increased by about 1 m/s at the same electrolyte pressure. The overall trend of the electrolyte flow rate was basically consistent with the trend of 0.3 mm and 0.4 mm, and both of which kept floating up and down in a stable area.

IV. CONCLUSION

According to the velocity distribution of each control point from the above various machining gaps under different electrolyte pressure, it can be known that the velocity fluctuated up and down within a certain range of velocity, and the variation of velocity tended to be basically the same. The control point velocity under the same electrolyte pressure and different machining gaps was analyzed. When the electrolyte pressure was 0.30 MPa, the flow velocity distributions of the machining gaps of 0.3mm, 0.4mm, and 0.5mm were compared, and the flow velocity distribution at each point was as shown in Fig.12.



(a) Velocity of control points on the blade back under different gaps



(b) Velocity of control points on the blade basin under different gaps

Figure 12. Flow velocity distribution at different gaps under the pressure of 0.30Mpa

The following conclusions were obtained from the above analysis and charts:

- When the geometric structure of machining clearance was determined, there was a one-to-one relationship between flow rate and pressure, and the higher the pressure of electrolyte, the higher the flow rate.
- When the inlet pressure and outlet pressure were constant, the electrolyte flow rate gradually increased as the machining gap increased.
- When the machining gap was 0.3mm, the flow velocity change trend of each section point was more consistent than other gaps, and the flow field was more uniform and the machining accuracy was higher. The smaller the machining gap was, the more beneficial it was to eliminate the original unevenness of the workpiece surface, eliminate the genetic error of the workpiece, improve the processing precision, reduce the surface roughness of the workpiece, and improve the surface quality. However, if the gap was too small, the electrolysis product will increase, resulting in excessive liquid flow resistance and reduced flow velocity, so that the electrolytic products cannot be eliminated in time. It will affect the machining accuracy and surface quality.
- Different machining gaps had a certain impact on the accuracy of electrochemical machining. The more uniform the distribution of flow field, the higher the precision of electrochemical machining.

ACKNOWLEDGMENT

This paper was supported by the postgraduate education reform research project of Xi'an Technological University (NO: XAGDYJ190106).

REFERENCES

[1] Zhu Shunkang, Liu Jia, Zhu Di. Design and Experimental Investigation on Flow Field with Equivalent Inflow Angles in ECM of Turbine Blades[J]. Electromachining and Mould, 2016(3):27-32.

[2] Sun Chunhua, Zhu Di, Li Zhiyong, Wang Lei. Cathode design and simulation of ECM turbine blade based on characteristics of liquid field[J]. Journal of Southeast University(Natural Science Edition), 2004,34(5):613-617.

[3] Rajurkar K P, Sundaram M M, Malshe A P. Review of Electrochemical and Electrodischarge Machining[J]. Procedia CIRP, 2013,6(1):13-26.

[4] Wang Jianye, Xu Jiawen. Principle and application of electrochemical machining[M].Beijing: National Defense Industry Press, 2001.

[5] Peng Suhao, Xu Zhengyang, Gu Zhouzhi, Zhu Dong, Liu Jia. Flow Design and Experiment of Electrochemical Machining of Integral Components Circumferential Blade[J]. Journal of Nanjing University of Aeronautics & Astronautics, 2014,46(5):750-756.

[6] Jia Minghao. Flow Field Design of Electrochemical Machining[J]. Die & Mould Manufacture, 2006(12):56-58.

[7] Xu Zhengyang, Zhu Di, Wang Lei, Shi Xianzhuan. Character of Flow Field on Turbine Blade with 3-Elecrtrode Feeding Method in Electrochemical Machining[J]. Chinese Journal of Mechanical Engineering, 2008,44(4):189-194.

[8] Li Qingliang, Fan Zhijian, Mu Qian. Emulation for Flow Field in Electrochemical Machining of Closed Integral Structure Based on COMSOL[J]. Electromachining & Mould, 2014(1):28-31.