Knowledge E
Engaging minds

Conference Paper

Development of A Cathode Designing Method to Avoid Electrodes' Interference during Blisk Electrochemical Machining

J.C. Zhang, Z.Y. Xu, W.F. Su, and D. Zhu

College of Mechanical and Electrical Engineering, Nanjing University of Aeronautics & Astronautics, 210016 Nanjing, China

Abstract

Electrochemical machining plays a prominent role in blisk (bladed integrated disk) construction process. Since blisk channel is narrow and twisted, interference between electrodes may happen during electrochemical machining. Therefore, this paper develops a cathode designing method to avoid interference. Firstly, according to theory of electrochemical machining, machined channel is predicted by calculation. Second, with this channel, interference analysis is carried out and a cathode is designed. Finally, the cathode is employed in experiment and no interference appears.

Keywords: cathode designing; electrochemical machining; blisk; interference

Corresponding Author: Z.Y. Xu; email: xuzhy@nuaa.edu.cn

Received: 9 September 2016
Accepted: 19 September 2016
Published: 12 October 2016

Publishing services provided by Knowledge E

Selection and Peer-review under the responsibility of the ASRTU Conference Committee.

1. Introduction

Blisk (bladed integrated disk) is construction used for advanced heavy-duty compressor rotors in military and also civil turbine aircraft engines [1]. Blisk has essential advantages, such as weight reductions, improved aerodynamics and reductions in fuel consumption. However, since blisk usually is made by difficult-to-machine materials and requires high machining accuracy, it brings a great challenge to manufacturing. Therefore, diverse advanced machining methods, such as Linear Friction Welding (LFW) [2], Electro Discharge Machining (EDM) [3], and Electrochemical Machining (ECM) [4] are introduced into blisk process. Especially, due to characteristics of non-existent tool wear and short process-time, ECM plays a prominent role in the blisk process [5]. Lots of efforts have been devoted to blisk ECM. A multi-physical approach is presented for modeling the ECM material removal process by coupling all relevant conservation equations [6]. Flow models such as Π-shaped flow mode and dynamic additional electrolyte flow are developed to raise quality of electrolyte flow field [7, 8]. An extended cathode is employed to improve trailing edge accuracy by optimizing the electric field [9].

Since blisk channel is narrow and twisted, interference between cathode and anode may happen during blisk process with ECM method. To avoid this interference, this paper studies a promising blisk ECM, namely the spiral ECM. Due to cathode's complex movement, spiral ECM succeeds in improving machining accuracy and surface

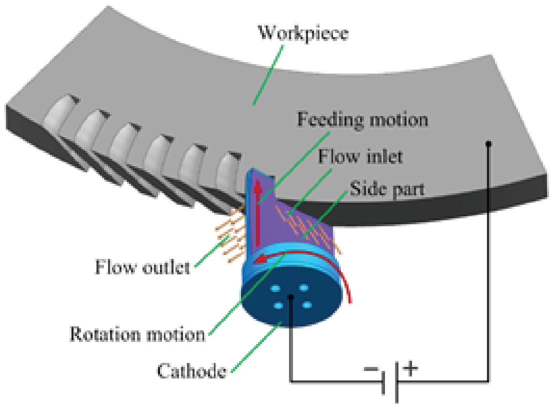

Figure 1: Sketch of spiral ECM.

quality [10]. This complex movement also increases interference possibility between electrodes. To eliminate interference, some researchers focus on changing cathode trajectory with a trajectory control strategy [11]. However, changing cathode trajectory is not suitable for spiral ECM, because the trajectory of cathode is optimized on the aim of obtaining a high machining accuracy and could not be changed [10]. Therefore, a cathode designing method is developed to avoid the interference between electrodes.

This paper develops a cathode designing method to avoid interference. First, according to theory of electrochemical machining, machined channel is predicted by calculation. Second, with this channel, interference analysis is carried out and a cathode is designed. Finally, the cathode is employed in experiment and no interference appears.

2. Methods

2.1. Description of Spiral ECM

Sketch of spiral ECM is illustrated in Fig. 1. While the workpiece is fixed, the cathode has a complex movement. The cathode feeds from the tip of blade to the bottom with a rotation motion simultaneously. Thus, the cathode actually has a spiral movement. During machining, cathode is connected to the negative pole of power and workpiece is connected to the positive pole. Owing to continuously pumped electrolyte, electrolytic products are taken away and electrolyte is kept clean in the machining gap. Most of the areas in the side surfaces are covered with insulated materials except the exposed regions, illustrated in Fig. 2a. Thus, only exposed regions are involved in the reaction.

2.2. Prediction of Blisk Channel

To avoid the interference, the channel must be predicted. It can be made basing on electrochemical theory.

Structure of cathode is given in Fig. 2a. If width of exposed region is *h,* the value of the side gap *G* can be calculated with the following relationship [12]:

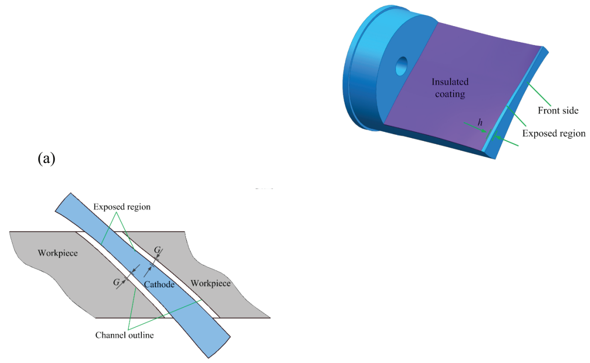

Figure 2: Structure of cathode (a) and calculation of channel outline (b).

$$G \approx \sqrt{2 * h * \Delta + \Delta^2} \tag{1}$$

in which, Δ is inter-electrode frontal gap determined by the following equation:

$$\Delta = \frac{\eta \omega \kappa U_R}{v_f} \tag{2}$$

where η is the current efficiency, ω is the volume electrochemical equivalent of the material, κ is the conductivity of the electrolyte, $U_R$is the potential difference in the machining gap, and v_f is the cathode feed speed. By offsetting exposed region with a distance of *G*, channel outline can be obtained (Fig. 2b).

2.3. Cathode Designing

It is necessary to obtain positions of channel relative to cathode. Since the cathode is moving in process, the relative positions are changing all the time. Thus, while an absolute coordinate *C* is located in the initial position, a relative coordinate *C′* is located at the cathode, shown in the Fig. 3. Due to the movement of cathode, the relative coordinate has an angle difference of θ around *Z* axis combined with position difference *F* in the direction of *Z* axis. A plane *P* is built in the relative coordinate and plane *P* has distance of *D* from *X′*- *Y′*. A point *A* is located in the intersection curve *l* of plane *P* and blisk channel. Thus, if the coordinate of *A* is (X, Y, Z) in coordinate *C*, the coordinate of *A* in coordinate *C′* (X′, Y′, Z′) is given as follows:

$$X' = X * cos\theta \ - Y * sin\theta \tag{3}$$

$$Y' = X * sin\theta + Y * cos\theta \tag{4}$$

$$Z' = D \tag{5}$$

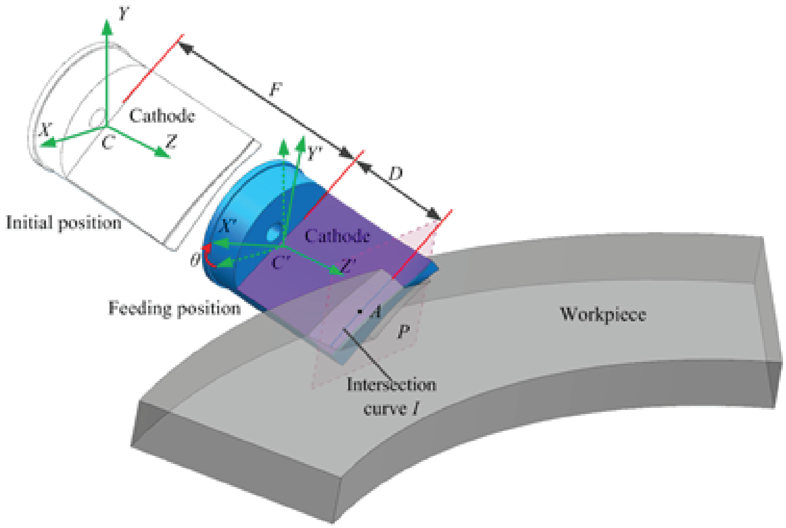

Figure 3: Sketch of spiral ECM.

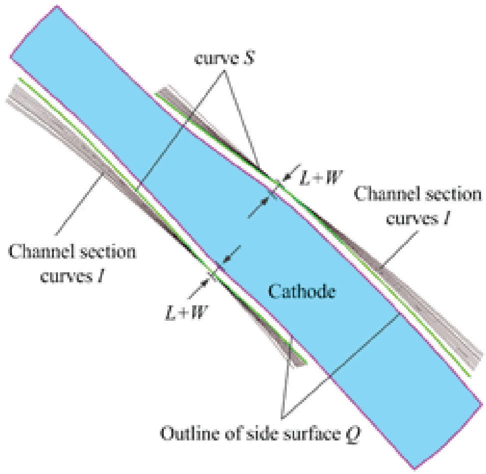

Figure 4: Acquisition of a single outline curve *Q* of cathode side surface.

Then, keeping the value of *D* constant and changing the value of *F*, a cluster of curves *I* can be obtained (Fig. 4). If the cathode is designed inside all the curves *I*, just as the green curve *S*, it should not collide with channel shown in Fig. 4. Since the cathode has a thickness of insulated coating *L* and a width of flow passage *W*, the outline curve of side surface *Q* is obtained by offsetting curve *S* with a distance of *L*+*W*.

Selecting *D* with different value, a series of outline curves of side surfaces in the cathode can be obtained. Through linking the curves, the two side surfaces of cathode are finally constructed (Fig. 5a). To avoid undesirable erosion in the side machining gap, the side surfaces is usually coated with insulated materials, such as ceramics and epoxy resin (Fig. 5b).

Interference detection is carried out in the Computer Aided Design (CAD) software (Fig. 6). Fig. 6a shows cathode employed previous cathode design method, in which the side surface of cathode is a ruled surface. The ruled side surface has a difference relative to twisted channel, which leads to large width difference of side gap. And

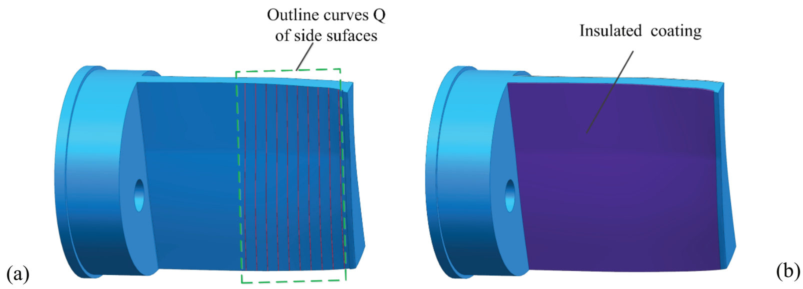

Figure 5: Side surface construction (a) and insulated coating (b).

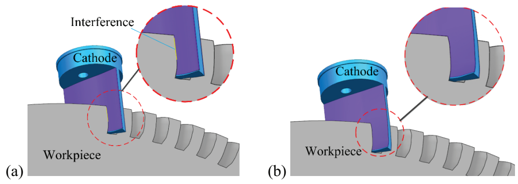

Figure 6: Interference detections with previous cathode design method (a) and cathode design method presented in this paper (b).

interference between cathode and anode even appears in some areas, marked by yellow line. Fig. 6b shows the detection result employed cathode designed with method presented in this paper. The width side gap is almost uniform and no interference happens.

3. Experiment and Results

The designed cathode is employed under the experimental conditions shown in the Table 1. The cathode is made from stainless steel 304 by CNC machine center (Fig. 7). Side surfaces of cathode are covered with high-hardness ceramic. Experimental system is shown in Fig. 8a. During machining, machining gap is pumped with clean electrolyte of 228 g/L $NaNO_3$. A potential difference of 20 V is applied to the electrodes by a DC power supply. Cathode is fixed to the main spindle and feeds with a constant feed speed of 1.2 mm/min. Fig. 8b shows final position of the process, which illustrates that side surfaces of cathode suits the channel exactly. There is a large space between blisk channel and cathode side surfaces. Thus, the design is verified to be reasonable and successful.

4. Conclusion

This paper develops a cathode designing method, which is verified by the experiment. The method contains three steps:

Firstly, inter-electrode frontal gap is calculated based on the electrochemical theory. Blisk channel shapes are obtained by offsetting the cathode outline with a distance of inter-electrode frontal gap.

Figure 7: Result of designed cathode.

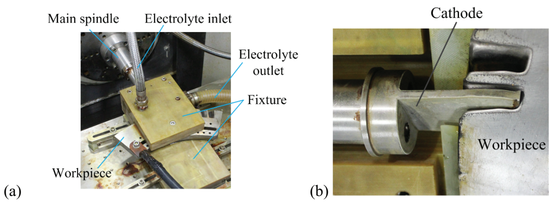

Figure 8: Experimental system (a) and final position of machining (b).

Secondly, a relative coordinate system is built on the cathode. Through transformation of coordinates, blisk channel shape is converted to the relative coordinate system. Shape of cathode is finally calculated based on the relationship between of cathode and channel.

Thirdly, an experimental system is employed to verify that the design allows avoiding interference completely.

Parameters	**value**
Workpiece materials	Inconel 718
Cathode material	Stainless steel 304
Insulated coating	Ceramic
Machining voltage	20 V
Cathode feed speed	1.2 mm/min
Electrolyte	228 g/L $NaNO_3$

Table 1: Experimental conditions.

Acknowledgements

This study was sponsored by the National Natural Science Foundation of China (51205199) and the Natural Science Foundation of Jiangsu Province (BK2012387).

References

[1] M. Bußmann and E. Bayer, Market-oriented blisk manufacturing - a challenge for production engineering

[2] A. Mateo, On the feasibility of BLISK produced by linear friction welding, *Revista de Metalurgia*, **50**, no. 3, p. e023, (2014).

[3] F. Klocke, M. Zeis, A. Klink, and D. Veselovac, Technological and economical comparison of roughing strategies via milling, EDM and ECM for titanium-and nickel-based blisks, 98–101

[4] F. Klocke, M. Zeis, A. Klink, and D. Veselovac, Technological and economical comparison of roughing strategies via milling, sinking-EDM, wire-EDM and ECM for titanium- and nickel-based blisks, *CIRP Journal of Manufacturing Science and Technology*, **6**, no. 3, 198–203, (2013).

[5] M. Burger, L. Koll, E. A. Werner, and A. Platz, Electrochemical machining characteristics and resulting surface quality of the nickel-base single-crystalline material LEK94, *Journal of Manufacturing Processes*, **14**, no. 1, 62–70, (2012).

[6] F. Klocke, M. Zeis, S. Harst, A. Klink, D. Veselovac, and M. Baumgärtner, Modeling and simulation of the electrochemical machining (ECM) material removal process for the manufacture of aero engine components, 265–270

[7] D. Zhu, J. Zhang, K. Zhang, J. Liu, Z. Chen, and N. Qu, Electrochemical machining on blisk cascade passage with dynamic additional electrolyte flow, *International Journal of Advanced Manufacturing Technology*, **80**, no. 1-4, 637–645, (2015).

[8] Z. Xu, L. Sun, Y. Hu, and J. Zhang, Flow field design and experimental investigation of electrochemical machining on blisk cascade passage, *International Journal of Advanced Manufacturing Technology*, **71**, no. 1-4, 459–469, (2014).

[9] J. Zhang, D. Zhu, Z. Xu, K. Zhang, J. Liu, N. Qu, and D. Zhu, Improvement of trailing edge accuracy in blisk electrochemical machining by optimizing the electric field with an extended cathode, *Journal of Materials Processing Technology*, **231**, 301–311, (2016).

[10] J. Zhang, Z. Xu, D. Zhu, and W. Su, Study of tool trajectory in blisk channel ECM with spiral feeding, *Mater Manufact Proc*, Article ID 1151040, (2016)., DOI: 10.1080/10426914.2016. (published online.

[11] D. Zhu, D. Zhu, Z. Xu, and L. Zhou, Trajectory control strategy of cathodes in blisk electrochemical machining, *Chinese Journal of Aeronautics*, **26**, no. 4, 1064–1070, (2013).

[12] D. Zhu, K. Wang, and N. S. Qu, Micro wire electrochemical cutting by using in situ fabricated wire electrode, *CIRP Annals - Manufacturing Technology*, **56**, no. 1, 241–244, (2007).