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# A high efficiency electrochemical machining method of blisk channels

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ABSTRACT

This paper presents an electrochemical machining method in which three stainless steel tubes as cathode tools move towards workpiece parts with space trajectories and electrolyte is ejected from the outlets of the tool tube walls to the workpiece to electrochemically produce three blisk channels simultaneously. The shape and structures of cathode tool tubes are optimized numerically and experimentally for distributing the electrolyte flow more uniformly. A special experimental system with synchronous motion of three tool tubes has been developed. Experimental results indicate that three channels can be produced at one time with good quality and high efficiency.



## 1. Introduction

Blisks (bladed integrated disks) are among the most innovative and challenging components in modern gas turbine engines. They could reduce weight obviously and significantly improve efficiency and reduce fuel consumption and emissions [1]. Therefore Blisks are widely used now in military engine and commercial turbofan. The disadvantage of blisks is laborious manufacturing [2]. Because of working under the severe condition, blisks are usually made of titanium alloys or Ni-base superalloys which are extremely difficult to be machined. Moreover the shapes of these blisk profiles are very complex and usually channels are narrow, so it is very difficult to achieve the required component by traditional methods such as cutting processes.

Electrochemical machining (ECM) is an important technology in processing difficult-to-cut alloys and to shape free form surfaces [3]. It has been widely applied in aeronautics, aircraft and aerospace industries especially in the blisk which is difficult to cut [4]. However, because there are often several tens to hundreds blades in each blisk, and in recent blisk ECM method only one channel can be machined each time, the machining time is long and the process is inefficient [5]. This paper aims to present a high efficiency ECM method of blisk channels in which three stainless steel tubes as cathode tools move towards workpiece parts with space trajectories and the electrolyte is ejected from the outlets of the tool tube walls to the workpiece to electrochemically produce three blisk channels simultaneously. A special experimental system with synchronous motion of three tool tubes has been developed and the space trajectory of tool tubes is optimized. The shape and structures of electrolyte outlets on the tool tube wall are also optimized for distributing the electrolyte flow more uniformly. Experimental results indicate that three channels can be produced at one time with good quality and high efficiency.

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## 2. Principle of the proposed process

Blisk ECM includes two steps. First is the machining of channels. With this process several tens to hundreds channels which have allowances are machined electrochemically for the subsequent finish machining. The second step is the precise shaping of blade profiles based on the pre-machined channels. Fig. 1 shows steps of blisk ECM. This paper focuses on the first step which is very important to the efficiency and quality of blisk ECM. The purpose of the step is to machine channels with high efficiency and keep uniform allowances of the channel for the next machining.

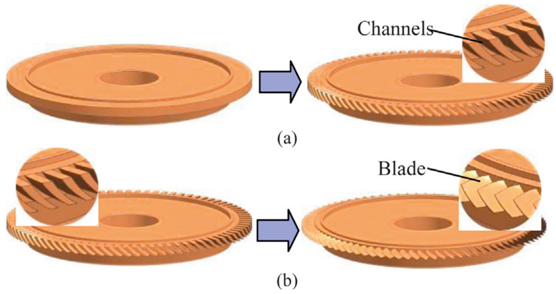


**Fig. 1.** The steps of blisk ECM. (a) The channel ECM and (b) the blade profile ECM.

This paper presents a high efficiency ECM method of blisk channels. The machining process of single channel with this method is schematically depicted in Fig. 2. A stainless steel tube is the cathode tool connecting negative pole of power and the workpiece is the anode. The tool is a dead-end tube and there are outlet holes or slits on the tube wall. The electrolyte is pumped into the tube and is ejected from outlet holes or slits to the workpiece surface. During the process there are three motions of cathode and blisk. As shown in Fig. 2, the blisk rotates around its axis at the velocity $\omega_1$. At the same time the cathode tool feeds down at the velocity $v_2$ and swings around the axis $L$ at the velocity $\omega_3$ to remove workpiece material electrochemically. The axis $L$ is perpendicular to the plane of the disk at the end of tool

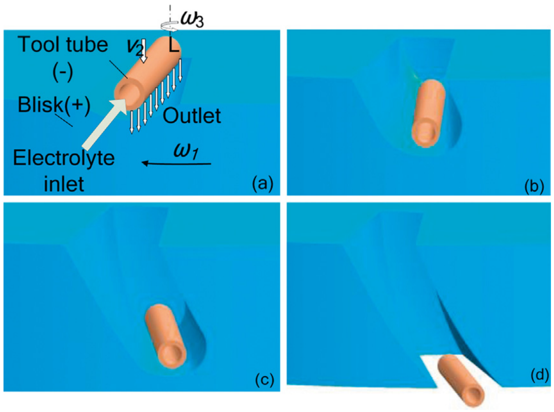


**Fig. 2.** The machining process of single channel with ECM.

tube. After one channel was machined, the workpiece will be rotated at certain angle for the next channel machining. Finally all of the curved channels with allowances could be machined.

The above-mentioned method is the way to machine single channel at one time. In order to improve the efficiency of channel machining, more cathode tools could be used to machine multi channels at the same time. As Fig. 3 shows, three stainless steel tubes as cathode tools are distributed horizontally at the same plane. The tubes could feed down and rotate synchronously to machine three channels simultaneously. With this method the machining efficiency could be improved obviously especially with more electrodes. Fig. 4 shows the developed synchronous movement apparatus of tools. With the apparatus three tool tubes could feed down and swing at the same time.

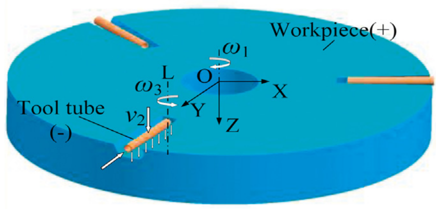


**Fig. 3.** Schematic view of blisk channel ECM.

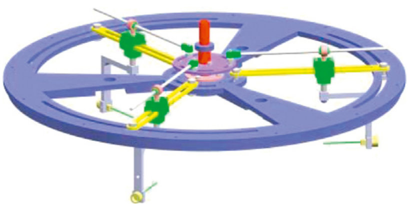

**Fig. 4.** Schematic view of tubes movement apparatus.

There are two main aspects which should be studied in the paper for machining channels with good quality and stability. First is the optimization of space trajectory of tool and second is the analysis of flow distribution.

## 3. Space trajectory of cathode

In order to improve the allowance uniformity of channel, the space trajectory of tool tube is analyzed and optimized in the paper. Firstly the primary space trajectory could be obtained by connecting the midpoints of suction surface and pressure surface. With a set of equidistant planes perpendicular to the $Z$ axis slicing section curves of standard blade profiles, discrete points are obtained and straight lines which fit the discrete points could be calculated based on the least square method.

Then the fitting line of suction surface at the plane $z = z_j$, $D_{jl}G_{jl}$ as shown in Fig. 5, can be obtained. The fitting line of pressure surface at the same plane, $D_{jr}G_{jr}$, could also be got by the same method. Therefore the position of tube axis at this plane could be obtained by connecting the midpoints of $D_{jl}D_{jr}$ and $G_{jl}G_{jr}$ ($M_{jd}M_{jg}$ shown in Fig. 5). Then the space trajectory of the cathode tool could be achieved by connecting all positions of the tube axis in every plane.

However these positions of tube axis are only based on standard contour profiles of blade. With this trajectory machining allowances are not very uniform because lateral gaps of suction surface and pressure surface in horizontal plane are not equal when feeding direction is not vertical. Therefore considering the lateral shaping law of ECM the space trajectory could be optimized in order to improve the uniformity of machining allowances of suction surface and pressure surface.

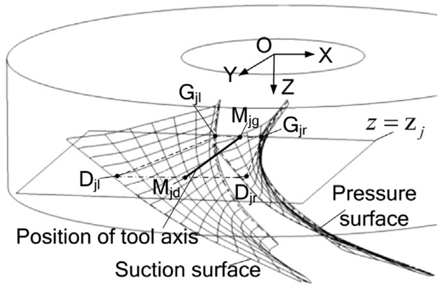


**Fig. 5.** The position of tool axis at the plane $z = z_j$.

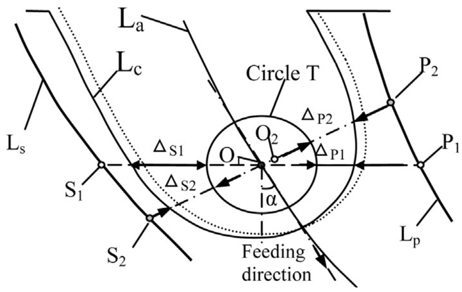


**Fig. 6.** Inter-electrodes gap of tool tube and blisk channel.

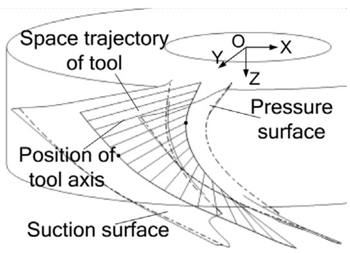


**Fig. 7.** Space trajectory of tool.

Fig. 6 shows the inter-electrodes gap of tool tube and blisk channel in a certain plane and schematically depicts the optimization method of tube axis. As Fig. 6 shows, $L_s$ and $L_p$ are the standard profile lines of blisk suction surface and pressure surface. $L_{cd}$ is the contour line machined by ECM. Circle $T$ is the section plane of tool tube and $O_1$ is the axis centre of tool as well as the midpoint of horizontal line $S_1P_1$. The line $L_{ab}$ is the movement trajectory of tool in this plane and the angle between the feeding direction and vertical direction is $\alpha$. $\Delta_{S1}$ and $\Delta_{P1}$ are the lateral gaps of suction surface and pressure surface respectively between tool circle and machined contour line of workpiece in the horizontal direction. As the feeding direction of tool is not perpendicular to the horizontal plane, $\Delta_{S1}$ is not equal to $\Delta_{P1}$ according to the lateral shaping law. As a result, the machined allowances of suction surface and pressure surface are not uniform. On the contrary, perpendicular to the tool feeding direction the lateral gaps of ECM, $\Delta_{S2}$ and $\Delta_{P2}$, are more consistent. Therefore the position of $O_1$ could be changed to obtain more uniform allowances of suction surface and pressure surface. Through point $O_1$ a straight line is drawn perpendicular to the tool feeding direction which intersects $L_s$ and $L_p$ at point $S_2$ and $P_2$. The midpoint of $S_2$ and $P_2$, namely point $O_2$, is the new position of tool centre in the plane. Connecting all of positions the new space trajectory of tube axis (Fig. 7) could be obtained.