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Trajectory control strategy of cathodes in blisk electrochemical machining

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Abstract A turbine blisk, which combines blades and a disk together, is one of the most important components of an aero engine. In the process of blisk electrochemical machining (ECM), the sheet cathode, which is usually used as a tool electrode, has a complicated structure. In addition to that, the channel between the adjacent blades is narrow and twisted, so interference is apt to happen when the sheet cathode feeds into the channel. Therefore, it is important to choose suitable trajectory control strategy. In this paper, a new trajectory control strategy of the sheet cathode is presented and corresponding simulation analysis is conducted on the basis of an actual blisk model. The simulation results demonstrate that the sheet cathode can feed into the channel by a spatial line trajectory without interference. Moreover, the verification experiments are carried out according to the simulation. The experimental results show that the cathode can move into the channel without interference. It is verified that the new trajectory control strategy is correct and can be used in the blisk ECM process successfully.

1. Introduction

Blisks (bladed integrated disks) are used for advanced heavy-duty compressor rotors in military and also increasingly civil turbine aircraft engines.[1,2] The manufacturing challenges in the production of blisk compressors are: hard-machining materials, ultrathin and complex blades, stringent quality and accuracy requirements, etc. These challenges are aggravated by even more demanding cost targets that can be achieved only by means of innovative manufacturing technologies.

Electrochemical machining (ECM) has become the preferred manufacturing approach for blisks of nickel alloys, owing to the significant savings in tool cost. It is characterized by small gap dimensions (usually 0.2–0.6 mm) between the electrode and a workpiece. This enables high conformance of the workpiece shape to that of the cathode. The ECM process does not generate any wear at the electrode, even when working on nickel alloys that are difficult to be machined.[3–5] It has been developed and employed in highly specialized fields such as aerospace, aeronautics, and medicine.[6–8] In the manufacturing of nickel-alloy blisk blades, a two-stage approach has been adopted. Firstly,

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airfoils with a machining allowance are produced using the ECM process in which the ruled surface is used to approximate the freeform surface of a blade and the boundaries of the tunnel are determined. Profile ECM is then used to generate the final shape of airfoils and annulus.

Due to complexity of sculptured surface geometry, it is difficult to obtain tool paths for sculptured surface machining. Burns et al.[9] illustrated a method and an apparatus for electrochemically machining airfoil blades in which the workpiece moved in the *Z* direction toward the electrode. The tool path between the electrode and channel of the workpiece was a linear path. Hinman and Conn[10] developed a cathode which had a pocket to receive an airfoil blade adjacent the individual blade to be machined. The cathode fed along the axes or directions that were located at an inclined angle relative to the horizontal, e.g., the *X* axes were oppositely inclined at a 30° angle relative to the horizontal. Lamphere et al.[11] proposed an electrochemical apparatus and the cutter was rotated and plunged twisted into the workpiece (blisk). McGee et al.[12] expounded a rotary drive subassembly (cathode) which was lowered downward the workpiece so that the blades were positioned in the slots. Wei et al.[13] presented a multi-axis machine which was used to drive the tool and workpiece movements necessary to machine complex airfoil geometry. Ibler[14] proposed a method of making a bladed rotor with the blades being machined by ECM by means of forming cathodes reaching into the gaps. Many efforts have been focused on finding the interference-free tool path. Li et al.[15] developed special CAD/CAM software which consisted of five modules such as electrode design, path searching, and machining simulation modules for electro-discharge machining of shrouded turbine blisks. Zhan and Zhan[16] discussed the searching of an interference-free path to feed the electrode to machine blisks in the electrical discharge machining (EDM) process. Hu et al.[17] presented a new method for 5-axis machining of blisks and developed a spiral tool path to finish milling thin-walled blades. Wu et al.[18] described a new method which was based on the quadratic programming to generate an interference-free tool path to manufacture shrouded turbine blisks in EDM. Xu et al.[19] proposed an optimization method which optimized the movement paths of the tool cathode on the blade tip and foot cylinder surfaces in ECM of blisk channels, and the new paths were obtained by fitting the midpoints of vertical lines into the splines based on the sample points of the old paths. Wang et al.[20] proposed a fractional step method for machining large-diameter blisks on the basis of analysis of the blade features and a comparison of the available process schemes. Zhu et al.[21] promoted a combined slice cathode for producing big twisted blades.

According to the structures of the sheet cathode and the channel together with the characteristics of blisk ECM, a new trajectory control strategy of the sheet cathode is investigated for interference-free feed in multi-axis feeding process in this study. The strategy includes three main parts: (1) discretization treatment of the sheet cathode and the channel; (2) determination of the optimization criteria of the feeding direction; (3) simulation of the feeding process. Then, corresponding simulation analysis is done based on an actual blisk model according to the new strategy. The simulation results demonstrate that the sheet cathode can feed into the channel by a space line trajectory without interference. Moreover, the verification experiments are carried out on the basis of the simulation. The experimental results show that the cathode can move into the channel with no interference. It is verified that the new trajectory control strategy is accurate and can be used in the blisk ECM process. This new method can also be applied to many other machining applications involving complicated geometrical shapes.

2. Description of the feeding process

2.1. Blisk structure introduction

A blisk is a key engine component comprising a rotor disc and blades, which is machined from a solid piece of material. It is made from a high-temperature alloy (e.g., nickel-based alloy or titanium alloy) and hence, is difficult to be machined. In addition, its geometrical shape is complicated involving many semi-enclosed, twisted, and free-form surfaces. In order to ensure the best performance, its dimensional accuracy is highly demanded.

In the blisk ECM process, there are generally two machining steps named rough machining and finish machining. After rough machining, a blisk is divided into two regions, the blanks and the channels (see Fig. 1). The channels are where the cathodes are fed into, and the schematic feeding direction is shown in the figure. The blanks have bigger machined surface errors than the given tolerance and should be machined by the blade basin and back cathodes in the finish machining process. The cathodes continuously machine an unfinished blade until the machined surface errors are smaller than or equal to the given tolerance. The main research content of this paper is the cathode feeding process which happens between the rough and finish machining.

The blank generally has enough allowance for a blade's final forming, so a narrow channel is left. Meanwhile, the allowance on the blade basin and back profiles must be uniform so that over-cutting in blade machining can be avoided. Because the blade surface is complicated, the blank surface is also complicated. Due to the complicated blank surface and the narrow channel, it is very difficult for the cathode feeding process to be conducted. Therefore, finding an appropriate and accurate interference-free tool path is very necessary and important;

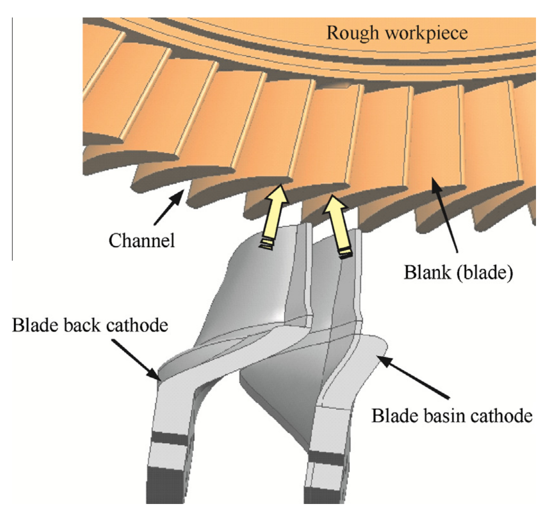

Fig. 1 Schematic illustration of the channels and the cathodes.