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# Blasting Erosion Arc Machining of Turbine Blisk Flow Channel with Laminated Electrode

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**Abstract**

This paper presents a new process for machining the flow channels of wide gap shrouded blisk. It utilizes the blasting erosion arc machining (BEAM) process with laminated electrode which contains a number of curved flushing holes. The laminated electrode is an integration of several layers (slices) of electrode plates. As a strong inner flushing in the gap is the prerequisite for the hydrodynamic arc breaking mechanism for BEAM, curved flow slots are machined on each electrode plate surface to enable the working fluid to flow through and perform a strong inner flushing. Machining experiment with laminated electrode was carried out to demonstrate the feasibility of this novel machining technology. By optimizing the contour profile of the laminated electrode, the geometry of the inner slots as well as the feeding path, a stable and continuous electro-arcing process of BEAM was achieved and a blisk channel was machined efficiently.



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*Keywords:* blasting erosion arc machining (BEAM), turbine blisk, laminated electrode, inner flow slots, fluid flushing

## 1. Introduction

Turbine blisks in aerospace industries are usually made from super alloys which have excellent mechanical properties [1], but these alloys are also belong to difficult-to-cut materials and hard to be machined by traditional cutting processes [2]. It induces workpiece vibration and severe tool wear [3] during machining. Milling process for Ni-based alloys has economical drawbacks such as long machining time and high tool cost. Non-traditional machining processes such as EDM, ECDM [4][5] show a great advantage in processing of the difficult-to-cut materials. The averaged MRR of EDM for Ti6Al4V is 220 mm$^3$/min [4]. Normal EDM doesn't have high efficiency. By applying pipe electrode, high speed EDM milling and arc machining [6][7] can achieve a high material remove rate (MRR) of 21,494 mm$^3$/min with 700 A peak current, when processing titanium alloy Ti6Al4V. High speed electro-erosion milling of super alloy has also shown high efficiency and potential in blisk machining [8][9].

Blasting Erosion Arc Machining (BEAM) [10] is a new technique of non-traditional machining. Different from Electric Discharge Machining (EDM), it erodes material by electric arc instead of electric spark. It can reach a high MRR, up to 14,000 mm$^3$/min when machining nickel-based alloy with a 500 A peak current [11]. Therefore, high efficiency is the great advantage of BEAM. Since BEAM is an economic way to perform bulk material especially the difficult-to-cut alloys removal, its potential on machining wide gap blisk should be investigated.

The key mechanism of BEAM is how to control the electric arc during machining. The inner flushing between electrode and workpiece induces intensive hydrodynamic force on the arcing plasma column to distort, elongate, or even break the arc column. During the arc breaking process, the blasting force will blow off the molten material and form a deep crater. Hydrodynamic arc breaking mechanism is the principle of BEAM and a strong inner flushing is a prerequisite for BEAM process [10]. Besides, the flushing



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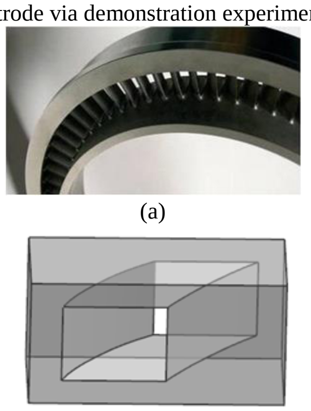
fluid can carry large amount of heat and debris away from the gap.

To perform a high velocity inner flushing, there are multi-holes inside all BEAM electrodes. Bundled electrode [12], multi-hole solid electrode [11], and laminated electrode [1] have various structures with specific functions for certain cavities machining. A Bundled electrode composes of many hollow tubular cell electrodes and its surface fits to the surface of a traditional solid electrode. A bundled electrode usually feeds in one direction, especially the Z axis.

A multi-hole milling electrode is a solid cylinder electrode with some inner holes. During BEAM process, the electrode rotates and feeds in a milling type, accompanying with a strong inner flushing. By feeding in a milling-like mode, it's possible to machine most open and semi-open cavities.

However, for some special features with complex concaves or curved flow channels, such as the shrouded blisk, how to design a suitable electrode is still a big challenge for the BEAM process. Neither bundled electrode nor solid tubular multi-hole electrode is suitable for machining such features. The blisk channels can only be BEAM machined by using a solid multi-hole electrode and performing a 4-axis or 5-axis NC machining. Generally, the channels are not straight and even the cross sections are different for an optimized flow field. As can be seen in figure 1. (a), the shrouded turbine blisk has curved flow channels. Figure 1. (b) is the model of one simplified shrouded channel which also generates the model of electrode introduced in the second part. How to fabricate multiple flushing channels inside a solid electrode is a big challenge. In order to solve this problem, laminated electrode was proposed. A laminated electrode is composed by several layers of electrode which has flow slots on the surface of each electrode. After stacking and fixing the laminated electrodes together, the outside profile of the electrode is machined to fit the geometry of solid electrode accurately. The inner slots will provide strong inner fluid flushing during machining. Hence it is capable to perform die-sinking BEAM and machine complex 3D cavities.

This paper fist studied the principle of laminated electrode design, and then investigated feasibility of BEAM with this electrode via demonstration experiment.



(a)

(b)

Figure 1. (a) A turbine blisk; (b) A shrouded blisk channel

## 2. Laminated Electrode

For one specific cavity machining, the contour shape of the laminated electrode is almost same as the solid die-sinking electrode. Because an intensive flushing is a prerequisite of BEAM process, the key feature of laminated electrode is that it has flow slots going through from the working fluid entrance to the top end of the electrode. So the difference between these two electrodes is the flow slots inside the laminated electrode can be curved or even have a varied cross-section while it is impossible to prepare such channels in the solid electrode.

### *2.1. Design of Laminated Electrode*

The design of laminated electrode includes two stages: retrieve the outline profile geometry and design the inner fluid chamber and slots on each layer.

According to the turbine blisk model, the flow slots can be separated by subtracting the blisk from a bounding 3D body. Then the cavity part of the workpiece could be acquired by trimming using specific planners. And it's also the part to be removed during machining. The solid die-sinking electrode was generated by considering the machining allowance. Then the outline geometry of the designed electrode was acquired, as shown in figure 2.

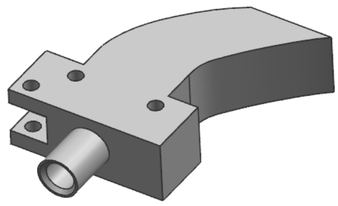


Figure 2. The outline geometry of the designed laminated electrode

The second step was to design the working fluid chamber inside the laminated electrode. By considering the rigidity of each layer, the whole electrode was divided into several 8 mm thick layer electrodes. On the surface of each layer, flow slots were designed to guide the flow inlet from the chamber to the outlet at the end. The main purpose of the chamber inside the electrode is to decrease the hydraulic resistance and increase the flow velocity as much as possible. The width and depth of the slots are about 2-3 mm to keep the fluid flushing in a high speed. Another problem is to keep the strength of the layer electrode. When designing the structure of the whole electrode and each layer, the mechanical property and machinability of the electrode should also be considered. The final designed laminated electrode with inner flow slots is shown in figure 3. There are through-holes on each layer of the laminated electrode, therefore 2 bolts can be used to fasten and stack them together.