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Angular Movement Ratio Planning of the rotary axes for Shrouded Blisks Multi-Axis EDM

CHEN Hao[a], XI Xue-Cheng[a], ZHAO Wan-Sheng[a,*]

a *State Key Laboratory of Mechanical System and Vibration, Shanghai Jiao Tong University, Shanghai 200240, China*

* Corresponding author. Tel.: +86-21-3420 3694; fax: +86-21-3420 3694. *E-mail address:* zws@sjtu.edu.cn

Abstract

Compared to traditional machining approaches, multi-axis EDM has its unique advantages in machining components with complex structures made of difficult-to-cut materials, such as shrouded blisks. The manufacturing process of such complex parts involves both synchronized movements of both linear axes and rotary axes. Due to the geometrical difference between the linear and rotary axes, improper resultant velocity which is the combination of each individual axes, is likely to cause inconsistent discharge gaps. In most multi-axis CNC systems for EDM, angular movement ratio is kept to be constant, which may result in an instable discharge status. In order to ensure the machining stability, this paper proposes an angular movement ratio planning method. In this method, CAD models of both electrode and shrouded blisk will be taken into account. For each rotary axis, a parameter is used to represent the angular movement ratio. The ratios help to obtain a single-axis motion constant discharge gap and weighted average movement ratio algorithm can reduce the feedrate fluctuation of synchronized movements.

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Keywords: multi-axis EDM, angular movement ratio, shrouded blisks, CNC system

1. Introduction

Turbine blisks play a vital role in aero and rocket engines. The performance of turbine blisks has a great influence on the engine performance, reliability, thrust-weigh ratio and maintenance cost[1]. Compared with unshrouded blisks, shrouded blisks have advantages such as high efficiency and high reliability so that shrouded blisks gained much more applications in the field of turbine engines, especially in rocket engines during recent years[2].

Multi-axis electrical discharge machining (EDM) is regarded as the most effective approach for machining shrouded blisks[3]. Compared to traditional machining approaches, multi-axis EDM has its unique advantages in machining components with complex structures made of difficult-to-cut materials. In EDM of shrouded blisks, the tool electrode is shaped and reduced according to the profile of the flow channel so as to get enough space for electrode feeding. By feeding the tool electrode along an interference-free and optimized pre-designed path and copying the blade profile, the flow channels are carved.

The initial feed path was manually searched which is still in use. Each axis of the feed path that obtained manually moves individually. Wu et al generates tool path in two steps, a feasible zone is generated by a coarse search first and the actual NC path is found by a fine research through CNC multi-axis simultaneous control simulation[4]. Li developed a CAD/CAM system based on UG/OPEN API for EDM of shrouded turbine blisks[5]. Liu proposed a tangent tracking feed path method which based on dynamic programming to solve the problem constrain of electrode dimension[6,7]. The feed path of their searching methods involves at most synchronized movements of both 3 linear and 2 rotary axes.

Due to the geometrical difference between the linear and rotary axes, improper resultant velocity which is the combination of each individual axes, may lead to inconsistent discharge gap and feedrate. A servo control system is applied to provide an appropriate discharge gap for maintaining a stable discharge process. In most multi-axis CNC systems for EDM, angular movement ratio is kept to be constant regardless of the variations in the diameters of different parts. In the servo control process, when the same discharge status

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has been estimated, the increments of coordinate values are proportional of the feedrate which neglect the radius. Because of the difference meanings of same increments of coordinate values and same displacements of rotary axes, a constant angular movement ratio is thus likely to cause an instable discharge status. For instance, with the same angular feedrate, the point on the circumference of an electrode with a radius of 100 mm moves 10 times faster than that on an electrode with a radius of 10 mm.

Few papers have been reported in angular movement ratio planning of rotary axes for multi-axis EDM. In order to ensure the machining stability of the single rotation axis machining, Liang developed an angular speed ratio adaptive control technique[8]. However, Liang's method cannot be applied in coordinated movement involved both linear and rotary axes. To machine a contoured geometry, 5-axis high-speed milling also need adjust the feedrate to achieve high efficiency. To obtain a uniform feedrate, a post-processing process is adopted but the speed fluctuations of tool tip still exist[9]. A look-ahead function was used in transforming G01 codes into cubic Bezier curves to alleviate speed fluctuations which is only useful in 3-axis milling[10]. Therefore, the methods used in multi-axis milling are not suitable in the shrouded blisk multi-axis EDM and an angular movement ratio planning method is needed to ensure the machining stability.

In this paper, an angular movement ratio planning method is proposed. In this method, CAD models of both the electrode and the shrouded blisk will be utilized for the choice of movement ratios. The ratios help to obtain a single-axis motion constant discharge gap and weighted average movement ratio algorithm can reduce the feedrate fluctuation of synchronized movements.

Nomenclature

V_{TW}	velocity of electrode to workpiece
V_{EW}	erosion speed of workpiece
S_{EW}	discharge gap
λ_i	scale of axis *i*
k	movement ratio
k_i	movement ratio of axis *i*
r_i	radius of axis *i*
ω_i	increment proportion of axis *i*
Δi	increments of axis *i* in a G-Code block
F	feedrate of a G-Code block
Δs	equivalent movements of a G-Code block
Δt	theoretical feed time of a G-Code block
Δx	increments of x axis in a G-Code block
Δy	increments of y axis in a G-Code block
Δz	increments of z axis in a G-Code block
Δb	increments of b axis in a G-Code block
Δc	increments of c axis in a G-Code block

2. Angular Movement Ratio Planning of the rotary axes for Shrouded Blisks

Figure 1 shows a schematic diagram of the 6-axis EDM machine kinematic structures for machining shrouded blisks. In addition to three linear axes (*X*, *Y*, *Z*), 6-axis EDM machine tools also involve 3 rotary motions around the rotational axes, which are designated as *A*, *B* and *C* to present the rotary axes around the *X*-axis, *Y*-axis and *Z*-axis, respectively. In typical EDM of shrouded blisks, the electrode path is achieved through the coordinated motion of the electrode in the *X*, *Y*, *Z* and *C* axial directions, and the blisk in the *B* axial direction. The consecutive structural elements can be described according to Fig. 2 in which *A*-axis need not move in the machining process.

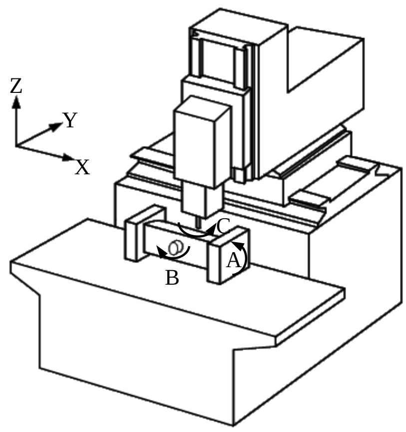

Fig. 1 Schematic diagram of 6-axis EDM machine kinematic structures for machining integral shrouded blisk

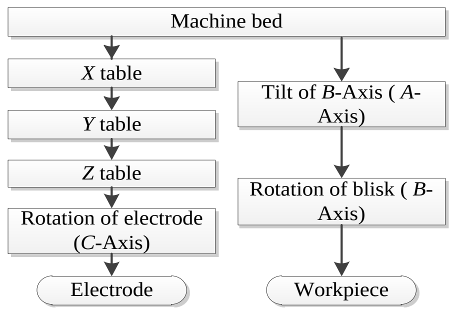

Fig. 2 Relationship of structural elements of 6-axis EDM machine

EDM is a non-contact machining process in which a proper electrode-to-workpiece discharge gap needs to be maintained. During stable electrical discharging, the workpiece is eroded at a speed V_{EW} and the discharge gap becomes wider. In order to maintain a stable discharge process, the electrode needs to feed at a speed V_{TW} to compensate the erosion of workpiece. The servo control system estimates the current discharge gap by measuring the voltage and current, and decides the feed V_{TW} of electrode by using empirical algorithm. In empirical algorithms, the measurement of V_{TW} is millimeter per second. However, in CNC system, the measurement of V_{TW} converts to minimum interpolation unit which namely basic length unit (BLU) per interpolation period. During the servo control involving rotary axes, the CNC system may not know the radius of the rotary axes, so the actual feedrate may have a large difference with the demanded feedrate which is