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Processing Method of Spatial Complicated Curved Surface of High-speed WEDM

***Abstract**. To solve the difficult problems of machining spatial curved surface parts in high-speed wire cut electronic discharge machining (WEDM), an automatic indexing and turnover NC rotary table based on the mathematical models of spatial complicated curved surface was designed. Then the multi-axis movement WEDM system and its experimental device were established. Through machining experiment, it shows that the multi-axis movement WEDM system has high machining quality and low cost and has practical applicability, to produce a novel research direction for solving the difficult problems of machining spatial curved surface parts in high-speed WEDM.*

***Streszczenie.** W artykule przedstawiono projekt stołu rotacyjnego typu NC stworzonego na potrzeby stanowiska do wycinania elektroerozyjnego. Budowa stołu oparta została na modelach matematycznych obiektów o przestrzennie zakrzywionych płaszczyznach. Wykonano i przedstawiono wyniki prac eksperymentalnych, potwierdzających wysoką użytkowość stołu dla metody WEDM. (**Obróbka i wycinanie obiektów o skomplikowanych krzywiznach przestrzennych metodą elektroerozyjną WEDM o dużej prędkości**).*

Keywords: wire cut electronic discharge machining (WEDM); spatial curved surface parts; NC rotary table; multi-axis movement.
Słowa kluczowe: obróbka elektroerozyjna WEDM, części o płaszczyznach zakrzywionych przestrzennie, stół rotacyjny NC, ruch wieloosiowy.

Introduction

WEDM is a machining technique which uses the pulsed spark discharges to produce local instantaneous high temperature to realize the ablation of materials [1, 2]. It is suitable for machining spatial complicated curved surface and be widely used in die manufacturing industry field. However, the machining of spatial complicated curved surface abroad is realized on low-speed WEDM, which has high cost and is unsuitable in high-speed WEDM for our country [3, 4]. To get high tapered spatial complicated curved surface parts, it is necessary to do some further studies for the additional device. Some scholars of Harbin institute of technology designed a two-axis CNC worktable, which could drive the machined part to rotate with a fixed-axis and meanwhile to swing with another axis. However, it could only machine some simple spatial surface parts [5, 6], and its applied range urgent to be expended [7, 8].

In this paper, the spatial complicated curved surface machining of high-speed WEDM was studied, and a NC rotary table which can indexing and turnover automatically was designed. Then the mathematical models of spatial complicated curved surface and the multi-axis movement WEDM experimental device were established. It provides a foundation for solving the difficult problems of machining spatial curved surface parts.

Turnover NC rotary table design

For the high-speed WEDM, the machining for rotational surface is always the bottleneck to hinder its development [9]. The multi-axis movement WEDM system is composed of a high-speed WEDM and a turnover NC rotary table. The schematic diagram of transmission principle of the NC rotary table is shown in Fig. 1.

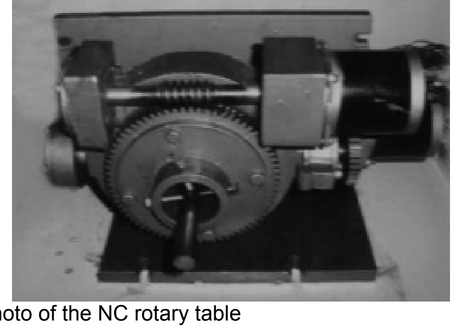


Fig. 1. Photo of the NC rotary table

Models of spatial complicated curved surface

Taking the central axis of workpiece as X axis, and the polar coordinate of machining system is established as shown in Fig. 2. ±X is the horizontal feed movement along positive and negative X axial direction. ±A is the clockwise and anticlockwise rotation with X axis. E is the distance between X axis and the wire electrode. θ is the angle between X axis and the wire electrode. α is the angle between processing direction of wire electrode and the projection line of X axis on worktable.

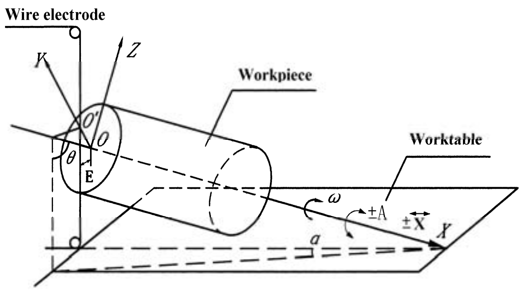


Fig. 2. Polar coordinate of machining system

The general formula of motion form can be expressed as $\sum\left[(\pm)X+(\pm)A+E+\theta+\alpha\right]$, which contains all motion parameters under the polar coordinate of machining system. The other motion forms can be transformed from the general formula. Taking the coordinate plane YOZ rotating for φ with X axis to get a new coordinate O1X1Y1Z1, the relationship can be expressed:

$$(1)\qquad \begin{cases} X_1 = X \\ Y_1 = Y\cos\phi + Z\sin\phi \\ Z_1 = -Y\sin\phi + Z\cos\phi \end{cases}$$

Taking the point O_1 moving horizontally to point O_t ($vt\cos a\cdot\sin\theta, -vt\sin a, vt\cos a\cdot\cos\theta$) to get a new coordinate $O_tX_tY_tZ_t$, the relationship can be expressed as the following:

(2) $$\begin{cases} X_1 = X_t + vt\cos a \cdot \sin\theta \\ Y_1 = Y_t - vt\sin a \\ Z_1 = Z_t + vt\cos a \cdot \cos\theta \end{cases}$$

When the workpiece moves with speed v and rotates with angular speed ω until time t, it can be:

(3) $$\begin{cases} Y_t = E \\ Z_t = -\tan\theta \cdot X_t \end{cases}$$

Taking Eq. (2) into Eq. (3), we can get:

(4) $$\begin{cases} Y_1 = E - vt\sin a \\ Z_1 = -\tan\theta \cdot X_1 + vt\cos a \cdot \dfrac{1}{\cos\theta} \end{cases}$$

From Eq. (4) and Eq. (1), the model of system can be expressed as the following:

(5) $$\begin{cases} Y\cos\phi + Z\sin\phi = E - vt\sin a \\ -Y\sin\phi + Z\cos\phi = -X\tan\theta + vt\cos a \cdot \dfrac{1}{\cos\theta} \end{cases}$$

where: $\theta \in [0, \pi/2]$ and $\alpha \in [-\pi/2, \pi/2]$.

According to the processing principle of WEDM, any complicated ruled surface parts can be machined by the multi-axis movement WEDM, which can realize the composite motions by using the NC rotary table.

Establishment of multi-axis movement WEDM system

Flow diagram of the multi-axis movement WEDM is shown in Fig. 3. Taking PC as NC device, most of the functions of WEDM can be achieved easily. Besides, it has favorable expansibility and real-time responsive properties. PMAC multi-axis motion controller and the corresponding interface integrated card (ACC-8S) are used to control the motion of all transmission shafts to realize the machining process. The multi-axis movement WEDM system is composed of DK7740B high-speed WEDM, PC, PMAC multi-axis motion controller, ACC-8S interface integrated card, SMD-530F driver, 86BYGX450B-02 stepping motor and the NC rotary table.

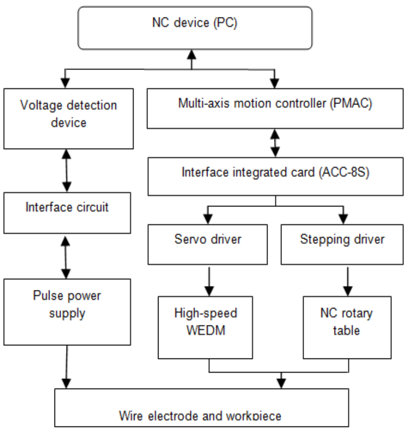
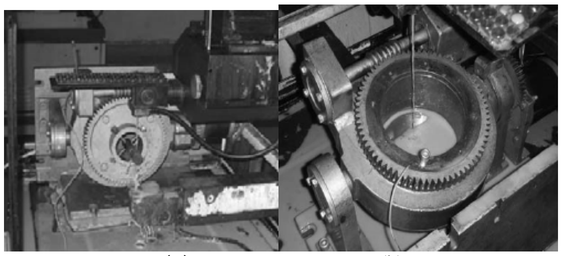


Fig. 3. Flow diagram of the multi-axis movement WEDM

The tool parameters: the work table length is 800 *mm* and width is 500 *mm*; the operating stroke along axial *X* is 400 *mm* and 500 *mm* on axial *Y*; the maximum cutting depth is 250 *mm*; the maximum cutting inclination is ±6°; the maximum working thickness is 50 *mm*; the maximum cutting speed is 100 *mm/min*; the maximum working current is 6 *A*; the working surface roughness is Ra≦2.25*μm*; the diameter range of the wire electrode is 0.13 *mm* to 0.25 *mm*; the wire travelling speed is 11.6 *m/sec* or 5.8 *m/sec*; the carrying weight of the work table is 550 *kg*; the working fluid: the special working liquid; the tankage of the working liquid: 50 *L*; the tool power supply: AC 3N 380*V*±10%50±1*Hz*; the tool power: 2 *KVA*; the type of controlling machine: BKDC. The NC rotary table can be placed horizontally and vertically with *Y* axis to extend its processing range as shown in Fig. 4.



(a) (b)

Fig.4.Horizontally (a) and vertically (b) placement of NC rotary table

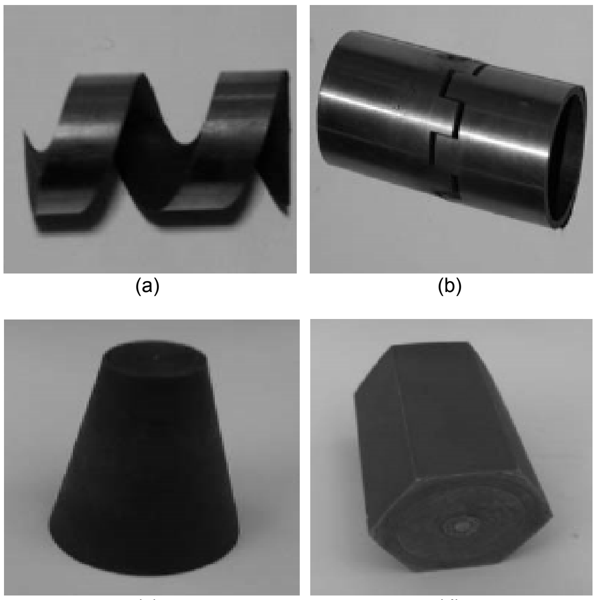
Experimental condition and results:

Taking the machining process of the normal helicoid as example, the motion and processing parameters of the NC rotary table are as shown in Table 1.

Table. 1 The motion and processing parameters

NO.	Parameters	Values
1	Power voltage (*V*)	24
2	Driver current (*A*)	0.8
3	Motor step angle (°)	1.8
4	Whole/half step selection	half
5	Level direction	low
6	Pulse numbers	2000
7	Pulse frequence (1/s)	1
8	Cutting speed ($\mu m/s$)	20

The sample pieces of processing experiment are shown in Fig. 5.



(a) (b) (c) (d)

Fig. 5. Sample pieces photos of processing experiment: (a) oblique helicoid; (b) face tooth; (c) truncated cone; (d) hexagonal-pyramid

From the processing experiment results, it shows that the apparent shape of these samples are desired. However, there are some errors for the geometric parameters, such as the error of machine tool, the error of turnover NC rotary table, the clamping error of samples and the error of control system.

Conclusion

A novel multi-axis movement processing method based on a NC rotary table and a high-speed WEDM was present, then the NC rotary table which can indexing and turnover automatically was designed. The mathematical models of spatial complicated curved surface and the multi-axis movement WEDM experimental device were established. Through machining experiment, it shows that the multi-axis movement WEDM system has high machining quality and practical applicability. From error analysis, it shows that the errors are mainly from machine tool, the NC rotary table, installation of sample pieces and control system. It provides a foundation for solving the difficult problems of machining spatial curved surface parts in high-speed WEDM.

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