Investigation on Orbital EDM for Double-Hole Thin Wall of Integrated Flexible Joint

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Abstract

The thin neck structure of integrated flexible joint is the key factor to realize high-precision navigation in dynamically tuned gyroscope. The thin neck structure is composed of two adjacent circular holes and the thin wall between the two holes. The thin wall is easy to deform under the external force and vibration exerted by the tool when using traditional machining methods such as drilling and boring, and the cutting tools are easily to be damaged for the machining of small holes in superhard materials, inducing high processing cost. Aiming at these problems, the machining method of double-hole thin wall in the step-by-step orbital electrical discharge machining (EDM) with a high rotation speed electrode is proposed. The procedure for EDM of double-hole flexible thin wall is designed, and the process parameters of each step machining are optimized using orthogonal experiment and signal-to-noise ratio analysis. The machining experiments of double-hole thin wall of 3J33B material are proceed using the optimized parameters. The results show that the hole diameter of the double-hole flexible thin wall is 2 mm, the hole depth is 8mm, and the average thickness of the thin wall is about 46.5 μm . The thickness range between the measured point and the average is 1.55 μm , that compared with average thickness of 46.5 μm , the error is less than 3%, the overall thickness is uniform relatively.

1 Introduction

With the continuous progress and development of science and technology, the miniaturization and portability of devices have been the development trend of modern equipment. Microstructural systems have been widely applied in industry fields, such as aerospace and electronic, the typically application includes dynamically tuned gyroscope (DTG), printed circuit board (PCB) board and so on [1-3]. As the key component of DTG which mainly used in inertial navigation technology, flexible joint plays an important role in inertial system. The manufacturing accuracy of the flexible joint directly determines the performance of the inertial system. Flexible joints are mainly including two kinds, combined type and integrated type. At present, the integrated flexible joint widely used in developed countries, which processed from a whole bar. This avoids the assembly error of the combined flexible joint and greatly improves the navigation accuracy and service life of the gyroscope [4].

The thin neck structure of integrated flexible joint is the key factor to realize high-precision navigation. The navigation function of gyroscope is realized mainly through deformation of the hinge in the thin neck structure [3,5]. The thin neck structure is composed of two adjacent circular holes and a thin wall between the two holes. The thickness of the thin wall is only several micron meters. The metamorphic layer and micro crack during the processing of the thin wall may lead to the damage of the thin neck [6,7]. Therefore, high dimensional and position accuracy, and strict stiffness are basic requirements of the thin neck structure.

Many researchers had studied how to process high-quality thin wall. Deng et al investigated the effects of parameters on surface roughness and cutting vibration in micro parts with thin bottom surface, then obtained the better surface roughness of thin bottom wall with a thickness of 80 μm in precision turn-

milling machine tool by using optimized process parameters [8]. Ramanaiah et al studied the influence of the deflection and surface roughness of the thin walls at various feed rate, cutting speed and cutting depth. The researchers optimized the machining parameters by ANOVA regression technique, manufactured high-quality alloy thin walls with a thickness of 5mm [9].

However, the thin wall is easy to deform under the external force and vibration exerted by the cutting tool when using traditional machining methods such as drilling and boring [10]. In addition, in order to drilling small hole on difficult-to-machine materials, the special cutting tool or bit need to be fabricated with good wear resistance, leading to high processing cost and increasing the manufacturing difficulty of flexible joints [11-13].

EDM is a process which continuously discharge between tool electrode and workpiece in insulating working oil and removes the material by its transient local high temperature [14,15]. Comparing with traditional machining method, EDM does not directly contact the workpiece during machining process, inducing smaller macro force. It has specific advantage in machining low stiffness micro structural parts required high machining precision and good surface quality [16,17]. Previous studies had shown that EDM can be used for thin-wall machining [18]. However, the EDM process of thin wall has the problems, such as a large thickness of heat affected layer, a low shape accuracy in the hole depth direction caused by electrode loss in the machining process. There are few studies on EDM for double-hole thin wall machining of integrated flexible joints, it limits the application of EDM in the field of double-hole thin wall machining.

Thus, aiming at these problems, the step-by-step orbital EDM method with a high rotation speed electrode is used to machine the double-hole thin wall of integrated flexible joint in this study. The procedure of double-hole flexible thin wall is designed, and the process parameters are optimized based on orthogonal experiment and signal-to-noise ratio analysis. Moreover, the experiments of double-hole thin wall of 3J33B material with a single-hole diameter of 2 mm and a thin-wall thickness of 40 μm are carried out.

2 Prophase Experiments And Analysis

The double-hole flexible thin wall is mainly composed of two adjacent blind holes. The geometric tolerance of thin wall can be guaranteed only when the quality of deep blind holes is good. Therefore, the machining of the high-quality blind hole is the key to process high-quality thin wall. The preliminary experiments are carried out to study and find the processing problems of EDM for double-hole thin wall.

The EDM machine was high-speed perforating EDM machine (DS703T, Suzhou Sanguang Science Technology Co., Ltd.). The experiments were carried out on the high elastic alloy of 3J33B, the tool electrode was a copper tube electrode with an outer diameter of 1.7 mm and an inner diameter of 1 mm, and the target depth of the blind holes was 8 mm. The process parameters were: peak current of 17A, pulse duration of 36 μs , duty ratio of 0.5, injecting liquid pressure of 3 Mpa.

Although material removal rate (MRR) was high by EDM with injecting fluid from tube electrode, but the boss remained on the bottom of blind holes due to the structure and wear of the electrode. Besides, the debris generated during the process, inducing concentration discharge which made bad lateral. With the loss of electrode, the taper of hole became larger, inducing nonuniform thin wall, as shown in Fig. 1.

The problem with electrode wear and heat affected layer make one-step machining of the flexible thin wall with no boss, lesser taper, higher lateral quality and better uniform thickness be difficult. Moreover, the gap between tool electrode and workpiece during EDM processes is difficult to measure. Thus, it is necessary to adopt a step-by-step machining method to solve the problems in each processing step.

Orbital EDM is a machining method that relies on the moving axis other than the machining axis of the machine tool to move periodically with a certain track [14]. Orbital EDM increases the distance between the electrode and the hole lateral, the debris generated during EDM process can be easily flushed away from the hole, thus the quality of lateral can be improved. The orbital radius can be changed during EDM process to expand the holes based on the material removal volume, which can develop the accuracy of the processed hole diameter and the thickness of the thin wall. In addition, the high-speed rotating electrode with orbital EDM method can remove the bottom boss and reduce the taper of the hole, as shown in Fig. 2. Therefore, this paper proposes a step-by-step orbital EDM method with a high-speed rotating electrode to process the double-hole flexible thin wall in high elastic alloy 3J33B.

3 Decision Of Edm Method For The Double-hole Flexible Thin Wall

3.1 Procedure of EDM for the double-hole flexible thin wall

It was found in the prophase experiments that the hole machined by EDM had the problems of large hole taper, large roughness and boss at bottom. For these problems, the processing with high MRR can be used as the first step of machining process. Then, rough machining, semi finishing and finishing machining of holes and flexible thin wall can be processed using orbital EDM, and the process parameters can be optimized according to the processing objectives of each processing step.

The procedure for step-by-step orbital EDM of double-hole thin wall is shown in Fig. 3. The workpiece was high-elastic alloy 3J33B with a thickness of 10 mm. First, a brass tube electrode with a diameter of $\Phi 1.5\text{mm}$ was used to machine two pre-holes with a size of $\Phi 1.7 \times 7.8\text{ mm}$, and the center of the holes was 2mm apart in 3J33B. Then, a brass electrode with a diameter of $\Phi 1\text{ mm}$ was selected to carry out step-by-step orbital EDM with optimized process parameters. The detailed processing procedure is shown as follows:

1. Parameters with the largest MRR were selected as the first rough machining parameters to remove bottom boss.
2. Parameters with the best hole taper were selected as the second rough machining parameters to expand the pre-holes and maintain the hole taper.

3. Parameters with the lest flange length were selected as the semi finishing machining parameters to develop the machined surface of hole wall.
4. Parameters with the best surface roughness were selected as the finishing machining parameters to generate the flexible thin wall.

In addition, to machine a thin wall with uniform thickness of only tens of microns at the thin neck, the clamping error of workpiece and electrode and the manufacturing accuracy of electrode should be meet the requirements of processing. Therefore, the block electrode discharge grinding technology was carried out before and during machining to reduce the eccentric and perpendicular errors caused by the manufacturing accuracy and clamping of the electrode. Meanwhile, the movement error of workbench was calibrated by the dial indicator, and compensated during the EDM process, to reduce the repeated positioning error caused by the movement of the machine tool.

3.2 Compensation method of electrode wear

The Fig. 4 shown the electrode material is removed in radial direction during prophase experiments, which affects the diameter of the hole and the thickness of the thin wall, and the electrode wear rates (EWR) varied with the diameters of the electrodes. The electrode wear in radial direction was compensated as following methods:

1. The EWR based on parameters for the first rough machining, the second rough machining, the semi-finishing machining and the finishing machining were calculated. Then the electrode wear length of each machining step in radial direction can be obtained, the diameters of the holes can be controlled initially.
2. As shown in Fig. 5, the rotation of the electrode and the motion of the workpiece along a circular track were proceed simultaneously. If there was no eccentric error to the rotation center of the spindle after the electrode was clamped, the electrode wear in the radial direction was regarded as uniform. Therefore, as long as there was no electrode eccentric error, the electrode wear volume in the radial direction after each machining can be accurately measured and compensated by using the NC and contact sensing function of the machine tool, the size of hole can be accurately controlled.

The loss of electrode in radial direction can be calculated roughly by the method of relative EWR in step (1). The electrode wear can be obtained accurately by the method of contact perception in step (2), and then the loss of electrode was compensated during EDM processing.

4 Parameters Optimization Experiments Of High Elastic Alloy 3j33b Orbital Edm

The MRR, flanging width, taper and surface roughness as the processing objectives. Peak current, pulse duration, pulse interval, reference voltage, level of machining time, level of servo feed speed were used as the experimental factors, the orthogonal experiments was designed. The signal-to-noise ratio (SNR)

analysis method was used to optimize the orthogonal experiments results, and the optimized parameters were verified by experiments.

4.1 Orthogonal experiments and signal-to-noise ratio analysis

Orthogonal experiments were carried out on a EDM machine tool (HCD400K, Hanchuan Co. Ltd., with repeat position accuracy of 2μm) with high speed motorized spindle (NR-3060S, NAKANISHI Co. Ltd., with centering precision of 1μm), the brass electrode diameter was 1 mm, and workpiece material was 3J33B. The kerosene was chosen as working oil to avoid oxidation of 3J33B during high-temperature machining process.

In order to improve the machining efficiency, the high-speed EDM drilling machine was used to machine the pre-holes with the depth of 8 mm and the diameter of 1.7 mm, then orbital EDM method was used to enlarge the holes. Set the radius of orbital track as 250 μm, 290 μm, 310 μm, 340 μm, 370μm and 400 μm in turn, and the workpiece was connected to cathode. In order to avoid accidental errors, each group of parameters was carried out 3 times. The designed orthogonal experimental table $L_{25}(5)^6$ of six factors (peak current I_p , pulse duration T_{on} ,

pulse interval T_{off} , reference voltage U_s , level of machining time T , level of servo feed speed V) and five levels is shown in Table 1, and the orthogonal experimental results are shown in Table 2, including MRR, the width of flanging of hole (L), the taper of the hole wall (α) and the surface roughness (Ra).

During EDM process, the machining efficiency and machining quality can be influenced by many factors. Even under the same machining parameters, the machining results can be different each time because of random interference. Therefore, the changes of repeatability experimental results need to be taken into account in the post-processing analysis. SNR analysis was used to analyze the influence of experimental parameters and random interference on experimental objectives.

For the experimental objectives of 3J33B in EDM, the width of flanging, taper of the hole wall and the surface roughness are required to be very small and low, the SNR of these objectives should be calculated according to the expected small characteristic calculation by Eq. (1). On the contrary, the high MRR is required, and should be calculated according to the expected large characteristic calculation as Eq. (2).

$$LB: S/N = -10 \lg \left(\frac{1}{n} \sum_{i=1}^n y_i^2 \right) (\text{db}) \quad (1)$$

$$HB: S/N = -10 \lg \left(\frac{1}{n} \sum_{i=1}^n \frac{1}{y_i^2} \right) (\text{db}) \quad (2)$$

Where S/N is the value of SNR, N is times of repeat experiments, y_i is the objective value of the number i experiment, $i=1,2,3$

4.2 Optimal analysis for material removal rate

The SNR of MRR were calculated in Eq. (2). As shown in Table 3, the MRR of the 25th experiment has the largest SNR, the machining speed is the fastest, that is, the removal speed of material is the fastest. In range analysis, the value of R reflects the influence of factor changes on the variation magnitude of experimental objectives. As shown in Table 4, the influence order of various factors on the MRR is: peak current, pulse interval, pulse duration, level of servo feed speed, level of machining time. In the study, the large MRR is required. Thus, the optimal parameters should be the group with the largest SNR of each factor, the optimal parameters for MRR of 3J33B in EDM are: 9.6 A of I_p , 60 μs of T_{on} , 15 μs of T_{off} , 20 V of U_s , level 2 of machining time, and level 0 of servo feed speed.

The confirmation experiments were carried out, which were repeated for 3 times. The results are shown in Table 5. It can be known that the average for MRR of the optimized process parameters is increased by 20.58% compared with the result of the group with the largest MRR in the orthogonal experiments, which means that the optimized parameter group is the best scheme for MRR of 3J33B in EDM.

Table 1 Orthogonal experimental table $L_{25}(5)^6$

No.	I_p (A)	T_{on} (μs)	T_{off} (μs)	U_s (V)	T	V
1	0.64	5	15	20	0	0
2	0.64	10	25	30	2	2
3	0.64	20	50	40	4	4
4	0.64	40	80	60	6	6
5	0.64	60	120	80	8	8
6	2	5	25	40	6	8
7	2	10	50	60	8	0
8	2	20	80	80	0	2
9	2	40	120	20	2	4
10	2	60	15	30	4	6
11	3.3	5	50	80	2	6
12	3.3	10	80	20	4	8
13	3.3	20	120	30	6	0
14	3.3	40	15	40	8	2
15	3.3	60	25	60	0	4
16	5.6	5	80	30	8	4
17	5.6	10	120	40	0	6
18	5.6	20	15	60	2	8
19	5.6	40	25	80	4	0
20	5.6	60	50	20	6	2
21	9.6	5	120	60	4	2
22	9.6	10	15	80	6	4
23	9.6	20	25	20	8	6
24	9.6	40	50	30	0	8
25	9.6	60	80	40	2	0

Table 2 Orthogonal experimental results

No.	MRR (mm ³ /min)			L (μm)			α (deg)			Ra (μm)		
	1	2	3	1	2	3	1	2	3	1	2	3
1	0.496	0.473	0.413	17.49	16.37	16.42	0.638	0.617	0.642	2.495	2.420	2.520
2	0.397	0.432	0.363	15.47	14.64	15.34	0.687	0.727	0.646	3.520	3.880	3.670
3	0.325	0.313	0.323	14.28	14.55	13.38	0.497	0.565	0.543	2.955	2.995	3.025
4	0.247	0.272	0.238	14.26	13.27	15.31	0.448	0.482	0.453	3.450	3.350	3.245
5	0.213	0.221	0.193	17.67	18.36	18.54	0.440	0.411	0.474	3.325	4.705	3.965
6	0.339	0.429	0.366	10.64	8.11	9.22	0.597	0.585	0.604	3.090	3.160	3.170
7	0.349	0.437	0.384	13.31	11.56	12.26	0.584	0.616	0.552	2.770	2.485	3.125
8	0.318	0.342	0.373	15.58	16.54	15.82	0.393	0.454	0.424	3.865	4.295	4.185
9	0.305	0.302	0.328	19.16	18.34	19.43	0.392	0.431	0.419	4.365	4.465	4.430
10	0.396	0.378	0.426	23.38	24.75	22.32	0.401	0.482	0.477	4.641	4.730	5.550
11	0.336	0.304	0.319	16.37	16.23	17.22	0.303	0.331	0.324	4.460	3.995	4.155
12	0.399	0.357	0.411	23.53	22.15	23.85	0.326	0.340	0.398	5.320	4.375	4.715
13	0.378	0.413	0.329	21.55	23.33	25.71	0.371	0.424	0.396	5.365	5.100	4.628
14	0.535	0.485	0.561	25.78	26.14	26.82	0.380	0.407	0.359	6.295	5.405	5.825
15	0.590	0.556	0.523	21.46	19.84	22.31	0.375	0.381	0.362	6.750	7.580	7.170
16	0.331	0.415	0.375	23.85	25.72	22.89	0.646	0.648	0.69	6.470	6.960	6.340
17	0.390	0.311	0.357	38.13	34.31	37.68	0.478	0.450	0.418	6.775	5.820	6.335
18	0.911	0.905	0.872	41.93	43.21	45.45	0.480	0.514	0.447	7.400	6.830	6.792
19	0.780	0.756	0.736	42.67	45.78	39.73	0.420	0.458	0.459	7.320	7.045	7.295
20	0.785	0.772	0.782	40.33	43.21	38.27	0.458	0.482	0.413	7.935	6.630	6.380
21	0.449	0.573	0.593	18.42	21.32	23.06	0.638	0.617	0.642	2.495	2.420	2.520
22	1.542	1.359	1.676	29.19	34.54	31.34	0.687	0.727	0.646	3.520	3.880	3.670
23	1.559	1.634	1.671	34.57	29.16	31.18	0.497	0.565	0.543	2.955	2.995	3.025
24	1.810	1.775	1.756	43.64	41.56	46.29	0.448	0.482	0.453	3.450	3.350	3.245
25	1.834	1.799	2.140	50.92	55.73	47.75	0.440	0.411	0.474	3.325	4.705	3.965

Table 3 Orthogonal experimental results of MRR and its SNR

No.	MRR (mm ³ /min)			SNR	No.	MRR (mm ³ /min)			SNR
	1	2	3			1	2	3	
1	0.496	0.473	0.413	-6.82	14	0.535	0.485	0.561	-5.62
2	0.397	0.432	0.363	-8.08	15	0.590	0.556	0.523	-5.13
3	0.325	0.313	0.323	-9.90	16	0.331	0.415	0.375	-8.66
4	0.247	0.272	0.238	-11.99	17	0.390	0.311	0.357	-9.17
5	0.213	0.221	0.193	-13.64	18	0.911	0.905	0.872	-0.96
6	0.339	0.429	0.366	-8.57	19	0.780	0.756	0.736	-2.42
7	0.349	0.437	0.384	-8.28	20	0.785	0.772	0.782	-2.16
8	0.318	0.342	0.373	-9.32	21	0.449	0.573	0.593	-5.58
9	0.305	0.302	0.328	-10.14	22	1.542	1.359	1.676	3.57
10	0.396	0.378	0.426	-7.99	23	1.559	1.634	1.671	4.19
11	0.336	0.304	0.319	-9.93	24	1.810	1.775	1.756	5.01
12	0.399	0.357	0.411	-8.25	25	1.834	1.799	2.140	5.61
13	0.378	0.413	0.329	-8.68					

Table 4 Average for SNR of MRR at different parameters

Level	I_p (A)	T_{on} (μs)	T_{off} (μs)	U_s (V)	T	V
1	-10.08	-7.91	-3.56	-4.64	-5.08	-4.12
2	-8.86	-6.04	-4.00	-5.68	-4.70	-6.15
3	-7.52	-4.93	-5.05	-5.53	-6.83	-6.05
4	-4.68	-5.03	-6.52	-6.39	-5.57	-6.98
5	2.56	-4.66	-9.44	-6.35	-6.40	-5.28
R	12.64	3.25	5.88	1.75	2.13	2.86

Table 5 Experimental results for single objective optimization of MRR

	MRR (mm ³ /min)			Average MRR (mm ³ /min)	SNR
	No. 1	No. 2	No. 3		
Confirmation Experiment	2.210	2.157	2.309	2.230	6.94
Group 24	1.834	1.799	2.140	1.924	5.61

4.3 Optimal analysis for flanging width of hole

The working oil will be vaporized, expanded and exploded, the removed metal will be thrown out from the hole by the high-temperature heat source generated during EDM. However, part of removed metal will be cooled by the flowing working oil and solidified again, attached to the raised recast layer around the orifice, forming the flanging as shown in Fig. 6. Fig. 7 illustrated that, since the width of flanging is not uniform, 8 positions around the orifice were measured and the average was calculated as flanging width of hole.

The optimal parameters of minimum flanging width were obtained by SNR analysis. As shown in Fig. 8, the optimal parameters should select the group with the largest SNR of each factor, so the optimal parameters for the smallest flanging width are: 2 A of I_p , 5 μs of T_{on} , 25 μs of T_{off} , 60 V of U_s , level 6 of machining time, level 4 of feed speed. Through the comparative experiments, it is found that the average value of flanging width using the optimized process parameter is reduced by 10.19% compared with that the previous experiment. In addition, based on the SNR analysis, the single objective optimizations of hole wall taper and surface roughness were also carried out, and the optimal parameters for each processing were obtained as shown in Table 6. Through the comparative experiments, it is found that the taper and surface roughness of the optimized process parameters are reduced by 7.50% and 25.61%, respectively.

Table 6 Optimal parameters of taper and surface roughness

	Ip (A)	Ton (μ s)	Toff (μ s)	Us (V)	T	V
Optimal parameters for taper	5.6	40	15	30	0	4
Optimal parameters for surface roughness	0.64	5	80	40	4	8

Furthermore, the experimental results showed that the thickness of recast layer increased with the increase of peak current, which had the same trend as the influence of peak current on surface roughness. Other studies showed that the thickness of metamorphic layer in surface increased with the increase of roughness of machined surface[19,20], it can be concluded that reducing the surface roughness of EDM can also reduce the thickness of machined metamorphic layer.

5 Results Analysis For Edm Machining Of Double-hole Thin Wall Based On Optimized Process Parameters

Using the optimized parameters for each step machining, the experiments of high-speed rotating electrode orbital EDM for thin wall were carried out. The morphologies of holes and thin wall in thin-wall structure are observed using scanning electron microscopy (SEM, Merlin Compact, Carl Zeiss AG, Germany). As show in Fig. 9, there are no obvious cracks and very small width of flanging at the orifice. The tiny flanging may be removed by electrochemical machining (ECM).

To observe the uniformity of the overall thickness of the thin wall, the thin wall was cut into two section along a parallel line at certain distance from the center line of two holes by WEDM. Then, the denture base resin was injected into the hole, gradually polishing the section to the thinnest part of the thin wall to observe the thickness uniformity. The section morphology of the thin wall is shown in Fig. 10(a), there is no obvious deformation from the top to the bottom with a good uniformity of thin wall. The thickness of recast layer is shown in Fig. 10(b), the thickness of melting layer is small, with an average value of 4.2 μ m. However, the thin wall is slightly damaged due to the polishing process, and it is difficult to evaluate the surface quality of the thin wall in the hole. Thus, the inner wall of the single hole processed with the optimal parameters was observed. As shown in Fig. 11(a), there are no crack on the wall, no boss at the bottom of hole, less discharge debris in the hole. The surface roughness was measured using a Laser scanning confocal microscope (LEXT OLS3000 Microscope, Olympus Corp.) as shown in Fig. 11(b), and the roughness was about 0.61 μ m.

In order to calculate the thickness of thin wall, the segmented radial cutting method was adopted to observe the radial sections of thin wall at different depths. This method can reduce the deformation of thin wall caused by WEDM. The workpiece was cut at 3 mm and 7 mm away from the upper surface by

WEDM, the diameters of the double holes on the plane of each workpiece and the distance between them were measured by digital microscope, and then the thickness of the thin wall can be calculated.

The measurement results of thickness of thin wall are shown in Table 7. It can be seen from Table 7 that the overall thickness of the thin wall is relatively uniform, and the average thickness at the orifice, hole depth of 3mm and hole depth of 7mm is 46.12 μm , 45.79 μm and 47.52 μm , respectively. Comparing with average thickness 46.5 μm , error is within 3%, which meets the processing requirements of thickness uniformity. However, it is not the target value of 40 μm , the reasons may be that the electrical contact sensing accuracy of the EDM machine is low, and the measured electrode diameter is inaccurate, inducing in inaccurate calculation of electrode radial loss and orbital radius. Even the dial indicator measurement was added to avoid the movement error of the machine tool, the movement error was accumulated due to multiple movements, resulting in the difference between the theoretical value and the actual value. It is possible to reduce the deviation by using a EDM machine with higher repeat positioning accuracy.

Table 7 Measurement results for thickness of thin wall

No.	Thickness of orifice (μm)	Thickness at hole depth of 3mm (μm)	Thickness at hole depth of 7mm (μm)
1	46.39	45.75	48.05
2	45.62	46.72	47.09
3	46.36	44.89	47.42

6 Conclusions

In this paper, the orbital EDM machining for double-hole flexible thin wall of high elastic alloy 3J33B was studied. The single objective optimization was adopted for each machining step, and the experiments for orbital EDM of thin wall based on optimal process parameters were carried out. The conclusions are shown as following:

1. A high-speed rotating electrode step-by-step orbital EDM method for double-hole flexible thin-wall machining is proposed, and the processing procedure is designed.
2. Using the optimal process parameters for each step machining, the MRR of EDM machining for 3J33B elastic alloy was increased by 20.58%, the width of flanging was reduced by 10.19%, the taper of hole was reduced by 7.50%, and the surface roughness was reduced by 25.61%.
3. The double-hole thin-wall structure was processed, which its thin neck with an average thickness of about 46.5 μm , its single hole with the diameter of 2 mm and depth of 8mm. The thickness range between the measured point and the average was 1.55 μm , compared with average thickness 46.5 μm , the error was less than 3%.

Declarations

Author contribution Yang Liu: Conceptualization, investigation, methodology, writing-original draft preparation

Yunlong Du: Writing-review, editing, validation,

Weifeng Li: Investigation, validation.

Yerui Feng: Data curation.

Yongfeng Guo: Writing-review, funding acquisition, project administration, supervision.

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Conflict of interest The authors declare no competing interests.

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Figures

Figure 1

The machined hole by EDM drilling with injecting fluid

Figure 2

The machined hole by orbital EDM

Figure 3

The procedure for orbital EDM of double-hole thin wall

Figure 4

Electrode wear in radial direction: (a) Electrode of $\Phi 1\text{mm}$ diameter, (b) Electrode of $\Phi 1.5\text{mm}$ diameter

Figure 5

Schematic diagram of orbital EDM with a high-speed rotating electrode

Figure 6

Morphology for flanging of 3J33B hole

Figure 7

Schematic diagram for measurement of flanging

Figure 8

Relationship between SNR value of flanging width and machining parameters

Figure 9

Schematic diagram for measurement of flanging

Figure 10

Morphologies of (a) machined thin wall and (b) recast layer

Figure 11

(a) Morphologies of machined hole and (b) its surface roughness