
Research on non-contact ultrasonic vibration assisted rotating electrical discharge machining (EDM) machine tool

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Abstract: Electrical discharge machining (EDM) is a nontraditional machining method by using pulsed spark discharge between workpiece and electrode to melt and remove metal. The traditional power supply method uses carbon brush and slip ring. This contact type has power supply at the contact point. Problems such as carbon deposition, leakage, and easy generation of electric sparks restrict the improvement of the rotation speed of the electrode and pose a safety hazard. The non-contact power supply technology based on the principle of electromagnetic induction can effectively solve the above problems, which can provide conditions for high-speed rotation of the electrode. In order to improve the processing quality and efficiency, this study aimed to design a small ultrasonic vibration assisted EDM machine, which can effectively avoid spark concentration and abnormal arc generation.

Keywords: EDM; electrical discharge machining; electromagnetic induction; non-contact; ultrasonic vibration; EDM machine.

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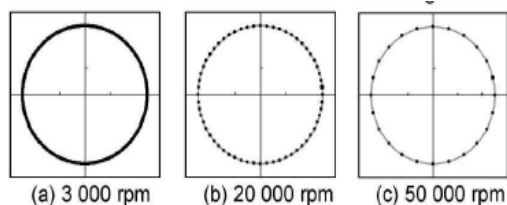
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1 Introduction

Non-discharge parameters such as spindle rotation, power supply mode, and ultrasonic vibration have a great influence on the machining effect. Wang et al. (2002) found that increasing the electrode rotation speed can reduce the relative loss of the electrode. Tian (2012) proposed that the high-speed rotation of the electrode can disperse the discharge position with rotation, effectively preventing multiple spark erosion of the spark at the same position (Figure 1). Yang Xiaodong and Zhengzhi proposed a new method for electric spark power supply by means of capacitive electric field power supply on the periphery of the electrode. This kind of non-contact power supply based on electrostatic induction method can rotate the electrode at a maximum speed of up to 50,000 rpm (Hanada et al., 2006; Kunieda et al., 2007; Yang et al., 2002). The experiment verified that the EDM efficiency, surface quality and machining accuracy were improved under the high-speed rotation of the spindle (Koyano et al., 2010; Yahagi et al., 2010). Lin et al., (2014) proposed that ultrasonic vibration has a great influence on material removal, surface morphology and roughness.

Figure 1 Distribution of discharge points at different speeds



The traditional electric spark power supply method uses a contact power supply method with a brush or a slip ring. Contact type power supply has problems such as contact point wear, leakage, electric shock, electric spark, carbon accumulation, etc. Long-term processing will certainly influence processing quality, processing efficiency and power supply stability. There is a greater hidden danger in the whole process. In EDM, the introduction of brushes and slip rings causes radially vibration for the spindle, which affects the spindle rotation accuracy.

Therefore, this paper designed a small EDM machine, presented a non-contact wireless energy transmission method and an ultrasonic vibration table to introduce

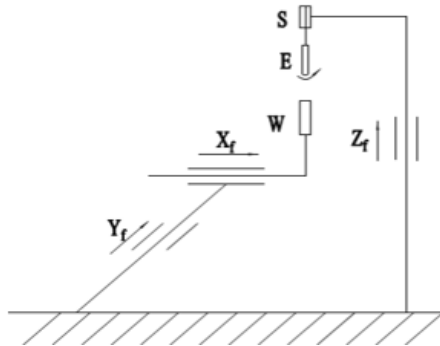
electric energy by electromagnetic induction coupling transmission. A loosely coupled magnetic can transformer is added between the pulse power source and the electrode. According to the principle of electromagnetic induction, the power source and the electrode are connected together by a magnetic field to realise non-contact power supply, and the vibration of the workpiece electrode is realised by the ultrasonic vibration table. The machining performance was verified by experiments, and the electrode rotation speed, workpiece processing quality, processing efficiency and processing stability were improved.

2 Machine tool structure

2.1 Machine tool body structure

Figure 2 shows the motion principle diagram of the non-contact rotary EDM machine. In the figure, E represents the electrode, W represents the workpiece, $X_f/Y_f/Z_f$ is the linear axis, S is the electric spindle, and the linear axes complete the spatial positioning of the workpiece. The spindle realises the rotation processing of the electrode.

Figure 2 Schematic diagram of machine tool motion

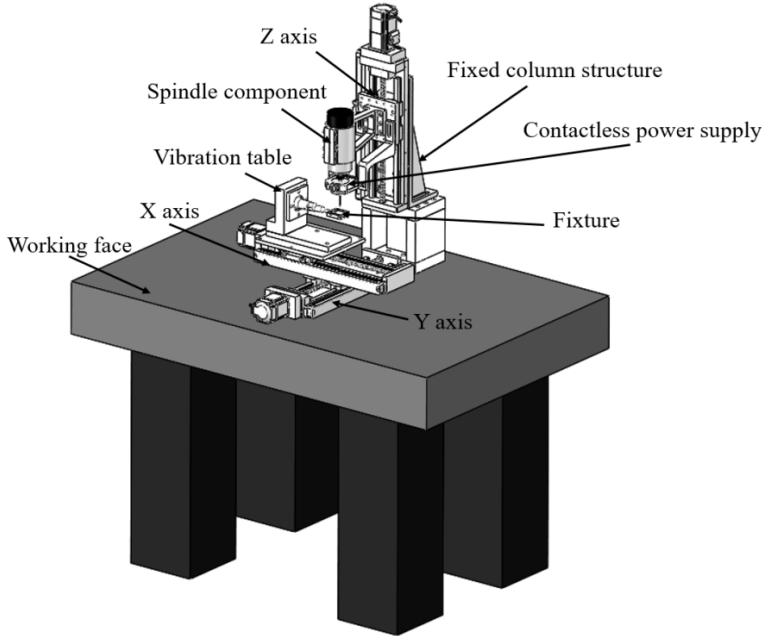


The mechanical structure of the machine tool plays the role of supporting, connecting, fixing parts and workpieces, and it is an important basis for the overall rigidity, precision and stability of the computer numerical control (CNC) machine tool. The fixed column structure is simple in layout, easy to set up, and can guarantee good precision and rigidity. It is widely used in small EDM machine tools. According to the schematic diagram of the machine tool movement, the spindle is installed in a fixed column structure, and the three-dimensional model diagram was shown in Figure 3. The mechanical device of the machine tool includes a machine tool platform, a linear transmission mechanism, a spindle component, a fixture device, an ultrasonic vibration table, auxiliary devices and contactless power supply devices.

In order to meet the high precision, high static and dynamic stiffness requirements of the machine platform, a marble platform with flatness of class 00 is selected as the working surface. The coordinate axes of the machine tool are X/Y/Z three linear coordinate axes, which are arranged according to the structure of the three-axis vertical milling machine. The fixture device is fixed on the X-axis slide table, the X-axis is stacked on the slide table of the Y-axis, the Y-axis is fixed on the machine platform, and

the Z-axis is vertically mounted on the machine platform through the support device. The X-axis and the Y-axis move horizontally, the Z-axis moves in the vertical direction and the three axes are perpendicular to each other. The cutting tool can reach any point in the working area due to three-axis linkage. The spindle components are installed on the Z-axis slide through the spindle bracket, and the spindle servo motion is realised by the Z-axis slide. The contactless power supply unit is installed on the Z-axis slide table to realise the contactless power supply of the tool electrodes, and the other EDM parts are externally connected to the machine tool.

Figure 3 Three-dimensional structure of the machine tool

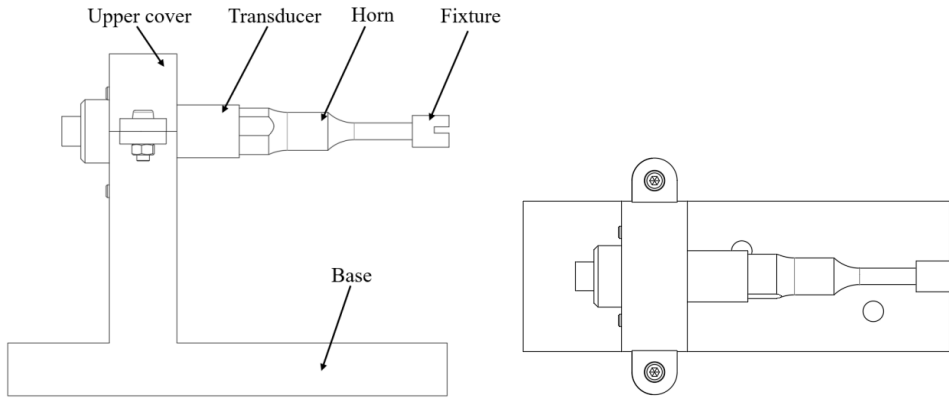


2.2 Ultrasonic vibration table

The ultrasonic vibration system (Figure 4) for auxiliary machining of electric discharge machining is mainly composed of an upper cover plate, a transducer, a horn, a clamp and a base. For the entire vibration system to resonate, the frequency of the vibration platform should be consistent with the transducer. The working frequency of the ultrasonic vibration platform is $f = 28$ kHz, the material is 45 steel, the density is $\rho = 7800$ kg/m³, and the elastic modulus is $E = 209$ GPa.

The high-frequency voltage generated by the ultrasonic generator is transmitted through the transducer, which generates high-frequency and low-amplitude vibration. The workpiece connected with the horn generates high-frequency and large-amplitude tangential vibration through the amplification of the horn. Liu et al. (2011). The ultrasonic vibration table is shown in Figure 4.

Figure 4 Ultrasonic vibration table



2.3 EDM non-contact power supply device

In order to improve the rotation speed of the electrode, a non-contact wireless energy transmission method is introduced to avoid various problems caused by the power supply by brush and slip ring. The electromagnetic induction coupling transmission method is used to introduce electric energy. A loosely coupled magnetic tank transformer (Figure 5) is added between the pulse power supply and the electrode. According to the principle of electromagnetic induction, the power source and the electrode are connected together by the magnetic field to realise non-contact power supply. The working principle is shown in Figure 6. The primary windings of the pot core transformer are connected and fixed to the machine tool. The pulse current with a certain frequency is injected into the primary windings to generate the magnetic field with high frequency changes by using the spark pulse power supply. Through electromagnetic induction, the induced electromotive force is generated in the secondary windings, so as to transfer energy from the static end to the rotating end. The secondary windings of the pot core transformer are coaxially arranged with the rotating electrodes, which can be rotated with the electrodes together. Connect the sensitive high-potential end to the tool electrode, and connect the workpiece to the grounding of the machine tool. In this case, the potential of the workpiece end is zero. A potential difference is generated between the tool electrode and the workpiece to achieve spark discharge. The system structure is shown in Figure 7.

In order to realise the non-contact electric energy introduction and the high-speed rotation of the electrode, the coaxial non-contact structure is selected for power supply. As shown in Figure 8, the primary winding is mounted on the machine body with a stationary state. The secondary winding is connected to the electrode and rotates at high speed with the electrode. The pot core is selected as shown in Figure 9 for arranging the coil, which has the advantages of axisymmetric structure, electromagnetic compatibility shielding, large facing area, small leakage inductance and distributed capacitance, high transmission energy and low loss.

Figure 5 Non-contact power supply mode

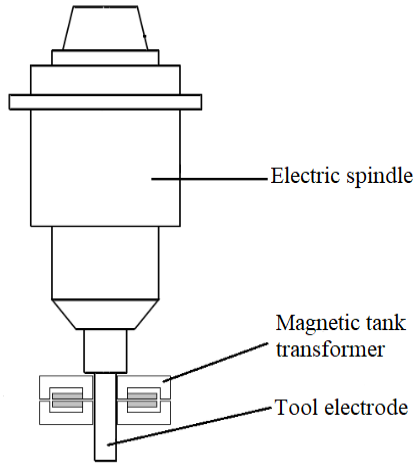


Figure 6 Schematic diagram of the non-contact power supply

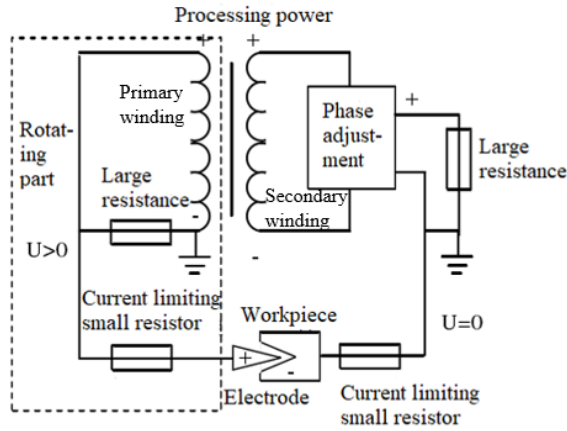


Figure 7 Non-contact power supply structure

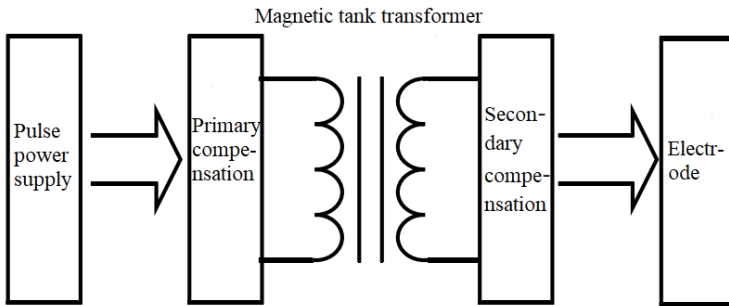
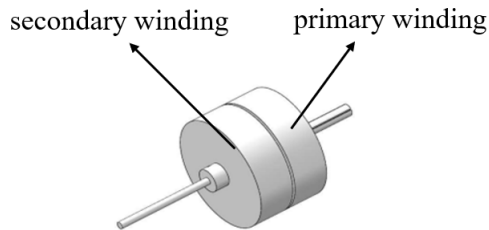


Figure 8 Contactless power supply structure**Figure 9** Pot core

3 Fixing and installation

In order to combine the wireless energy transmission device with the platform, a primary winding fixture and an electrode chuck were designed. The primary winding fixing bracket can fix the primary winding core and the platform body, and ensure that the central hole and the motorised spindle are on the same axis. The electrode chuck can effectively fix the electrode and secondary winding core and insulate the live electrode from the motorised spindle. The primary winding of the static part is located on the upper part close to the motor-spindle, the secondary winding of the moving part is located on the lower part and the gap between the primary winding is 1 mm. This upper and lower arrangement makes it easy to replace the electrode, and the primary winding only needs to be installed once.

3.1 Primary winding fixing bracket

Considering the processing and installation errors, in order to ensure the centre hole of the primary winding core can be kept on the same axis as the electric spindle, the designed primary winding fixing bracket can be slightly adjusted in three degrees of space when installing (Figure 10).

3.2 Electrode clamping and secondary winding fixing

In the EDM processing, there is a high voltage on the electrode. The traditional spindle rotation is connected to the motor through the belt. The belt can ensure the insulation between the charged electrode and the motor. The motorised spindle integrates the motor inside the spindle, which needs to consider the insulation between the charged electrode and the motorised spindle. Therefore, the electrode holder is designed by using an

insulating material. The electrode and the chuck are interference-fitted, which are clamped on the electric spindle by the chuck. The secondary winding of the non-contact power transmission device needs to rotate with the electrode together, the electrode holder has an interference fit with the secondary winding core centre hole to fix the relative position of the electrode and the secondary winding. A set screw is designed on the electrode chuck, and the lead wire is connected with the screw, and the screw is pressed against the electrode to prevent the wire from being in poor contact with the electrode during the rotation. The electrode holder is shown in Figure 11. Excessive speed will cause the spindle to overheat and the spindle component to deform, resulting in changes in self-accuracy. Therefore, we have designed a water-cooling device for the spindle, and the spindle component has selected a hard aluminium material with high temperature conductivity coefficient. When installing the spindle and spindle components, there are corresponding positioning devices. The overall assembly effect is shown in Figure 12.

Figure 10 Primary winding mounting bracket

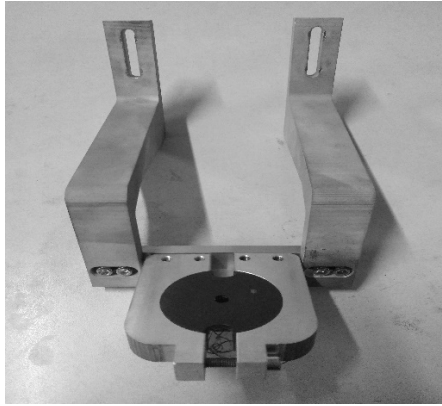


Figure 11 Electrode chuck

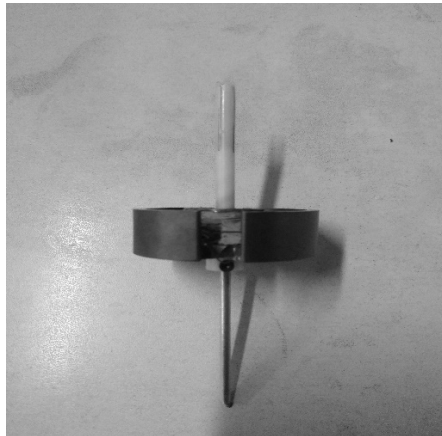
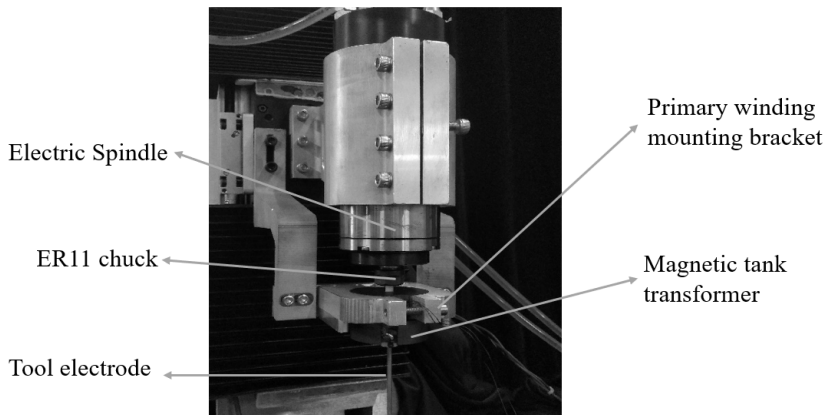


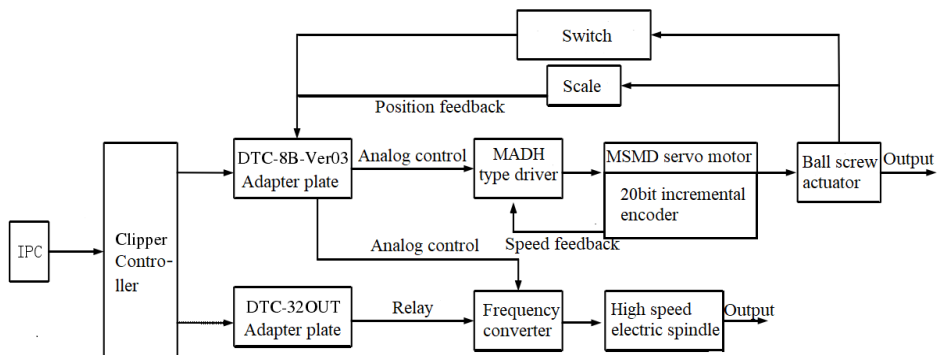
Figure 12 Integral assembly drawing



4 Motion control system structure

As shown in Figure 13, the motion control system adopted dual CPU control mode, which consist of IPC, motion control card and linear incremental encoder. IPC is used as the host computer and human-computer interaction interface is written by Visual C++ development software. Clipper motion control card and IPC contains RS232, USB and Ethernet multiple communication modes. We select Ethernet communication mode to transmit IPC host computer control information to the Clipper motion control card of the lower computer.

Figure 13 Motion control system



In order to prevent the strong current damaging the Clipper motion control card, DTC-8B-Ver03 adapter board is used to isolate the Clipper motion control card from the servo driver and motor. The DTC-8B-Ver03 transfer board also integrates the terminals into four channels to facilitate user connection. The three channels of the DTC-8B-Ver03 adapter board are connected to the servo drive of the three axes to control the movement of the mechanical motion platform. The fourth channel is connected to the external terminal of the analogue input of the inverter to control the rotation speed of the motor spindle.

Clipper motion control card can use DTC-32OUT output control signal. DTC-32OUT board can directly drive relay action and use relay to control the connection mode of external terminal of inverter, and then control the start and stop direction of rotation of motor. The grating scale is directly connected to the DTC-8B-Ver03 adapter board, the position signal is directly sent to the Clipper motion control card to realise the position closed loop. The control mode uses analogue quantity to control the motor speed, the grating scale feeds back position information. The motor encoder feeds back speed information to the drive's full closed-loop control, which improves the positioning accuracy of the control system.

5 Processing experiments and results

Traditional EDM machine tool uses contact power supply, self-designed EDM machine tool uses non-contact power supply. The electrode material is copper (0.5 mm in diameter). The electrode production method adopts the block electrode grinding back copy method, the electrode is not affected by the processing accuracy, and is not affected by the problems such as the secondary installation error and the repeated positioning error. The workpiece material is titanium alloy, the experimental current is 2 A, the amplitude is 50 V, the speed of the electrode is 1000 r/min and the processing depth is 0.5 mm. The experimental results are shown as below.

Figure 14 The machined aperture by different machine tools: (a) the machined aperture by traditional EDM machine tool processing and (b) the machined aperture by self-designed EDM machine tool processing

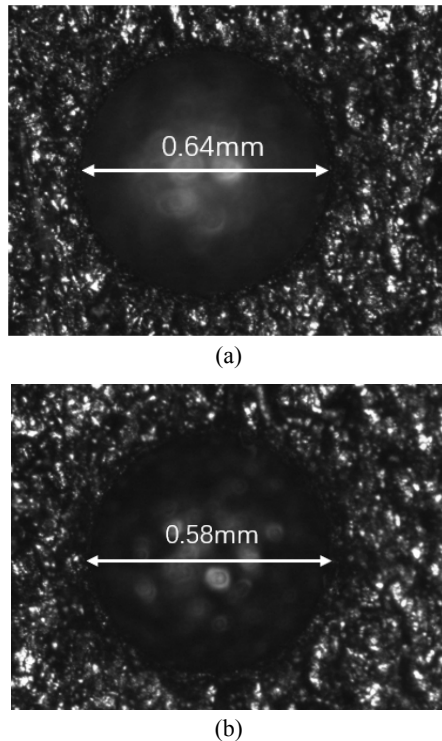
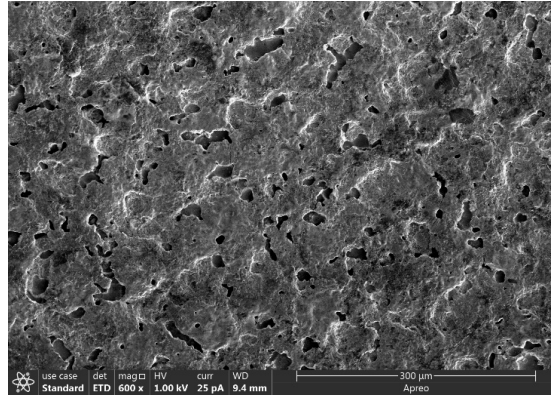
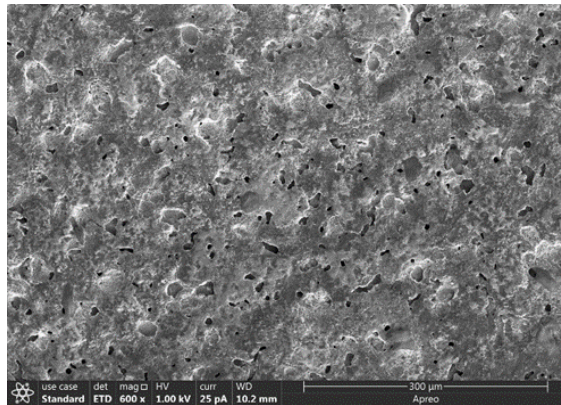


Figure 15 The machined work piece surface by different processing methods: (a) the machined surface by self-designed EDM machine tool processing and (b) the machined surface by ultrasonic vibration assisted self-designed EDM machine tool processing



(a)



(b)

Figure 14(a) and (b) respectively presented the experimental results which are processed by traditional EDM machine tool and self-designed machine tool. By contrast, under the same experimental conditions, the traditional EDM used 8'25" for 0.5 mm deep holes, and the self-designed EDM machine used 7'40" for 0.5 mm deep holes. The aperture obtained by self-designed EDM machine tool is smaller than traditional EDM machine tool and radial run-out accuracy of the motorised spindle used in the self-designed EDM machine and the spindle used in the traditional EDM machine are both 0.002 mm, so the influence of the spindle precision is excluded. The experiment proved that self-designed EDM machine can reduce the radial runout of tool electrode and improve the machining precision. Figure 15(a) and (b) respectively revealed the experiment results of self-designed ultrasonic EDM machine and additional ultrasonic machining. The experimental contrast illustrates the surface roughness obtained by ultrasonic vibration assisted EDM machining is relatively small. Under the same processing depth of hole, the machining time by using EDM without additional ultrasonic vibration is 7'40", and by using ultrasonic vibration assisted EDM is 6'58". The results show that the surface quality and processing efficiency of EDM can be improved by adding ultrasonic vibration.

6 Conclusion

In order to reduce the adverse effects of traditional power supply methods for EDM, and improve processing accuracy, a self-designed EDM machine was built in this study, and the new electrode electric energy introduction method was established by using the principle of electromagnetic induction. The non-contact power supply of the electrode was realised, and the working performance was verified by experiments. Following conclusions can be obtained:

- The non-contact power supply mode adopted by the self-designed EDM machine reduced the radial runout of the tool electrode and improved the machining quality of the workpiece.
- An ultrasonic vibration table is added to the self-designed EDM machine to vibrate the workpiece electrode. The additional ultrasonic vibration effectively improves the surface quality of the workpiece, which reflect as the roughness reduction, the surface processing accuracy and the processing efficiency improvement.

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