The experimental study on horizontal ultrasonic electron discharge machining

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Abstract. Aiming at reducing the shortcomings of existing ultrasonic electron discharge machining (EDM), a horizontal ultrasonic vibration EDM machining method is proposed. Orthogonal experiments of horizontal ultrasonic EDM were executed and compared with ordinary EDM, which indicated that the surface quality of parts and efficiency of the horizontal ultrasonic EDM method are improved. Experimental data results indicate that the horizontal ultrasonic EDM method has a positive role in guiding the actual application.

1. Introduction

Ultrasonic electron discharge machining (EDM) is a kind of compound machining method, which combines the characteristics of EDM of high quality and of ultrasonic machining with high efficiency, therefore, it has the ability to manufacture hard materials with high speed that are of high quality. The present study about ultrasonic EDM compound processing is that with the ultrasonic device loaded in the spindle of EDM machine [1, 2], although this method has advantages in the machining process, because the EDM method belongs to a precision machine which has a high requirement for the precision of the spindle, therefore, the heavy ultrasonic device which is loaded on the spindle will have a negative effect on the machining process, and the EDM advantage cannot be fully shown. Therefore, this paper considers the ultrasonic device being loaded on the workpiece, in this way, the formation of quality and machining efficiency can be guaranteed simultaneously.

2. Preparation

2.1. Experimental conditions

This experiment adopts the EDM450/60NC electric spark numerical control machine produced by Yueqing Henderson CNC Machinery Co., Ltd. Other main equipment is shown in table 1.
Table 1. main equipment for testing

| Machine tool   | EDM450/60NC EDM CNC machine tools |
|----------------|----------------------------------|
| Ultrasonic equipment | H66MC ultrasonic generator |
| Workpiece       | 45# steel                       |
| Tool electrode  | Ø 20 purple pillars shaped electrode |
| Machining polarity | Positive polarity machining |
| Measuring tool  | KEYENCE 3D measuring instrument for ultra-depth of field |
|                 | JB-5C roughness measuring instrument |

![Figure 1. The process of EDM](image)

2.2. Design of experiment scheme

The effect of electrical parameters and ultrasound parameters on surface roughness was studied. Six parameters were considered, including the pulse width, pulse interval, peak current, gap voltage, ultrasonic frequency and ultrasonic amplitude. An orthogonal experiment was used in order to reduce the experiment times [3].

First, the optimum parameters of EDM experiments are designed, and a set of optimal electrical parameters is found. Four main parameters were considered, including peak current, pulse width, pulse interval and gap voltage, combined with the orthogonal design manual, the orthogonal experiment with three levels and four factors (34) was designed, as shown in Table 2. The test process is shown in figure 1.

Table 2. Design of orthogonal experiment

| Factor   | Gap voltage | Pulse interval | pulse width | peak current |
|----------|-------------|----------------|-------------|--------------|
| Experiment 1 | 55          | 50             | 100         | 3            |
| Experiment 2 | 55          | 100            | 200         | 5            |
| Experiment 3 | 55          | 150            | 300         | 10           |
| Experiment 4 | 40          | 50             | 200         | 10           |
| Experiment 5 | 40          | 100            | 300         | 3            |
| Experiment 6 | 40          | 150            | 100         | 5            |
| Experiment 7 | 60          | 50             | 300         | 5            |
| Experiment 8 | 60          | 100            | 100         | 10           |
| Experiment 9 | 60          | 150            | 200         | 3            |
3. Experimental study on general EDM

3.1. Test data acquisition

Surface roughness is an important index to evaluate the advantages of machining methods, which
directly reflects the machining accuracy, assembly accuracy and working life. The purpose of this
experiment is to investigate the influence of EDM parameters on the surface roughness, and to find the
optimal electrical parameters.

In this experiment, the surface roughness in Ra is measured by the existing surface roughness
measuring instrument. The surface roughness of the original part is Ra=4.455 µm. To reduce the error,
each specimen is measured three times and then averaged, its measurements are shown in Table 3.

| workpiece | Measured value 1 | Measured value 2 | Measured value 3 | Measured value 4 |
|-----------|------------------|------------------|------------------|------------------|
| 1         | 3.266            | 3.242            | 3.275            | 3.261            |
| 2         | 4.428            | 4.419            | 4.428            | 4.425            |
| 3         | 4.750            | 4.722            | 4.754            | 4.742            |
| 4         | 3.323            | 3.301            | 3.309            | 3.311            |
| 5         | 2.550            | 2.537            | 2.542            | 2.543            |
| 6         | 3.131            | 3.142            | 3.135            | 3.136            |
| 7         | 4.678            | 4.692            | 4.691            | 4.687            |
| 8         | 3.652            | 3.644            | 3.648            | 3.648            |
| 9         | 3.299            | 3.295            | 3.294            | 3.296            |

Table 2 and Table 3 were combined into a complete orthogonal test table, as shown in Table 4, and the
individual indexes will be tested and analysed. \( K_1, K_2 \) and \( K_3 \) represent the sum of the roughness of
four factors and three levels, and \( k_1, k_2 \) and \( k_3 \) represent their respective average values.

| Factor | Gap voltage | Pulse interval | pulse width | peak current | Factor |
|--------|-------------|----------------|-------------|--------------|--------|
| 1      | 55          | 50             | 100         | 3            | 3.261  |
| 2      | 55          | 100            | 200         | 5            | 4.425  |
| 3      | 55          | 150            | 300         | 10           | 4.742  |
| 4      | 40          | 50             | 200         | 10           | 3.311  |
| 5      | 40          | 100            | 300         | 3            | 2.543  |
| 6      | 40          | 150            | 100         | 5            | 3.136  |
| 7      | 60          | 50             | 300         | 5            | 4.687  |
| 8      | 60          | 100            | 100         | 10           | 3.648  |
| 9      | 60          | 150            | 200         | 3            | 3.296  |

| \( K_1 \) | 8.990 | 11.259 | 10.045 | 9.100 |
| \( K_2 \) | 12.428 | 10.616 | 11.032 | 12.248 |
| \( K_3 \) | 11.631 | 11.174 | 11.972 | 11.701 |
| \( k_1 \) | 2.997 | 3.753 | 3.348 | 3.033 |
| \( k_2 \) | 4.143 | 3.539 | 3.677 | 4.083 |
| \( k_3 \) | 3.877 | 3.725 | 3.991 | 3.900 |
| range | 1.146 | 0.214 | 0.643 | 1.050 |

Optimal design | 40 | 100 | 300 | 3 |
3.2. Test data analysis

Figure 2 shows the relationships between the electrical parameters and the surface roughness. It can be seen that the peak current, the gap voltage and the pulse width are positively related to the surface roughness values, this is because the surface roughness of the workpiece is formed by the superposition of small pits formed by each pulse discharge on the surface of the workpiece [4]. The shape and depth of the small pits are determined by the energy released by each discharge. According to the energy calculation formula of \( Q=UIT \), the energy is proportional to voltage and current and time, so that the larger the pulse voltage, peak current and pulse width, the more energy is released and the small pits formed become more irregular, which results in poor surface roughness.

The surface roughness of the workpiece decreases first and then increases with the increase of the pulse interval. In the first 100 s, due to the increase of the pulse interval, the process has sufficient deionisation time, which means the machining environment can become neutral fully and has enough time to prepare for the next pulse discharge, so that each pulse discharge can make the processing of small pits more regular, the surface roughness quality increasing gradually. Then, as the pulse interval increases, the surface roughness increases because in a discharge period, the larger the pulse interval is, the smaller the pulse width will be. The surface of the workpiece is formed by numerous small pits, the interval is too long which lead to the pulse width decreases, the superposition of small pits in a single point reduction, small pits are formed by sputtered and shows more irregular, so the roughness value began to increase.

According to the above result it can be concluded that the most important factor is the gap voltage, followed by peak current, pulse width and pulse interval, which is consistent with the energy formula. The surface roughness is optimal (2.543 \( \mu m \)) when the gap voltage is 40V, pulse interval is 100 s, the pulse width is 300 s, the peak current is 3A, the surface roughness of the workpiece is minimum, this parameter set is the optimal which will be tested in the current study.

4. Experimental study of ultrasonic discharge machining

In this experiment, the effect of ultrasonic on the EDM process was studied by adding ultrasonic vibration to the workpiece. The mechanism of horizontal ultrasonic vibration EDM was also discussed. The main parameters affecting the ultrasonic machining surface quality are ultrasonic frequency and
amplitude, because the amplitude cannot be adjusted directly, therefore, output voltage was considered to adjust the amplitude indirectly. In current research, ultrasonic frequency \( f \) and output voltage \( V \) were investigated.

4.1. Test data acquisition

Ultrasonic vibration was loaded on the workpiece, the orthogonal experimental data were listed in Table 5, and the experimental process was shown in figure 3.

Table 5. Test results of ultrasonic EDM

| Experiment | Output Voltage | Ultrasonic Frequency | Roughness (without ultrasound) | Roughness (with ultrasound) |
|------------|----------------|----------------------|--------------------------------|---------------------------|
| 1          | 110            | 19.149               | 3.261                          | 4.564                     |
| 2          | 130            | 19.297               | 4.425                          | 5.541                     |
| 3          | 150            | 19.352               | 4.742                          | 5.236                     |
| 4          | 110            | 19.149               | 3.311                          | 2.053                     |
| 5          | 130            | 19.297               | 2.543                          | 2.050                     |
| 6          | 150            | 19.352               | 3.136                          | 3.023                     |
| 7          | 110            | 19.149               | 4.687                          | 4.347                     |
| 8          | 130            | 19.297               | 3.648                          | 3.236                     |
| 9          | 150            | 19.352               | 3.296                          | 3.153                     |

4.2. Test data analysis

It can be seen that the optimal surface quality of the workpiece can be obtained at moderate output voltage and moderate output frequency. This is because the released energy is limited in the low output voltage and low output frequency, so the effect is not obvious. The surface quality was not improved obviously; this is because the surface-forming quality of the workpiece is related to the four electrical parameters. The output voltage and output frequency, peak current and gap voltage are positively correlated with the release of energy, however, it is not clear whether the energy released can be fully applied to the workpiece. If the energy levels are high, there is not enough time for deionisation, then there will be a workpiece surface burning, even arc discharge, which causes a poor surface quality. If the pulse interval time is very long, but releases less energy, although it will produce a high quality surface, it will reduce the efficiency of processing. Therefore, as shown in Table 5, the surface quality of the workpiece increases after ultrasound is added, while others decrease, this is the result of energy allocation and time distribution. Only in the fifth experiment, the optimal surface quality was obtained under the conditions of small pulse interval and peak current, moderate output voltage and moderate output frequency.

In this experiment, the processing depth of the same workpiece is set at 0.5mm, and the processing times are shown in table 6.
Table 6. Electrical discharge machining and ultrasonic discharge machining

| Experiment | Processing time /min (without ultrasound) | Processing time /min (with ultrasound) |
|------------|------------------------------------------|----------------------------------------|
| Experiment 1 | 20’25                                    | 4’30                                   |
| Experiment 2 | 16’20                                    | 5’50                                   |
| Experiment 3 | 15’40                                    | 3’20                                   |
| Experiment 4 | 8’45                                     | 2’10                                   |
| Experiment 5 | 5’20                                     | 1’32                                   |
| Experiment 6 | 12’15                                    | 4’15                                   |
| Experiment 7 | 18’45                                    | 4’40                                   |
| Experiment 8 | 10’35                                    | 2’45                                   |
| Experiment 9 | 20’50                                    | 5’12                                   |

From Table 6, it can be concluded that the machining efficiency is obviously improved after ultrasonic vibration is added. On the one hand, the cavitation effect of ultrasonic vibration increased energy accumulation, water jet resulted by cavitation bubble has a removal function on the workpiece. On the other hand, the pump cavitation and eddy current effect can effectively improve the processing environment. Therefore, the horizontal ultrasonic discharge machining can improve machining efficiency noticeably.

5. Conclusion

Through comparing the experiment data of 45 steel manufactured by the conventional EDM and the horizontal ultrasonic EDM process, it can be concluded that the horizontal ultrasonic EDM process can significantly improve the surface quality of the workpiece, and machining efficiency also can be improved. The results presented in this study can be used in industry for the horizontal ultrasonic EDM process.

References

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