Study on Erosion Mechanism of Magnetic-field-assisted Micro-EDM

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Abstract. In order to study the influence of magnetic field assisted machining on micro-EDM, experiments of magnetic field assisted machining have been conducted with micro-EDM facilities which are independently designed. Through scanning discharge crater with SEM, the morphology and diameter of discharge crater have been gotten. Through comparing crater diameter of conventional machining under the same condition, it can be found that the crater of magnetic field assisted machining is relatively larger and shallower. Through analyzing the effect of magnetic field on plasma channel, it can be known that magnetic field increases the collision probability of free electron, which exacerbates the expansion of discharge channel and increases the consumption of transverse expansion energy, thus the energy which transfers to work piece is reduced.

Keywords: magnetic field assisted, micro-EDM, discharge crater, plasma channel.

1. Introduction

Micro-EDM has advantages of non-contact processing, high efficiency and low cost, so it is widely used in the production of high precision small parts [1] and also used for micro hole, micro shaft, micro crater and other three-dimensional machining [2]. After the analysis of factors which affect surface morphology and surface quality of micro-EDM, many scholars use different machining methods and machining parameters to improve the surface quality of EDM [3]. Because of the large impact of EDM recast layer on the quality of machining surface, many experts conduct a lot of researches for recast layer. Some scholars have achieved the removal of EDM surface recast layer by using etching techniques and mechanical grinding [4], but for the micro structure of workpiece, using post-processing methods to remove EDM surface recast layer is unrealistic. There are other scholars have adopted micro-EDM, micro electrochemical and other integrated machining methods for better results [5], but these require a lot of processing time and processing costs. Therefore, improving the surface quality of micro-EDM becomes one of the hot researches which make micro-EDM widely used. Some scholars have proposed ultrasonic vibration [6], piezoelectric adaptive [7] and other methods, which make the erosion of micro-EDM debris more easily and reduce the re-solidified possibility of debris. But installing the experimental device to these methods is not easy to achieve. Therefore, many scholars have proposed magnetic field assisted EDM. With the machining experiments, they not only analyze the efficiency of the magnetic field assisted machining, surface morphology and morphology, diameter and volume of long-pulse single crater, but also know that molten metal erosion of magnetic field assisted EDM relies on pressure generated by the rupture [8]. Due to small energy of micro-EDM, the pulse time is too short to melt the metal material [9], leading to the difference of the erosion mechanism of magnetic field assisted relative to conventional EDM. In order to obtain the mechanism of magnetic field assisted micro-EDM, the morphology and size of crater are obtained by a large number of experiments, and a detailed analysis of the experimental results has been conducted. The erosion mechanism of magnetic field assisted micro-EDM is preliminarily obtained, which not only provide experimental program for continuous machining, but also point out a new direction for improving the surface precision of micromachining.

2. The effect of magnetic field

Previous researches. In 1991, Dr. Xia Heng has studied magnetic field assisted EDM [10]. In this study, the change of crater diameter under magnetic field assisted machining is analyzed, and the increase of magnetic field assisted EDM crater diameter is proved by experiments. However, this paper is only the analysis of long pulse machining, but for a shorter discharge time like micro-EDM, the formation of crater is significantly different with long pulse machining, and the specific erosion process is also to be studied. P. Govindan et al have studied single discharge by electromagnetic force [11], but only for the erosion mechanism of long pulse, and achieving a magnetic field strength of 0.3T with electrified coil is not easy to implement. Therefore, it is hoped that under a great deal of theoretical analysis and experimental research for magnetic field assisted micro-EDM single pulse discharge, the influence of magnetic field on the erosion of micro-EDM can be grasped.

Force analysis of free electron. The plasma channel is formed by positive ions, neutral particles and free electrons formed which is substantially electrically neutral. Charged particles are affected by electrostatic force, the Lorentz force and other forces in the plasma channel. For a free electron, the role of other charged particles to a free electron is zero which can be considered from a statistical point of view, so a free electron in the discharge channel is only affected by the electrostatic force and Lorentz force. Under the magnetic field assisted positive-polarity machining, free electrons will play a major role in the processing of the work piece, assuming that electric field between two electrodes is uniform and applied magnetic field is uniform constant magnetic field, free electrons in the plasma channel is mainly affected by the electric force and Lorentz force, as shown in Fig.1.

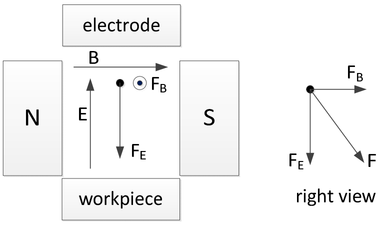


Fig.1 Force analysis of a free electron under positive polarity machining

Mathematical derivation of trajectory. Due to the influence of Lorentz force and electric field force, the kinematic equation of free electron in the electromagnetic field is:

$$m\frac{d\vec{v}}{dt}=e(\vec{E}+\vec{v}\times\vec{B}) \tag{1}$$

Where $\vec{v}$ is the electron velocity, m is the mass of electron, e is the charge of electron, $\vec{E}$ is the electrical field strength, $\vec{B}$ is the magnetic flux density.

It is easy to know that the trajectory of electron is in the X-Z plane by stress analysis. Assuming that the initial velocity of electrons is 0 and the initial position is 0, the path equations of electron can be obtained [12] by (1) is:

$$\begin{cases} x=\dfrac{Em}{eB^2}\left(\dfrac{eB}{m}t-\sin\left(\dfrac{eB}{m}t\right)\right) \\ y=0 \\ z=\dfrac{Em}{eB^2}\left(1-\cos\left(\dfrac{eB}{m}\right)\right) \end{cases} \tag{2}$$

Where x, y and z are the trace of electrons.

3. The design of experiment

Experimental facilities. The experiments are conducted on micro-EDM facility which is independently designed with linear motor drive for Z-axis and 0.05μm grating as a feedback element, and high-precision closed-loop control can be achieved, RC pulse power is used as machining power, as shown in Fig.2. The advantages of this experimental facility is that spindle uses high control precision linear motor as the drive (the control accuracy of 0.1μm), and work with marble platform as a basic platform that can reduce the interference of external capacitance.

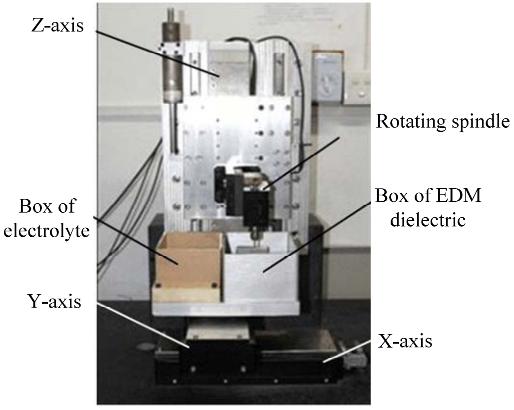


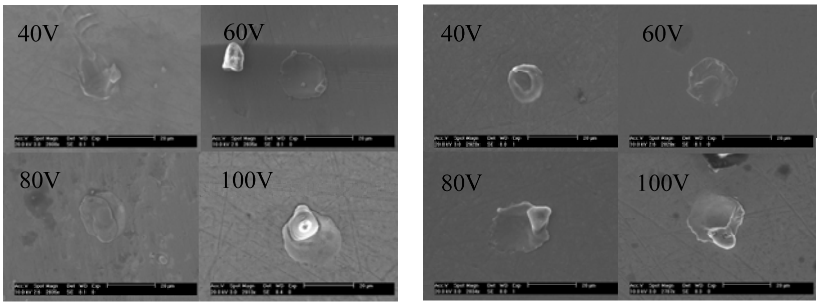
Fig.2 Machining facilities

Machining conditions. Titanium is used as work piece material in machining experiments, a diameter of 0.5mm copper wire as tool electrode, an RC pulse power as machining power source, the other machining conditions as shown in Table 1. In the air medium, two sets of experiments were conducted. One is with magnetic field, another is without magnetic field. Magnetic field distribution is shown in Fig.1.

Table 1 Machining conditions

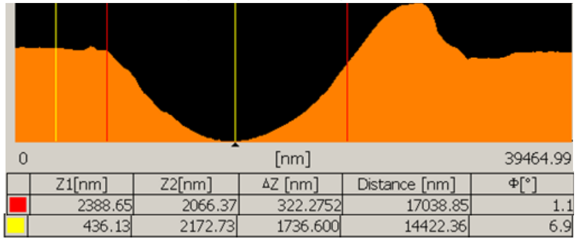
Magnet (T)	Voltage (V)	Capacitance (pF)	Resistance (Ω)
0	40, 60, 80, 100	10000	1000
0.3	40, 60, 80, 100	10000	1000

Results and discussion. Through the use of SEM and AFM, the discharge crater morphologies and data in two sets of experiments are obtained, as shown in Fig.3 and Fig.4.



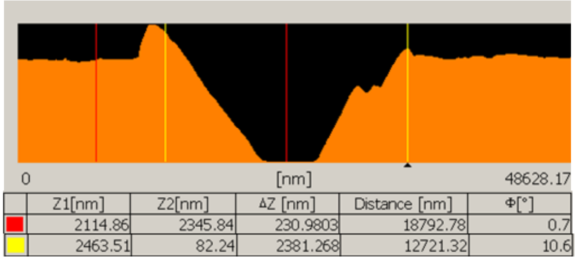
(a) (b)

Fig.3 Discharge crater morphologies ((a) magnetic field assisted (b) conventional)



	Z1[nm]	Z2[nm]	ΔZ [nm]	Distance [nm]	Φ[°]
🟥	2388.65	2066.37	322.2752	17038.85	1.1
🟨	436.13	2172.73	1736.600	14422.36	6.9

(a) magnetic-field-assisted



	Z1[nm]	Z2[nm]	ΔZ [nm]	Distance [nm]	Φ[°]
🟥	2114.86	2345.84	230.9803	18792.78	0.7
🟨	2463.51	82.24	2381.268	12721.32	10.6

(b) conventional

Fig.4 Discharge carter depth of 80V ((a) magnetic field assisted (b) conventional)

From the results of experiments, the crater diameter of magnetic field assisted micro-EDM is slightly larger than the conventional machining, and the statistical average of experimental data is obtained through a large number of experiments, as shown in Fig.5. But the crater depth is shallower, as shown in Fig.6. In magnetic field assisted micro-EDM process, when a uniform magnetic field is established vertically around electrical field, the trajectory of electron in plasma channel will be changed from linear to cycloid motion due to Lorentz force. Thus the curvature of electrons increases with strengthening magnetic field and electrons are not focused well in the spaces between electrodes. The number of particles in the discharge channel will exponentially increase with the increase of trajectory length, so the longer the trajectory, the more the number of particles, resulting in increasing the collision probability of free electrons and other particles, which intensifies channel expansion and increases the diameter of channel. Analyzing the influence of magnetic field on the plasma channel, it is obviously known that the trajectory of free electron under magnetic field assisted machining is much longer than which is under the conventional machining, so the plasma channel under magnetic field assisted machining is larger than which is under the conventional machining. The channel length becomes longer compared with the conventional micro-EDM, then the contact area of electrons and the surrounding medium is increased, so that the probability of heat transfer and chemical reactions at the channel boundary also increases, and the release of plasma discharge channels energy increases, thus the total energy of channel decreases. Above all, a larger and shallower crater is formed. But in low intensity magnetic field this curvature is less than high intensity one and leads to better concentration of ions in machining gap and improves the MRR.

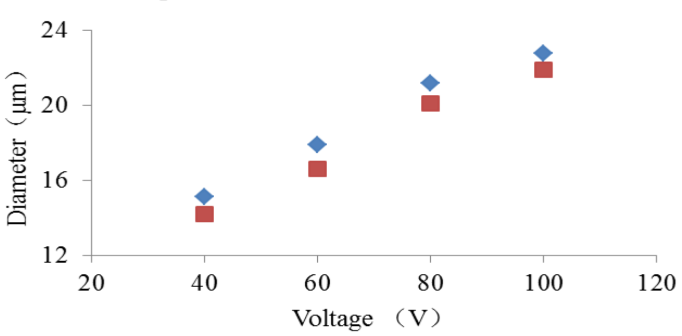


Fig.5 Discharge crater diameter

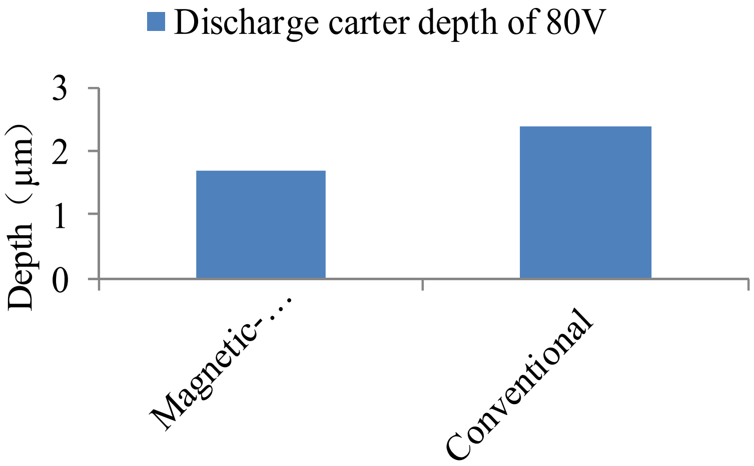


Fig.6 Discharge crater depth of 80V

4. Summary

The following conclusions can be drawn from this work:

Under the magnetic field assisted machining, free electron in the plasma channel is affected by the Lorentz force and electric force, so the trajectory of electron increases, which changes the crater morphologies.

Through conducting the micro-EDM experiments, the crater morphologies under magnetic field assisted machining and the conventional machining are separately obtained, the former is larger and shallower than the latter.

The reason why the magnetic field assisted machining crater morphology is larger and shallower is that the collision probability of free electron increases and the expansion of discharge channel exacerbates, which reduces the energy delivered to the work piece.

The erosion mechanism of magnetic field assisted micro-EDM is preliminarily obtained, which not only provide an experimental program for continuous process, but also point out a new direction for improving the surface precision of micromachining.

Acknowledgements

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