Simulation Study on Gap Flow Field in EDM Micro-hole Machining Based on Gas-liquid-solid Three-phase Flow

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Abstract: In the process of micro-hole machining in EDM, if the debris and bubbles are not removed from the gap flow field, the concentration of debris and bubbles will increase, which will cause arcing discharge and seriously affect the processing efficiency and surface quality. In this paper, the geometric model of three-dimensional cylindrical gap flow field was established. The influence of bubble generation on the gap flow field and the debris under single pulse discharge condition was analyzed by Fluent. Then using the secondary development function of Fluent, the process of the debris and bubble on the bottom surface is continuously generated and the influence of bubble on the movement of debris under continuous discharge conditions were simulated and analyzed. Finally, by considering side flushing, the motion process of bubbles and debris under the conditions of flushing was analyzed.

Keywords: EDM; micro-hole; debris; bubble; gap flow field

1. Introduction

EDM is a kind of non-contact machining. Most of the machining process occurs in the dielectric working fluid[1]. The local high temperature generated by the instantaneous pulse discharge is used to remove the workpiece. When machining micro holes, compared with traditional processing methods, it has strong applicability, no cutting force, and low processing cost, etc.[2]. However, the micro-holes in EDM also have certain limitations. During the processing, if the debris generated by the high-temperature etching materials and the bubbles generated by the cracking working fluid cannot be removed in time, the accumulation of debris and bubbles in the bottom gap will cause arcing discharge, thereby reducing processing efficiency and processing quality. For the movement of the micro-hole gap flow field in EDM. Zhang Jie et al. established a three-dimensional simulation model of the gap flow field, simulating the movement of the working fluid and the debris in the gap flow field during the lifting motion of the electrode. It is believed that the reciprocating tool movement can promote the movement of working fluid and debris in the gap flow field [3]. Koening W et al. simulated the flushing process in the EDM process, established a mathematical model in the flow field of the bottom machining gap during the flushing process, and calculated the pressure field and velocity field in the machining gap by mathematical methods [4]. Masanori Kunieda et al. simulated the flow field in the EDM process. In the course of the research, the effects of bubbles and working fluids in the flow field were considered, and the motion of the debris and the velocity field of the debris was simulated [5]. At present, scholars of the world have only considered the solid-liquid two-phase flow for the simulation
analysis of the gap flow field of the EDM, the effect of bubble generation on the movement of the debris in the gap flow field is not considered. Some studies have considered bubbles, but the bubble model does not reflect well the effects on debris and flow fields. In this paper, the gas-liquid-solid three-phase flow simulation model in the process of EDM micro-hole machining is established by analysing the characteristics of the gap flow field. The influence of bubble generation on the distribution of debris in the gap flow field is analysed, and the side flushing was considered to analyse the movement process of the debris and bubbles.

2. Gap flow field simulation mode
In the process of machining micro-holes in EDM, when electrode moves down to a position close to workpiece, the pulse voltage between the two electrodes breaks down the working medium to form an electrical discharge. As shown in Fig 1, The generation of the discharge channel converts most of the energy of the pulsed power source into thermal energy. Under the action of high temperature, two electrodes were melted and thrown into the working fluid medium to form debris, at the same time, the working fluid generates high-pressure gas under the high-temperature cracking.

![Figure 1. Physical model of EDM](image1)

2.1. Simulation parameter
When machining micro holes in EDM, different electrical parameters impact on the machining gap and the size of the bubbles. This paper does not consider the influence of electrical parameters. According to the existing experimental equipment, the simulation parameters are shown in table 1.

| Parameter          | Value     |
|--------------------|-----------|
| Discharge voltage  | 70V       |
| Peak current       | 2A        |
| Discharge cycle    | 40μs      |
| Working fluid      | Deionized water |
| Flushing speed     | 4m/s      |
| Electrode          | Copper    |
| Workpiece          | TC4       |
| Electrode diameter | 1mm       |

![Table 1. Acquisition simulation parameters in the experiment](image2)

2.2 Gap flow field geometry modeling
When machining micro holes in EDM, the shape of the electrode is cylindrical, which can simplify the gap flow field into a three-dimensional cylindrical assembly. As shown in Fig 2, based on previous research results, this paper estimates the bottom machining gap under the simulated discharge parameters is 50μm[6], through the experimental hole measurement, the single side machining gap is 100μm.

![Figure 2. Geometric simulation model of gap flow field](image3)
2.3 Bubble and debris generation model

The high temperature generated by the pulse discharge can crack the working fluid to generate bubbles. Since the pulse discharge process is short, the generated gas has a small density and a large volume, so in the process of machining micro-hole in EDM, the pressure of the bubble in the bottom surface gap is much larger than the surrounding fluid medium, so under the action of the pressure difference, the bubble will keep the surrounding working fluid away from the bubble, and the flow of the working fluid can drive the movement of the debris, realizing the coupling of the three phases. Since the movement of the bubble is formed under the action of the pressure difference, and the discharge time is short, considering the discharge efficiency, it can be considered that a small volume of high-pressure bubbles is formed in the bottom processing gap in every two discharge cycles, bubbles move freely under the influence of pressure difference. The VOF model is mainly used to describe this process. For the initial size and pressure of the bubble, it can be estimated by observing the bubble. The diameter of the bubble simulated in this paper is 0.04mm and the pressure is 1.5×10^8pa.

In the process of EDM, each pulse discharge will produce debris. The following assumptions are made on the gap flow field: (1) The working fluid in the gap flow field is a constant temperature and incompressible medium. (2) During the processing, after the flow field is stable, it is in steady state. (3) The debris are spherical. It is estimated by experiments that about 38 debris are produced every pulse discharge. Through the DPM model in Fluent, the secondary development function can be used to periodically generate particles randomly in the bottom machining gap, so that the movement state of the debris in the gap flow field can be visually seen.

3. Simulation result analysis

The distribution of bubbles and debris under single-pulse discharge was simulated. Based on the single-pulse model, the distribution of bubbles and debris under continuous discharge with or without side flushing was simulated.

3.1 Bubble and debris generation model

In order to better observe the motion of bubbles generated by pulse discharge, the first bubble was set at the bottom center, and then simulated and observed. As shown in Fig 3, the blue phase is the working fluid and the red phase is the gas. It can be clearly seen that the bubbles will expand and accumulate in the bottom gap.

![Figure 3. Bubble phase at bottom gap under single pulse discharge](image)

The liquid velocity contour and velocity vector contour of the bottom gap are shown in Fig. 4.
Figure 4. Velocity contour and velocity vector contour at bottom gap

(a) Bubble velocity contour  (b) Bubble velocity vector

It can be seen that when the bubble is generated, a velocity vector will be generated from the inside of the bubble to the outside of the bubble, and the velocity value will decrease with the increase of the volume of the bubble.

In order to study the effect of single pulse bubbles on the distribution of debris, a layer of debris is simulated in the bottom machining gap. As shown in Fig. 5 (a), the distribution of debris is shown in Fig. 5 (b) after a period of single pulse.

Figure 5. Distribution of debris under the action of bubbles generated by single pulse

(a) Initial distribution of debris  (b) Distribution after bubble formation

3.2 Effect of bubbles on debris under continuous discharge

Through UDF function in Fluent, a bubble is randomly generated in bottom gap every two discharge cycles. On the base of the initial distribution of a layer of debris, the randomly generated debris are added. The bubble distribution in bottom gap with processing time is shown in Fig. 6.

Figure 6. Bubble phase contour at bottom gap under continuous discharge

(a) Phase distribution of bubbles at 0.4ms  (b) Phase distribution of bubbles at 1ms

As can be seen from Fig. 6, single bubble was generated randomly at the bottom. As the processing time goes on, the number of bubbles increases, bubbles merge and accumulate in the processing gap at the bottom. The effect of bubbles generated on the distribution of debris under continuous discharge was shown in Fig. 7.
From Fig. 7 (a), it can be seen that when the processing time is 0.1ms, the pulse discharge occurs once. It can be seen that the randomly generated particles of the debris are added to the bottom gap, but bubbles are fewer at this time. It is not obvious that bubbles impact on the distribution of the debris. With the processing time going on, at 5ms, it can be seen that the distribution of the debris is affected by bubbles. Part of the debris are removed from bottom gap to side gap under the action of bubbles. By counting the number of particles, 342 particles can be obtained in the side gap. At this time, 3235 particles are generated in the bottom gap, the removal rate is only 10.5%. Therefore, it can be concluded that bubbles can make part of the debris remove from the bottom gap to the side gap, but it is difficult to ensure the continuous processing.

3.3 Distribution of bubbles and debris under unilateral flushing
flushing is a common debris removal method when machining micro holes in EDM, the flow state of gap flow field under side flushing was studied in this paper. Fig 8 shows the velocity contour of gap flow field and the distribution of debris.

Fig. 8 shows that when flushing fluid is added, a flow field will be formed in the gap flow field from the left side to the bottom to the right side. The debris will be removed from the gap flow field quickly under the action of flushing fluid. The removal effect of flushing fluid is much greater than that of bubbles, so that it can avoid the accumulation of debris in the bottom gap and ensure continuous processing. From the side of the electrode, the bubble phase distribution in the gap flow field can be seen as shown in Fig 9.
Figure 9. Bubble phase distribution in gap flow field

From Fig. 9, it can be seen that there are still some bubbles remaining in the bottom gap, but under the action of flushing, bubbles are continuously removed from the bottom gap, the concentration of bubbles in the bottom gap are reduced and ensuring the stability of processing.

4. Conclusion
In this paper, the characteristics of gap flow field in EDM were analyzed, the process of machining micro-holes in EDM was simulated. The gas-liquid-solid three-phase coupling model was established by Fluent, which showed the movement of debris and bubbles in gap flow field. Through the analysis of gap flow field, the following conclusions are obtained.

(1) The bubbles generated by high temperature cracking working fluid produce a decreasing velocity from inside to outside, and is reduced in a very short time. The bubbles will drive the debris to move away from the bubbles.

(2) During continuous machining, some of the debris will be removed from the bottom gap under the action of bubbles, but the effect of bubbles on the removal of debris is limited. If debris removal method is not considered, the debris will still accumulate in the bottom gap, which will affect the processing stability.

(3) Side flushing can form a flow field from the left to the bottom to the right in the gap flow field. The debris and bubbles can be removed from the processing gap under the action of flushing fluid.

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