Motion Process Research of Cavitation Bubble of Ultrasonic Electrical Discharge Machining

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Abstract. With the development of modern science and technology, the application of electrical discharge machining (EDM) has become more and more widespread. In this paper, GAMBIT software was used to establish the three-dimensional model of the deep hole machining process. On the basis of theoretical analysis of the gap of flow field working liquid, FLUENT software was used to simulate the bubble motion process for the multiple pulse discharge process. In addition, ultrasonic was imported into the EDM process, the bubble motion process was simulated and compared with the conditional process. The result presented was that the ultrasonic assisted machining process produced more bubbles, and the machining efficiency was improved.

1. Introduction
EDM has been widely used in the aerospace, automotive and aviation fields. In the EDM process, the performance of EDM is greatly influenced by the bubbled volume fraction [1-3]. The bubble motion situation of single pulse discharge machining was observed through transparent material [4, 5], the bubble volume endured expanding and contracting several times, and finally tended to be stable. However, the bubble variation of the continuous discharge process was not observed. J Wang observed the bubble motion process of continuous discharge process, but it is difficult to analyses quantitatively the bubble volume fraction. The bubble motion process was analysed for continuous discharge machining process, but they used a method of blowing to generate bubbles, which is different from the actual EDM condition.

Because the gap in EDM is of micro size, and general processing materials are opaque, it is impossible to measure the flow field by placing a measuring instrument into the gap. On the other hand, the movement of the flow field of the EDM gap is so complex that it is difficult to find directly the analytical solution by theoretical methods. In EDM, the bubble volume generated by interelectrode processing are different with varying combination of machining parameters, such as the
interelectrode discharge voltage, discharge current, pulse width, pulse, electrode machining time and the conditions of liquid, accordingly, the process stability and reliability of EDM are different. In the current production practice, the parameters of EDM are often determined by technicians through experience. Using the finite element simulation technology is a good way to analyze the flow field of EDM gap. In this paper, the generation and motion of air bubbles were simulated, which provides a guarantee for the actual analysis of the EDM process.

2. Theoretical analysis of the flow field in EDM electrode gap

2.1 Geometric modelling of ultrasonic EDM

In the ultrasonic EDM process, the interelectrode gap is generated between the electrode and the workpiece, and the gap is filled with processing liquid. Processing chips and bubbles can be produced during the processing. Bubbles are majorly composed of hydrocarbon gas and oxygen, and the generation time of bubbles is very short. The bubbles endure expanding and contracting, which makes the surrounding working fluid move simultaneously. In the whole process, the interelectrode discharge voltage starts to decrease after the end of one discharging, then the movement of bubbles returns to stable. When the discharging is repeated the bubble expanding and contracting repeated accordingly. The simulation model was built according to the basic equations of fluid dynamics, simultaneously, the mathematical model of the bubble was built.

The schematic diagram of Ultrasonic EDM as shown in Fig.1 (left), the relationship of the workpiece, the electrode and the working fluid was presented. The electrode moved forward when the processing began, an interelectrode gap exists between the electrode and the workpiece, and the working fluid in the discharge gap flowed out due to the pressure. The modeling of the interelectrode gap was simplified and meshed using GAMBIT software, as shown in Fig.1 (right) and Fig.2.

Figure 1. The schematic diagram of Ultrasonic EDM
2.2 Mathematical modeling of EDM

FLUENT software was used to simulate the EDM process, and VOF model was used to describe the transform process of working fluid and the bubble. The equation can be expressed as:

$$\frac{\partial}{\partial t} (\alpha_q \rho_q) + \nabla \cdot (\alpha_q \rho_q v_q) = \sum_{p=1}^{n} (m_{pq} - m_{qp})$$  \hspace{1cm} (2.1)

where, \( \rho_q \) is phase density of \( q \), \( v_q \) is the velocity vector of \( q \) phase, \( m_{pq} \) is the mass of fluid from \( p \) phase to \( q \) phase, and \( m_{qp} \) is the mass of fluid from \( q \) phase to \( p \) phase.

The transformation process of the wording fluid to the bubble was described using the UDF equation, the working fluid began to transform into bubble when the electric spark occurred. The return value of DEFINE_MASS_TRANSFER is the transfer rate, and the transfer mass was obtained by the time and volume.

The volume fraction \( a_0 \) of working fluid satisfies the following identical equation:

$$a_0 + a_g = 1$$  \hspace{1cm} (2.2)

where, \( a_0 \) is the volume fraction of working fluid, \( a_g \) is the volume of the bubble.

For the VOF model, a single momentum conservation equation can be expressed as:

$$\frac{\partial}{\partial t} (\rho a v) + \nabla \cdot (\rho a v v) = -\nabla p + \nabla \left[ \mu_a \left( \nabla v + \nabla v^T \right) \right] + \rho_a + F$$  \hspace{1cm} (2.3)

Among them, \( \rho \) and \( \mu \) are all taking the average of the volume fraction of each phase. When there are two phases, the volume fraction are \( \alpha_1 \) and \( \alpha_2 \) respectively, the formulae of \( \rho_a \) and \( \mu_a \) are expressed as follow:
3. The motion simulation of the ultrasonic EDM bubble

In order to analysis the influence of ultrasonic on the EDM bubbles, the comparison of the bubble motion situation were performed for EDM and ultrasonic EDM. Single pulse discharge and multiple pulse discharge was also compared. Ultrasonic was added using the UDF function DEFINE_GRID_MOTION.

3.1 Verification on the effect of ultrasonic on the generation of bubbles

In order to analyse the influence of ultrasonic on the generation of bubbles, the bubble generation process was simulated for the EDM and ultrasonic EDM.

3.2 Comparison of single bubble

![Figure 3. Single bubble without ultrasonic](image1)

![Figure 4. Single bubble with ultrasonic](image2)

Fig.3 and Fig.4 show the phase cloud of bottom gap in the moment of 200μs. The blue part represents the EDM oil; the light green part represents the conversion area; the red part represents gas. It is obvious that the red area increased when the ultrasonic was added, which indicates that the volume of the single bubble increased. It is also verified that ultrasonic accelerates the bubble’s generation rate and increased the gasification efficiency. In the practical production, the ultrasonic also has the function of heating working oil, which can generate more bubbles. Overall, the ultrasonic can increase the bubble generation rate.

3.3 Comparison of multi bubbles

Fig.5 to Fig.8 show the phase cloud of multi bubbles for traditional and ultrasonic EDM process at 3000μs and 5000μs, it can be observed that there are more bubbles for the ultrasonic EDM process. The phenomenon of bubble aggregation was also observed, however, it is worth noticing that the bubbles’ diameters decreased. The reason for the increasing number of bubbles is the same as that for a single bubble. Ultrasonic can reduce the generation threshold value of the bubble, decrease the aggregation time, and make more bubble nuclear in to bubbles. The reason for the reduction of the bubble radius is that 5000μs is the end of a cycle of the ultrasound, and there exists the alternating cycle of positive and negative pressure in the process of ultrasonic wave propagation. In the negative phase, the medium molecular is squeezed, and the density of the original medium is increased; compressing air bubbles can make the radius decrease.

\[
\rho_s = a_1\rho_1 + a_2\rho_2 \\
\mu_s = a_1\mu_1 + a_2\mu_2
\]  

(2.4)
In order to describe perfectly the effect of the joining ultrasound on air bubbles, the simulation times were extended.

Figure 9. Side face bubbles without ultrasonic at 105ms

Figure 10. Side face bubbles with ultrasonic at 105ms

Figure 11. Side face bubbles without ultrasonic at 601ms

Figure 12. Side face bubbles with ultrasonic at 601ms
Fig. 9 to Fig. 12 shows the bubble cloud of traditional and ultrasonic EDM process at 105 ms and 601 ms, in which the red area is for the bubble; the blue area for processing oil. Through the comparison of the two situations, it can be found that the number of bubbles and the bubble fusion rate are all increased during the time of multi-pulse discharge. Moreover, the increasing number of bubbles shows the intensity of EDM is increased. Loaded ultrasonic vibration can improve the clearance status and the processing efficiency.

4. The influence of ultrasonic vibration on the EDM gap

The cavitation effect produced by ultrasound has an important influence on the discharge of electric erosion objects. A large number of small bubbles will be generated when the ultrasound is applied to the liquid, the bubbles may experience the process of movement, growth, contraction, expansion or breaking with ultrasonic vibration. A huge increase of pressure and a water jet will be generated, impacting on the workpiece in the breaking of the cavitation bubble, which results in the material removal of the part. At the same time, enormous energy is released due to the sudden breaking of the cavitation bubble in the extremely small space, which can throw out the chippings and improve the material removal rate. Arc discharge can be effectively avoided when ultrasonic was applied on the electrode, then the EDM process can be run smoothly.

The electrodes can work normally in the EDM process when the distance of the two electrodes is between the minimum discharge gap and the maximum discharge gap. Arc discharge is reduced due to the variation of the discharge gap, which resulted from the ultrasonic vibration. At the same time, ultrasonic vibration can make electric corrosion product be distributed more evenly between the two electrodes, which is helpful to the next discharge. In addition, the ultrasound also has a vibration effect on electric erosion products, which makes it easier to link with medium particles and result discharge channel, then the discharge rate is improved. The ultrasonic vibration of workpieces may cause multi-channel pulse discharge and improve processing efficiency.

When ultrasound was applied in EDM, the ultrasonic propagation process will come into being in the liquid medium. The ultrasonic has little effect on the machining liquid if the amplitude of the ultrasonic wave is small, with the increasing of sound intensity, the sound waves will have a certain effect on the liquid medium.

5. Conclusion

The present paper being based on the relevant theory of EDM and the FLUENT software, the three dimensional model of the flow field in the interelectrode gap was built. According to the influence of the bubbles on the flow field of the gap, the conversion rate was determined by the mass transfer function. The ultrasound was applied using the dynamic mesh technique, the bubble generation and movement situation was compared for the ultrasound and without-ultrasound EDM process. It can be concluded that the number of bubbles was improved when ultrasound was applied, and the machining efficiency improved accordingly. The simulation results are consistent with the theoretical analysis. The present study can be used for the analysis and parameter optimisation of the actual EDM process.
References

[1] Ho K H, Newman S T. State of the art electrical discharge machining (EDM)[J]. International Journal of Machine Tools & Manufacture, 2003, 43(13):1287-1300.

[2] Abbas N M, Solomon D G, Bahari M F. A review on current research trends in electrical discharge machining (EDM) [J]. International Journal of Machine Tools & Manufacture, 2016, 47(7):1214-1228.

[3] Shi W, Liu Z, Qiu M, et al. Wire tension in high-speed wire electrical discharge machining [J]. International Journal of Advanced Manufacturing Technology, 2016, 82(1-4):379-389.

[4] Shervani-Tabar M T, Rambarzin F, Shabgard M R, et al. Numerical study on the dynamics of an electrical discharge generated vapor bubble in EDM with different shapes of the tool and the workpiece[J]. International Journal of Advanced Manufacturing Technology, 2011, 56(1-4):151-159.

[5] Shervani-Tabar M T. Numerical study on the hydrodynamic behavior of the dielectric fluid around an electrical discharge generated bubble in EDM[J]. Theoretical & Computational Fluid Dynamics, 2013, 27(5):701-719.