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NUMERICAL SIMULATION OF FLUSHING PHENOMENON IN VIBRATION-ASSISTED MICRO-EDM

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ABSTRACT
In this paper numerical simulation of vibration-assisted micro-EDM has been presented. The flushing of debris from machining area is a challenging issue in micro-EDM operation. In vibration-assisted micro-EDM, the introduction of workpiece vibration causes the pressure variation of dielectric, which results in the better ejection of debris from machining area, improves flushing efficiency.Simulation of the flow behavior of dielectric fluid inside the gap due to vibration of the workpiece has been carried out using ANSYS software. Simulation results reveal that the pressure variation in the dielectric fluid due workpiece vibration increases the kinetic energy of dielectric fluid and enhanced debris flushing.).

Keywords:
Debris flushing, vibration-assisted micro-EDM, numerical simulation

INTRODUCTION

Micro-holes are a basic feature of micro-components used in aerospace, biomedical, and electronic industries. Micro-EDM is a cost-effective non-traditional machining process for the fabrication of micro-feature components [1]. The capability of machining hard and difficult to cut material micro-EDM is gaining popularity. Moreover long machining time, the difficulty of debris flushing and short-circuiting limits its application for mass production [2, 3]. If the density of formed debris too large it increases the chances of abnormal discharges, and significantly increases electrode wear and reduces MRR [4]. The recent research trend in micro-EDM is to improve the machining performance. The vibration of the workpiece is one of the methods used to improve the machining performance by improving debris flushing. The vibration of workpiece promotes the pumping improves debris flushing and enhances MRR [5, 6].

Several researchers have reported that the vibration of tool or workpiece in EDM and micro-EDM improves the discharge characteristics [7, 8]. Wansheng et al. [9] investigated the ultrasonic vibration of the tool in micro-EDM improves the machining stability and discharge efficiency due to better dielectric circulation through the gap. Huang et al., [4] have studied the effect of vibration amplitude in assisted micro-EDM. It was observed that the increase in vibration amplitude increased machining efficiency, but excessive large amplitude resulted in the collision of tool to the workpiece and adversely affects machining stability. Bamberg and Eamawatanachai[10] presented a new orbital tool actuating micro-EDM process for the fabrication of microhole. The orbital motion of the tool increased the gap between the tool and the wall of the hole and provided better dielectric circulation within the gap. It resulted in a better surface finish and reduced machining time by reducing short-circuiting. Teimouri and Baseri[11] have shown that the vibration of the workpiece produced pumping action which improved debris flushing and enhanced MRR. Surface roughness first decreased due to better flushing and then increased gradually due to high MRR. Che et al., [12] reported that the MRR in USEDM three times greater as compared to conventional EDM due to more effective heat transfer to the workpiece surface. The better stirring effect of the dielectric fluid in the gap helps to remove impurities from the working area. As a result, better machining efficiency and good surface finish were achieved.

Many researchers have investigated the effect of the tool and workpiece vibration on machining performance of EDM/micro-EDM experimentally, but numerical modeling of vibration-assisted EDM is still limited. In this work, a numerical model of vibration-assisted micro-EDM has been presented.

Analytical model

In micro-EDM the dielectric fluid is moving from inlet to outlet hence the pressure acts on the debris will be dynamic pressure. The dynamic pressure is defined as the ratio of kinetic energy per unit volume.

$$p_d = \frac{K.E.}{V}$$

$$= \frac{1/2mv^2}{V}$$

$$= \frac{1}{2}\rho v^2 \qquad (1)$$

Where, V = the volume of the fluid (m^3), v = the velocity of the fluid (m/s), m = the mass of the fluid (kg) and ρ = density of the fluid

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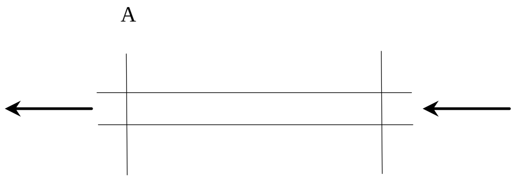


Fig: 1 Dielectric flow between the electrodes

Since the volume of fluid using for the flushing of debris from the machining area per cycle remains constant. Hence, the volume of fluid entering to section B-B is equal to the volume of fluid leaving at section A-A Fig. 1. Applying continuity equation at section A-A and B-B gives

$$Q = A_1 v_1 = A_2 v_2$$

$$v = \frac{Q}{A} \qquad (2)$$

From equation (1) and (2) it can be concluded that when the workpiece moves in the upward direction, the gap between the electrodes reduces. As a result, the velocity of fluid increases which improves debris flushing from the gap. Similarly, when workpiece moves downwards, the gap between electrodes downwards increases the velocity between the electrodes reduces. The variation in velocity of dielectric causes variation in dynamic pressure and helps in ejecting of debris from the machining gap.

Numerical modeling

Problem statement and geometry

Firstly, a three-dimensional model has been developed to perform the modal and harmonic analysis to obtain the required vertical mode of vibration of the workpiece. After obtaining the required vertical mode of vibration, a 2-D axially symmetric hydrodynamic model has been developed and solved using ANSYS Fluent software to analyze the behavior of dielectric fluid inside the gap due to workpiece vibration. This model predicts the high and low pressure in the flushing zone due to workpiece vibration. In this problem, it is assumed that the workpiece vibrates vertically perpendicular to its plane. Initially, the workpiece remains at the mean position, but when vibration applies to the workpiece, it reaches to closest position to the electrode, and during the downward motion of the electrode workpiece moves away from the electrode as shown in Fig. 1. The outer line represents the wall of the hole, and the inner line represents the electrode. The area between the electrode and workpiece represents the dielectric fluid. The dielectric enters from the top right sides and exit from the left side at the top. The gap between the electrode and workpiece changes continuously due to the vibration of the workpiece. The pressure boundary condition applied at the inlet forces the dielectric to flush the debris from the electrode gap between the tool and the workpiece.

Assumption:

- The analysis is done for single vibration.
- The workpiece surface is perfectly flat and free from any holes and cracks.
- The gap between the tool and the workpiece remains uniform for the different position of the workpiece.
- There is no pressure variation perpendicular to the plane

3.2 Modeling of workpiece vibration in assisted micro-EDM

In vibration-assisted micro-EDM, the workpiece vibrates periodically using a vibrating device like transducer. To obtain better machining condition workpiece should vibrate in the vertical direction because other vibrating modes may affect the machining stability and accuracy of the process. To obtain the vertical vibration mode of the workpiece modal and harmonic has been carried out. The vertical vibration mode of the workpiece improves the velocity of dielectric between the electrodes and enhances debris flushing.

Results and Discussion

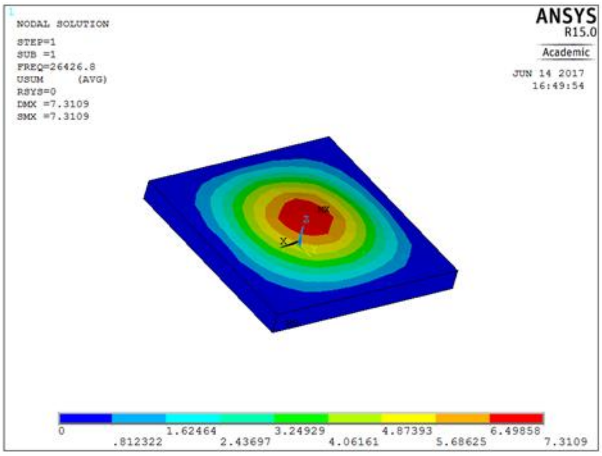
Modal analysis

The vibration analysis of workpiece has been carried out using modal analysis to obtain the required mode shape and natural frequency of the workpiece. Inconel 718 is selected as workpiece material. The dimension of the workpiece is taken as 50 × 50 × 10 mm. The material properties of Inconel 718 are presented in Table 1. The modeling has been carried out using Solid brick eight nodes 185 elements is used for the analysis. This element has eight nodes having three degrees of freedom at each node. Since workpiece remains clamped from all edges hence in modeling, all four sides are considered as a fix.

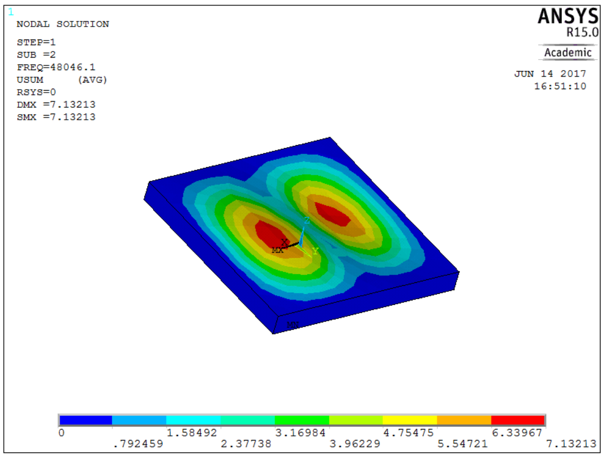
Table 1: Material properties of Inconel-718

Modulus of elasticity(N/m^2)	Density (kg/m^3)	Poission's ratio
204.9×10^9	8190	0.3

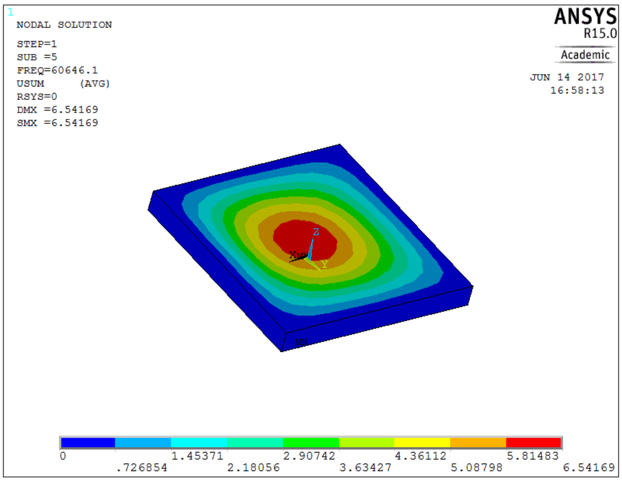
The contour plots of mode shapes obtained by modal analysis are shown in Fig.2 (a) the first mode shape obtained by modal analysis having natural frequency 26.426 kHz. In Fig.2 (a) the red region represents the maximum displacement at the center of the workpiece which is the required mode shape. In Fig.1 (b) the mode shape corresponding to natural frequency 48.04 kHz, the maximum displacements occur at two different places apart from the center of the workpiece. In Fig.2 (c) the mode shape corresponding to frequency 60.64 kHz there is in-plane vibration on the workpiece. The mode shape obtained corresponding to frequency 48.04 kHz, and 60.64 kHz are not desirable for machining because it may cause short-circuiting and adversely affect the accuracy.



(a)



(b)



(c)

Fig.2 Mode shape and natural frequency

Harmonic analysis

Harmonic analysis has been carried out to obtain the response of the workpiece under harmonic load at a given frequency. In vibration assisted micro-EDM the output of the vibrating device is frequency and displacement hence the amplitude of 2µm applied one face of the workpiece. Corresponding to the amplitude of 2µm the mode shape obtained by harmonic analysis is same as obtained in modal analysis. Hence, we conclude that at a vibration frequency of 26.426 kHz and amplitude of 2µm the workpiece vibrate in a vertical direction.

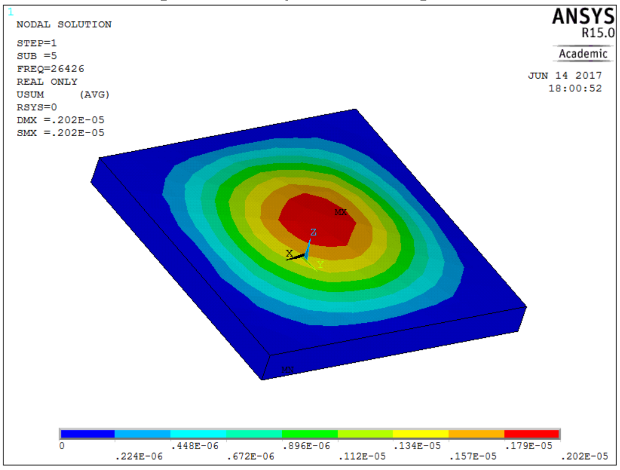


Fig.3 Mode shape corresponding to vibration frequency of 26.426 kHz and amplitude of 2µm

Modeling of pressure and velocity variation of dielectric fluid

The CFD simulation is carried out to understand the behavior of dielectric fluid in vibration-assisted micro-EDM using water as the dielectric fluid. In this study, a two-dimensional model has been created using ANSYS software as shown in Fig. 4. In the model the wall of the hole represented by outer lines while the inner line represents the wall of the electrode. The 2-D area created using these lines represents dielectric fluid flow between the electrodes.

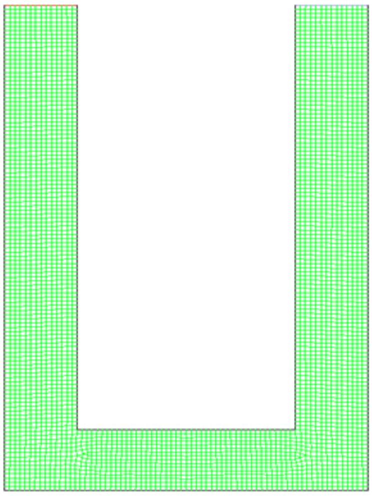


Fig.4 Two dimensional model with meshing

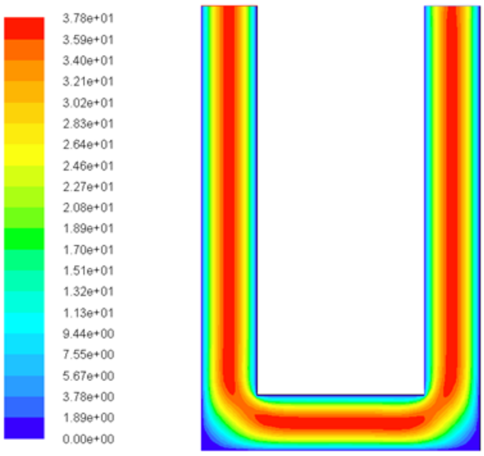
The CFD simulation has been carried out for three cases namely when there is no vibration, when workpiece moves upward and when workpiece moves in the downward direction. The analysis has been done only for single vibration with vibration frequency 26.426 kHz and amplitude 2µm respectively. The dielectric fluid entering from the right side and exit from the left. The pressure boundary condition applied at the inlet of the dielectric fluid. The dielectric fluid used here is water, and its properties are presented in Table 2. The dielectric fluid is considered as incompressible, isotropic, and homogeneous.

Table:2 Properties of dielectric fluid

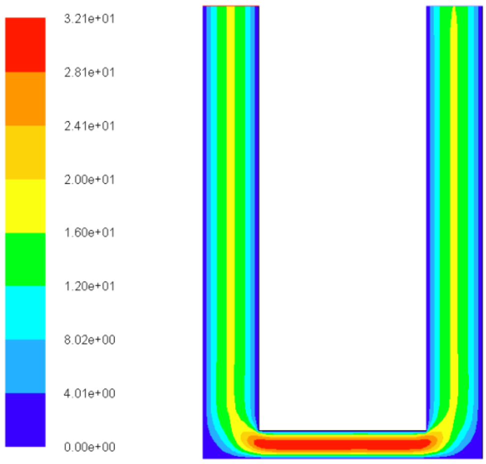
Density (kg/m^3)	Dynamic Viscosity (kg/m-s)	Thermal conductivity (w/m-k)
1000	1.787 10^{-3}	0.58

Contour plot of velocity and pressure

The contour plots of velocity and pressure are shown in Fig.5 (a) and Fig.6 (a) respectively. When there is no vibration, the dielectric flows with uniform velocity and pressure from inlet to outlet. But when the workpiece moves up due to external excitation the velocity and dynamic pressure at the machining area between the tool and electrode becomes maximum and minimum near the walls as shown in Fig. 5 (b) and Fig. 6 (b). This increase in a velocity increased the kinetic energy of dielectric fluid and flushed out the debris from the gap. When the workpiece moves in the downward direction, the gap between the electrodes increases as shown in Fig. 5 (c) and Fig. 6 (c) and there is a reduction in velocity and pressure of the dielectric fluid. As a result, fresh dielectric enters the gap and process is repeated for next cycle.



(a)



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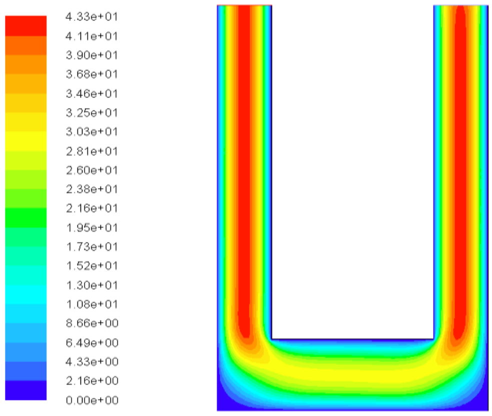
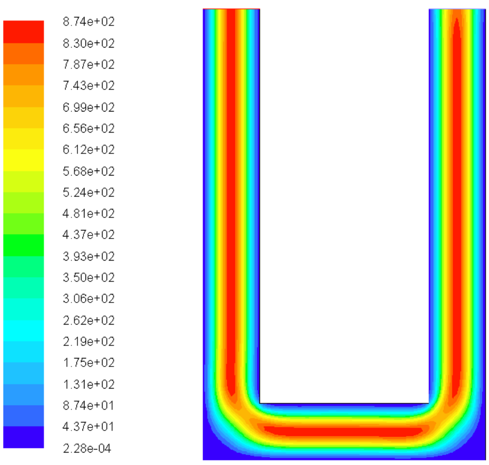
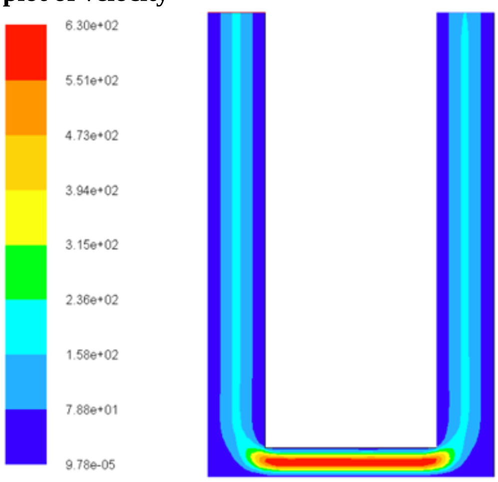


(c)

Fig. 4 Contour plot of velocity



(a)



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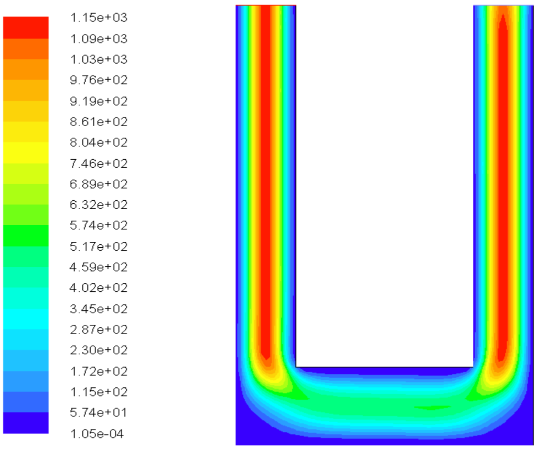

(c)

Fig 5. Contour plot of pressure

Conclusion

Numerical simulation of vibration-assisted micro-EDM has been presented. The ultrasonic vibration applied to the workpiece. The continuous upward and downward vibration of the workpiece cause pressure variation of dielectric between the electrodes, enhances debris flushing, and improves machining performance of micro-EDM.

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