Pulsed Electric Field Based Material Removal in Micro Electrical Discharge Machining

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Abstract: Micro electrical discharge machining (MEDM), a scaled down version of EDM process, is a micro machining process used to fabricate micro holes and intricate shapes in electrically conductive materials irrespective of its hardness. In this process, an electric spark is generated in the gap between the two electrodes (tool as cathode and workpiece as anode) submerged in dielectric that leads to a plasma formation, which eventually leads to material removal by melting and vaporization. The mechanism of material removal in MEDM is a very complex process and hence has not been understood fully. Simulation of material removal has been carried out in this study by using COMSOL Multiphysics® to understand the behavior of pulsating electric field in MEDM. Assuming a constant heat flux, it has been shown that material removal takes place whenever the electric field strength at any particular location on the workpiece crosses the threshold value.

Keywords: Micro Electrical Discharge Machining, Pulsed electric field, Material removal, Mesh quality.

1. Introduction

Micro electrical discharge machining (MEDM) is a micro machining process used to fabricate micro holes and intricate shapes in electrically conductive materials irrespective of its hardness. It is a scaled down version of EDM process [1]. The phenomena of material removal by melting and ablation in MEDM is a complex process and analytical modelling of the process is very difficult (Fig. 1). Various numerical techniques have been used to simulate material removal based on different forms of heat flux viz. Gaussian heat source [2], point heat source [3], uniform heat source [4] and so on. However, there has not been much work done on how the pulsating electric field generated due to charging and discharging of capacitor in RC circuit effects the heat flux and thereby remove material in MEDM. In this paper, an attempt has been made to simulate material removal in MEDM by using pulsed electric field.

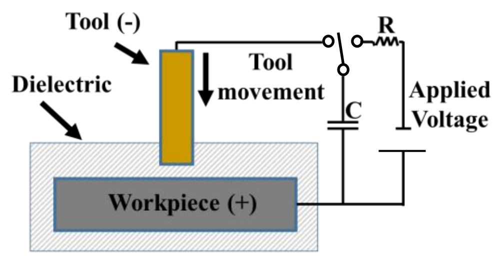

Figure 1. RC circuit in MEDM

2. Governing Equations

Governing equations are based on determination of electric field strength in a time dependent study. Eq. (1-3) shows the equations used for this study.

$$\nabla J = Q \qquad \text{.... (1)}$$

$$E = -\nabla V \qquad \text{.... (2)}$$

$$J = \sigma E + \frac{dD}{dt} + J_e \qquad \text{.... (3)}$$

where, E = Electric field strength
V = Applied Voltage
J = Conduction current density
D = Electric displacement
σ = Electrical conductivity

3. Methods

Material removal in MEDM is achieved by two mechanisms:

i. Melting
ii. Vaporization

This is contrary to the conventional process of EDM where dominant material removal mechanism is melting [5]. The pulse on time in MEDM is generally of the order of nanoseconds [6]. This leads to high amount of energy applied to the electrodes per pulse as compared to EDM.

In our model, we have assumed vaporization to the sole mechanism for material removal.

4. Theory

In MEDM, breakdown of dielectric liquid takes place as the capacitor discharges. This leads to formation of plasma channel in the gap between the two electrodes [1]. The plasma expands with time finally leading to material removal from the electrodes based on energy dissipation among the dielectric and the electrodes. Because plasma formation and expansion is a complex phenomenon, researchers usually simplify the plasma channel by a suitable heat source and carry out modelling and simulation studies. In our approach, a constant heat flux is assumed that ablates the workpiece due to pulsating electric field.

5. Numerical Model

In our model, Electric Current interface (AC/DC module) and Deformed Geometry interface were used. A sinusoidal pulse was assumed to simplify the complex nature of charging and discharging of capacitor in RC circuit. The applied voltage 'V' is a sinusoidal wave with open circuit voltage of 125 V (Eq.4). The workpiece (AISI 304) was assigned this terminal voltage while the tool (copper) was connected to ground. The entire dielectric boundary was electrically insulated.

The following assumptions were made:

i. No tool wear
ii. Dielectric fluid is stationary
iii. Heat source is assumed constant

$$V = \left(\frac{125}{2}\right) + \left(\frac{125}{2}\right) \times \sin(\omega t) \quad \text{.... (4)}$$

where, ω = angular frequency
t = time (seconds)

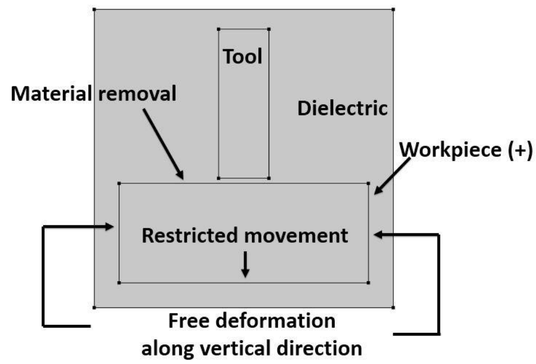

Figure 2: 2D Geometry Model

For the deformed geometry interface, the displacement of dielectric fluid was fixed on all sides. The bottom face of the workpiece was also fixed. The vertical faces of both tool and workpiece was free to move in the vertical direction. The movement of top and bottom face

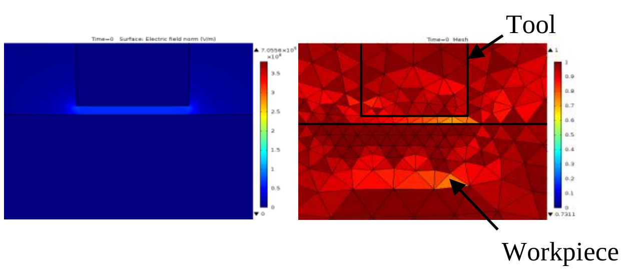

Figure 3(a): Electric field and Mesh quality at time *t=0*

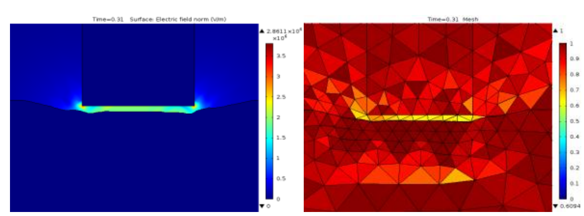

Figure 3(b): Electric field and Mesh quality at time *t=0.31*

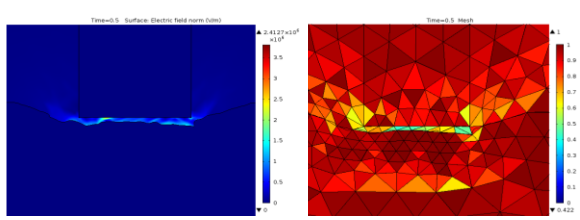

Figure 3(c): Electric field and Mesh quality at time *t=0.5 sec*

Table 1: Electric field variation and mesh quality with time

Time (secs)	Electric field strength (max) (MV/m)	Mesh quality (min)
0	7.0556	0.7311
0.02	1.4159	0.7267
0.04	1.3611	0.7219
0.06	6.0232	0.7177
0.08	1.0355	0.7106
0.1	5.2114	0.7033
0.12	1.5615	0.6974
0.14	2.0411	0.6901
0.16	1.389	0.6844
0.18	3.8581	0.6792
0.20	3.3478	0.6681
0.22	1.4869	0.6592
0.25	3.0974	0.6432
0.27	1.3273	0.6298
0.29	2.7305	0.6184
0.31	2.8611	0.6094
0.33	1.5542	0.6029
0.35	5.4034	0.5868
0.37	8.5437	0.569
0.39	2.6632	0.544
0.41	3.8	0.5171
0.43	2.8143	0.4888
0.45	1.4015	0.4638
0.47	1.3733	0.4441
0.5	2.4127	0.422

of tool was given a constant depth of cut with time. Normal mesh velocity was provided to the top face of the workpiece with a condition that at locations where electric field strength crosses the threshold value (1 MV/m), a constant heat flux is applied and material removal from this face takes place (Fig. 2).

6. Results and Discussion

Liquid dielectrics used in MEDM usually have a dielectric strength in the range of 1-50 MV/m [7]. Breakdown of dielectric occurs as soon as electric field reaches this value. Hence, for our study 1 MV/m has been used as the threshold value for material removal. Assuming a constant heat flux delivered in the gap due to threshold electric field, the material removal process has been simulated as shown in Fig. 3. Table 1 shows the variation of electric field and mesh quality with time. It has been seen that the mesh quality never degrades beyond 0.4 which was used as the threshold value for remeshing. This modelling technique eliminates the need for determining discharge location based on algorithm as it automatically calculates the favorable discharge spots based on electric field strength.

7. Conclusions

An attempt has been made in this study to simulate material removal in MEDM using the concept of pulsed electric field. Though a number of literature are available that deals with variation of heat flux source responsible for material removal, there are a few literatures that deals with the effect of pulsed electric field on the material removal. A pulsed electric field based material removal has the advantage of locating the minimum gap and hence no additional algorithm need to be added to find out location of material removal. As MEDM process uses an RC circuit, charging and discharging of capacitor leads to variation in electric field. This electric field generates heat flux which in turn is responsible for material removal. In this paper, we have considered a constant heat flux and have shown that for a particular threshold value of electric field, heat flux comes into play and it ablates the workpiece. A more detailed investigation into this problem can be considered in future by taking into account the Multiphysics based electric field and heat transfer module with temperature mapping.

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