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Modeling of Electrical Discharge Machining Process

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***Abstract* — Electrical discharge machining (EDM) process is a non conventional technique which is widely used in the industries from many years for making the complex geometries and for different material removal approaches. The objective of this work is to study the various exiting developed models of EDM and from that to develop the model for EDM for considering multi disciplinary approach. A non-linear, transient, thermal model of die-sinking EDM process has been developed. This work based on the thermal numerical approach and the thermal model is verified with the published work. The numerical approach has been developed with the finite element analysis solver Ansys. Optimization with the results from evaluation method will give the better results in the future.**

Keywords—Electrical discharge machining, finite element analysis

I. INTRODUCTION

Electrical Discharge Machining (EDM) is a non-conventional machining process which is available from last more than five decades. It is mostly used for machining the dies and moulds for job production as well as mass production. Apart from this EDM has been also used for cutting and for the production of finished parts. Material removal is held due to the process of thermal heating at the ends of both the electrodes with the help of dielectric spark between the suitable gap of two electrodes that is anode and cathode. Dielectric spark means that spark occurs in the dielectric medium like kerosene, distilled water etc. which conducts after the current passes through it. EDM process is used for complex geometries and the mass production of common objects. EDM has some limitations like it is only used for conductive materials, also material removal rate is too small and it is still difficult to estimate the outcome from EDM process. Models had been developed in the past to get the exact idea about the outcome of the process like material removal rate, cavity volume and the surface roughness.

II. LITURATURE REVIEW

Jeswani et al. [1] had adopted the dimensional analysis approach in developing the model for EDM process by considering input parameters as the pulse on time, gap voltage, spark frequency, gap current and material properties to predict the tool wear. They developed the equation to find material erosion. Authors have also developed a semi empirical model to predict surface finish, material removal rate (MRR) and tool wear using design of experimentation (DOE) and validated the same. Dibitonto et al. [2] had evaluated a simple cathode erosion model for EDM. Patel et al. [3] had invented the anode erosion model which accepts power as boundary condition at anode interface and assumptions to produce a Gaussian-distributed heat flux on the surface of the workpiece material. In sequence these researches had been done. Authors have developed many models in the different areas to get the idea about EDM process. Here also a different approach towards modeling EDM process through artificial neural network was carried out by Gopal and Rajurkar [4]. The input parameters like machining depth, tool radius, radial step, orbital radius, offset depth, pulse duration and discharge current have been taken. And experiments had been performed to evaluate the ANN model and it can be getting that the ANN model gives more accurate and faster results. Tsai and Wang [5] had also compared the ANN model based on MRR and that give a fruitful results.

Jilani and Pandey [6] created heat transfer model to study the effects of EDM variables like pulse on time, pulse energy and the material properties on MRR and crater shape. Pandit and Rajurkar [7] employed thermal modeling y using the data dependent system (DDS) which is a stochastic approach during the time. Shabgard et al. [8] had developed mathematical and numerical modeling of the effect of input-parameters on the flushing efficiency of plasma channel in EDM process. Zhange et al. [9] had made a different method of understanding the phenomena of the heat flux of EDM plasma. Mohanty et al. [10] presented a thermal-structural model to analyze the process parameters and their effect on the output parameters such as material removal rate, tool wear rate and residual stresses on work piece in electrical discharge machining (EDM) process. Joshi and Pandey [11] made thermo-physical modeling of die-sinking EDM process. Numerical analysis of the single spark operation of EDM process has been carried out considering the 2D model. The goal of this work is to develop a more comprehensive and realistic numerical process model based on the thermal analysis to understand the EDM criterion. Eubank et al. [12] had employed a variable mass, cylindrical plasma model (VMCPM) for sparks created by electrical discharge in a liquid media. This model consists of three differential equations that are from fluid dynamics, an energy balance, and the radiation equation-combined with a plasma equation of state.

III. PROBLEM DEFINATION AND OBJECTIVES

A. Problem definition

To develop the two dimentional numerical simulation model for electro discharge machining (EDM)

B. Objectives

- To understand the EDM process and its governing process parameters considering numerical approach.
- To study the various exiting developed models for EDM process.
- The numerical simulation model for EDM considering multi disciplinary approach.
- To evaluate the numerical simulation model of EDM with published as well as experimentation.

IV. MODEL FORMULATION

Before you begin to format your paper, first write and save the content as a separate text file. Keep your text and graphic files separate until after the text has been formatted and styled. Do not use hard tabs, and limit use of hard returns to only one return at the end of a paragraph. Do not add any kind of pagination anywhere in the paper. Do not number text heads-the template will do that for you.

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A. Assumptions

- Tool and workpiece are homogeneous and isotropic in nature.
- The material properties of the tool and work piece are temperature dependent.
- The spark radius is assumed to be a function of discharge current and time.
- The analysis is done for a single spark.
- The ambient temp is room temperature i.e. 300 K [10,11]
- In the present model, an energy distribution of 2-5% for work piece and 4-8% for tool material has been recommended [10] by employing inconel718 and copper as the work and tool material respectively comparing the experimental and numerical analysis.

B. Physics applied for modeling

We know that when the thermal heating occures, phase changes from solid to liquid or directly in vapour on the electrodes. To understand this non-linear transiant thermal analysis fourier heat transfer is taken as a governing equation in many researches [9-12]. In this current appraoch fourier heat trasfer equation has been taken as the governing equation.

$$\rho C\left(\frac{\partial T}{\partial r}\right)=\frac{1}{r}\frac{\partial}{\partial r}\left(Kr\frac{\partial T}{\partial r}\right)+\frac{\partial}{\partial Z}\left(K\frac{\partial r}{\partial Z}\right) \quad (1)$$

In this equations the terms r and z are the coordinates of cylindrical work domain; T is the temperature in K, Kt is the thermal conductivity in W/mK, ρ is density in kg/m3, and Cp is specific heat capacity in J/kgK of work piece material. The amount of heat known as fraction of current going th the electrodes. This is a very complex phenomena for understanding completely. So to simulate the effects of spark pasma on the workpiece a heat source model model is used to understand this phenomena. The heat source must be modeled in the way that it supplied the total heat flux at the rate that corelates with the heat input from plasma. Heat distribution on the workiece raplicates the actual plasma formation. Thus it is required to model the heat source.The heat input model for the energy distribution is taken as gaussian heat input model.

$$q(w)=4.45\frac{PVI}{\pi Rs^2}\exp\left\{-4.5\left(\frac{r}{Rs}\right)^2\right\} \quad (2)$$

Where q is the total amount of heat flux in W/m2, P is fraction of total EDM spark power going to the cathode; V is discharge voltage in V; I is discharge current in A, Rs is spark radius at the work surface in μm and r is r the radial distance at any point from the central axis of the spark plasma in μm.

Spark radius is an important factor in the thermal modeling of EDM process. In real practice, it is extremely difficult to experimentally measure the spark radius due to very short pulse duration of the order of few microseconds. Joshi and Pandey [11] had taken the radius of spark as given in equation 3. Also Mohantya et al. [10] had taken the same equation as Joshi used for the thermal modeling. This equation gives the radius of spark at certain amount of current and pulse on time. These two input parameters played the big role in this current research. Therefore the equation for radius of spark is taken as equation 3 for the thermal model.

$$Rs=(2.04\exp-3)I^{0.43}T_{on}^{0.44} \quad (3)$$

Where, Ton is the pulse-on-time in μs and I is the current in A.

C. Applied boundary conditions

A small cylindrical portion of the workpiece around the spark is chosen for analysis. Fig. 1 shows the two-dimensional axi-symmetric geometry and the associated boundary conditions taken for the analysis. Constants applied for this thermal model are also given in the table 1.

Table 1: Used constant in modeling

Constant	Value	Referances
Convective co-efficeient of kerocene	0.15	[12]
Density of Inconel 718	8.19 g/cm^3	[7]
Density of Copper	8.92	[10,11]
Time for simulation	10 min	[10]

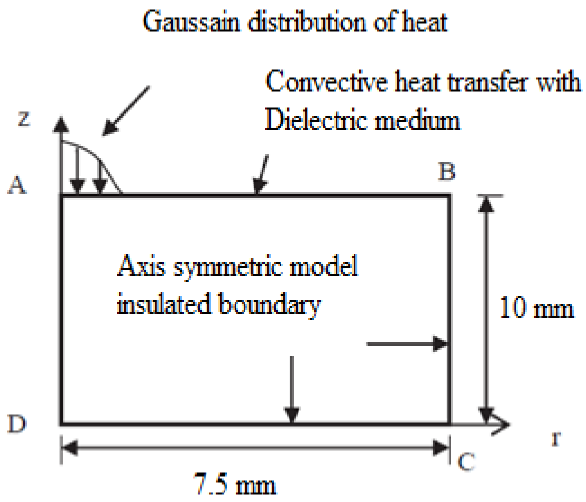

Figure 1: Boundary conditions given to the workpiece [10]

D. Simulation procedure used

The FEM software Ansys 14.5 has been used to solve with boundary conditions as shown in figure 1. The continuum of size 15×10 mm has been considered for the thermal analysis. Isometric material properties and thermal conductivity and temperature of 300K are given as inputs to the numerical model and crater and temperature distribution are obtained from the model. Model geometry is created in the design modular with suitable dimensions. Meshing has been done with element size of 0.5µm with the growth rate of 1.2. Tetrahedron shape elements are used for the further meshing in this approach. Fine relevance centre mesh is set.

Material properties such as density, specific heat and thermal conductivity are employed along with initial bulk temperature is set to at 300 K. Total time of machining is divided in number of sub steps to get accurate results. In this research five sub steps have been used in this simulation. Then isolation is given to the sides and bottom part of geometry. Then spark radius is applied to the heat flux equation (2) using the equation (3). Flux location equation is introduced equation (2) and applied to the spark location on the center of the continuum as shown in figure 1. After that the temperature distribution is obtained. MRR is calculated in this modeling by equation 4.

$$MRR = \{(C_v \times 60)/ (T_{on}+T_{off})\} \quad (4)$$

Where; C_v - Volume of the cavity above melting point temperature in mm^3, T_{on} -Pulse on time in µs and T_{off} - is Pulse off time in µs and MRR unit is mm^3/min.

E. Methodology for model verification

To check the consistency and compatibility of this model a task has been done. In this task suitable data must be collected from the past researches of Joshi and Pandey's [11] results. The data has been collected the author's model is resimulated with the past data specification. And then result of both models has been compared.

V. Results and Discussion

With all the parameters the simulation approach carried out for five set of parameters. Temperature profiles from that first set of parameters that is 2.83A current, 7.5 µs pulse on time and 1.3µs pulse off time has taken for simulation. We have seen that if we compared these two results, there is some deflection from both of them. This deflection occurs due to constant material properties used by author's model. This might not be the exact reason for that but this reason may be considered for this difference. Hear only the 1st case is taken in the fig 2. In table 2 five sets of parameters have been taken for this verification that we know. So for all the parameters this simulation process has been completed. And from that the MRR is found which has been situated in this table. Verification with Joshi's model gives the percentage of error between the ranges of 0.38 to 2.32. There has been very small percentage of differences. So it has been verified that temperature distribution gives good results with this approach. From this comparison it is seen that both MRR values are not equal but it fluctuates at certain level. But it is said that author's MRR value is too much nearer with the both published models. So the way of modeling is in the good manner and this verification gives that assumptions made by this model are in good manner.

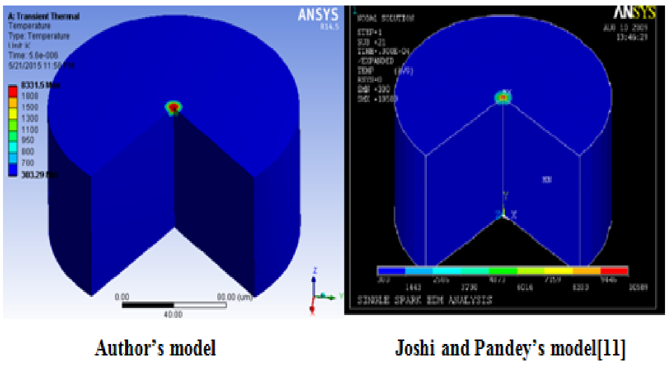

Figure 2: Temperature distributed model

Table 2: Results after verification

Sr no	Machining parameters			Published MRR (mm^3/min)	Author's MRR (mm^3/min)	Error in %
	Current (A)	Pulse on time (µs)	Pulse off time (µs)			
1	2.34	5.6	1	12.13	12.75	0.62
2	2.83	7.5	1.3	16.36	15.13	1.23
3	3.67	13	2.4	20.37	19.99	0.38
4	5.3	18	2.4	34.49	36.81	2.32
5	8.5	24	2.4	62.86	63.56	0.7

VI. CONCLUSIONS

- The reported theoretical models based on thermal analysis have limited applicability, as they are based on the assumptions like the use of constant spark radius, approximation of heat source to a point or disc shaped (uniform) and constant thermal properties of work/tool materials.
- A need thus, exists to develop a more comprehensive and realistic numerical process model based on the thermal analysis of EDM to predict accurately the shape and size of crater cavity by modifying the above stated assumptions.
- Thermal approch has been covered and it is in good aggreement with the published results.
- The percentage of difference between the published MRR values lies between 0.38 and 2.38.
- Experimentation and optimization with these results will give the better results in future.

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