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Inverse Simulation of Heat Source in Electrical Discharge Machining (EDM)

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Abstract

Temperature field is the main material loading in EDM and responsible for rim zone modifications. For adjusting dedicated surface integrity, it is necessary to quantify the material loading. A direct measurement of temperatures near the working area is not possible due to very high temperatures and corresponding gradients. Also numerical prediction of temperature field is difficult, because no general model for power distribution during EDM process exists. One possibility to obtain this power distribution is inverse simulation. For given temperatures in the inner workpiece a heat source with defined power fraction can be calculated. Hence, the entire temperature field can be determined.

Keywords: Electrical Discharge Machining; copper; temperature; FEM simulation; energy distribution

1. Introduction

Power distribution is an important aspect of Electrical Discharge Machining (EDM) to specify the temperature field as material loading. Because it influences the material removal from the workpiece and the tool electrode as well as the machining precision due to thermal expansion [1], but also the subsurface properties [2]. The thermal loading of the material is defined by the power distribution during the EDM process and the thermo-physical properties of the workpiece electrode.

An approach to describe these correlations are process signatures. This approach bases on an energetic description of the material modification as a function of material loadings [3]. Hence, the change in properties of the material can be determined independent of the manufacturing process. The requirement for this methodology is the knowledge of the spatial and temporal resolved material loading. A direct measurement of these values is not possible in the EDM process regarding short times and small discharge spots. An alternative method to determine the material loading is a finite element method (FEM) simulation of the temperature field during EDM process like conducted by several authors [4–7].

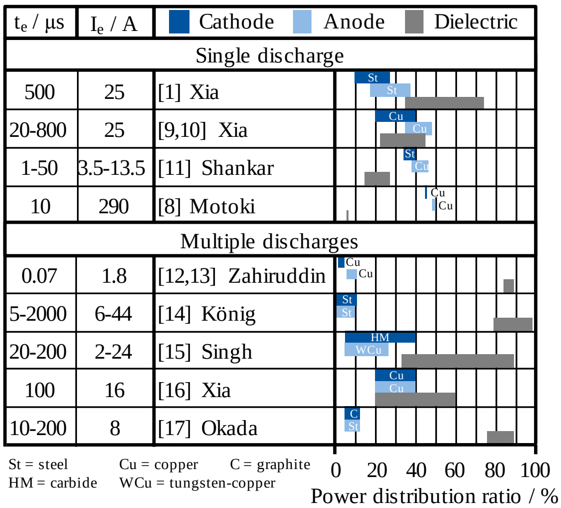

Fig. 1: Literature comparison of EDM power distribution ratios.

Heat source modelling poses a big challenge in particular to apply the correct power distribution [7]. Although, many

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authors [8–17] investigated the power distribution during EDM for a single discharge as well as for the continuous process no comprehensive model was found until today (Fig. 1).

In this work a method to determine the power distribution for a single discharge by analyzing a continuous erosion process with an inverse simulation approach will be presented. A direct temperature measurement near the discharge spot is not possible like mentioned before, but the heating of electrode in several defined distances can be measured by thermocouples. In this examination the tool electrode is observed. The only difference between tool and workpiece electrode are the polarity and the specific heat conductivity hence the introduced method can also be transferred to workpiece electrode. The measured temperatures are used as set point for the simulation model. Using the correct power distribution ratio to the electrode by input parameter variation for the FEM model (i.e. inverse approach) from experimental setup should then lead to similar temperature curves like the measured ones.

2. Experimental setup

The experiments were conducted on a GFMS AC FORM 2000 sinking EDM machine tool. The erosion took place in an electrically insulated reservoir filled with V_{DE} = 700 ml of CH-based dielectric. A l = 35 mm long cylindrical copper electrode with frontal area diameter of d_{TL} = 5 mm was used as a tool electrode (Fig. 2). Copper was used as tool material because of its high heat conductivity to minimize the influence of fluid flushing. A plate with the dimension of V_{WP} = 18 mm x 18 mm x 1 mm made of 42CrMo4 steel (1.7225) was used as workpiece. For constant flushing conditions in the working area, the dielectric fluid was pumped continuously with fluid velocity u_0 into the erosion zone (Fig. 2). The open circuit voltage was set to U_0 = 150 V and the discharge current to I_e = 11.5 A. Pulse time was t_e = 38 µs and pulse interval time was t_0 = 55 µs.

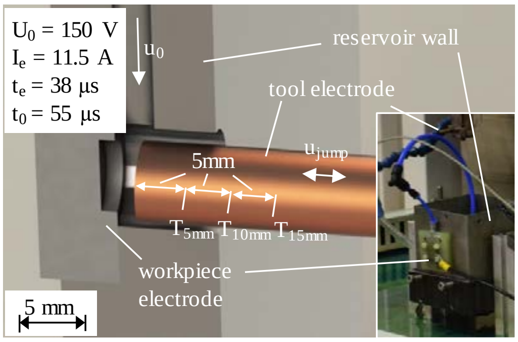

Fig. 2: Experimental setup and machining parameters.

The tool electrode was equipped with three thermocouples in different distances from the surface (z = 5 mm, 10 mm, 15 mm). Additionally, the discharge energy of every single discharge during the EDM process was recorded with an field-programmable gate array (FPGA) based measurement tool [18]. This tool evaluates current and voltage during the erosion process in real-time and retains only the calculated data like discharge energy or discharge duration. Thus, the experimental data for discharge energies can be used as the time resolved energy input for the tool electrode in the FEM-simulation (see Fig. 3).

3. Simulation model

3.1. Heat transfer and fluid dynamics

The FEM simulation model was built in COMSOL Multiphysics with coupled heat transfer and fluid dynamics modules. The geometry was assembled in 2D as axially symmetric components. The model consists of two components on the one hand the copper electrode as solid component on the other hand the dielectric fluid as liquid component.

Hence, the heat transfer in the model must be solved in solid as well as in liquid phase. In solid phase the heat transfer can be described by Fourier's law [19]:

$$\rho c_p \frac{\partial T}{\partial t} = \vec{\nabla} \cdot \left(\lambda \vec{\nabla} T\right) + \sum q \qquad (1)$$

Herein, ρ is the density, c_p is the specific heat capacity, λ the heat conductivity and q a specific heat source or sink. In liquid phase the conservation of mass, momentum and energy leads to the following equation [19]:

$$\rho \frac{d}{dt}\left(e + \frac{\|\vec{u}\|^2}{2}\right) = \rho \vec{g} \vec{u} - \vec{\nabla}\left(\lambda \vec{\nabla} T\right) - \vec{\nabla}(\rho \vec{u}) + \vec{\nabla}(\bar{\bar{\tau}} \cdot \vec{u}) + \sum q \qquad (2)$$

Whereby, e is the specific inner energy, $\vec{v}$ is the flow velocity vector and $\bar{\bar{\tau}}$ the shear stress tensor. With these equations, the heat conduction in the components can be described. The heat transfer between the two components is considered with the following heat transfer equation:

$$\vec{\dot{q}} = \alpha \cdot \frac{\partial T}{\partial \vec{x}} \qquad (3)$$

The transferred heat between the components $\vec{\dot{q}}$ depends on the spatial temperature gradient and the heat transfer coefficient α. The heat transfer coefficient is a function of the heat conductivity of the fluid λ, a characteristic length L and the Nusselt number Nu, which describes the ratio of convective to conductive heat transfer at the boundary. For a defined geometry the Nusselt number is a function of the Reynolds number Re and Prandtl number Pr. The Prandtl number is the ratio of kinematic viscosity to the thermal diffusivity. Hence, it describes the connection of velocity field and temperature field in the fluid.

$$\alpha = \frac{\lambda}{L} \cdot Nu(Re, Pr) \qquad (4)$$

The velocity field of the fluid can be calculated by solving the Navier-Stokes equations numerically. The Navier-Stokes equations describe the fluid flow of Newtonian fluids. $\vec{u}$ is the flow velocity vector, $\bar{\bar{\tau}}$ the shear stress tensor and p the pressure [19]: