Single Discharge Simulations of Needle Pulses for Electrothermal Ablation

Matthias Hackert-Oschätzchen[*,1], Markus Kreißig[1], Michael Kowalick[1], Henning Zeidler[1], Andreas Schubert[1,4], Oliver Kröning[2], Mathias Herzig[2], Hans-Peter Schulze[3]
[1]Technische Universität Chemnitz, Professorship Micromanufacturing Technology
[2]Leukhardt Schaltanlagen Systemtechnik GmbH, 39120 Magdeburg, Germany
[3]Otto-von-Guericke-Universität Magdeburg, 39106 Magdeburg, Germany
[4]Fraunhofer Institute for Machine Tools and Forming Technology IWU, Chemnitz, Germany
*09107 Chemnitz, Germany, matthias.hackert@mb.tu-chemnitz.de

Abstract: Within this study a model of a single discharge of micro scale electro discharge machining (EDM) was developed in accordance with Schulze et al [1]. The specific computation of the growth of the plasma channel has been derived from this literature. Applying COMSOL Multiphysics® a pseudo 3-D geometry was created based on the literature data. Afterwards the thermal heat transfer in solids was defined as well as the parameters and current and voltage curves. Within the plasma channel a high degree of temperature results. These temperatures are partially directed into the work piece surface. To visualize the crater of molten material, all mesh elements with a temperature higher than the melting point of the work piece material were defined as ablation geometry.

Keywords: Single Discharge, Micro EDM, Electrothermal Ablation

1. Introduction

In micromachining are steadily higher precision and better surface qualities required, while productivity should not be importantly reduced. In electro discharge machining with high energetic discharges edge layers, called white layers, with a high hardness arise. These layers influence the operational behavior of erosion components and often an expensive finishing is required. Thus an innovative development of this process under the points of resource efficiency belongs a high importance. To improve the resource efficiency of processing by EDM is sought that a thermal unaffected surface with high machining accuracy and suitable surface roughness is generated and therefore no finishing is required. A specific approach is to reduce the discharge energy.

The generation of a single discharge is shown in figure 1. Tool and work piece are separated by a dielectric medium and contacted with a voltage (1). Whenever the electric field is stronger than the dielectric strength it comes to discharge (2). The materials of the tool and work piece around the plasma channel are strongly heated and molten or vaporized (3), (4). After the discharge time the plasma channel implodes (5). The eroded material is flushed out by this implosion [2].

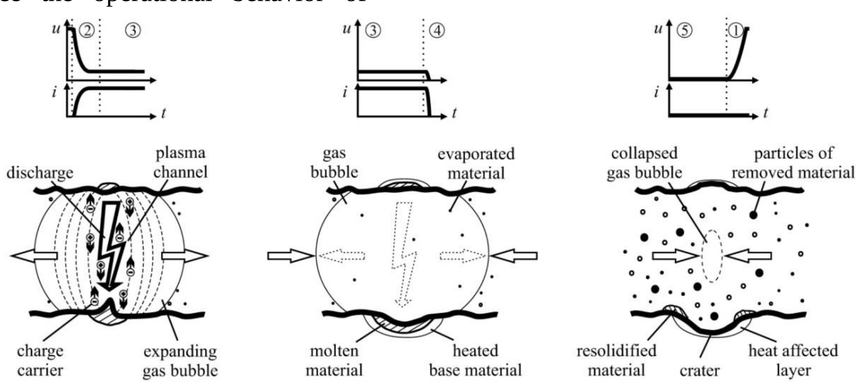

Figure 1. Phenomenological model of a Single Discharge [2]

A realistic modeling of a single discharge is possible by the assumption of a cylindrical plasma channel which expands time dependently. The approach was shown by Schulze et al. and is illustrated schematically in figure 2 [1].

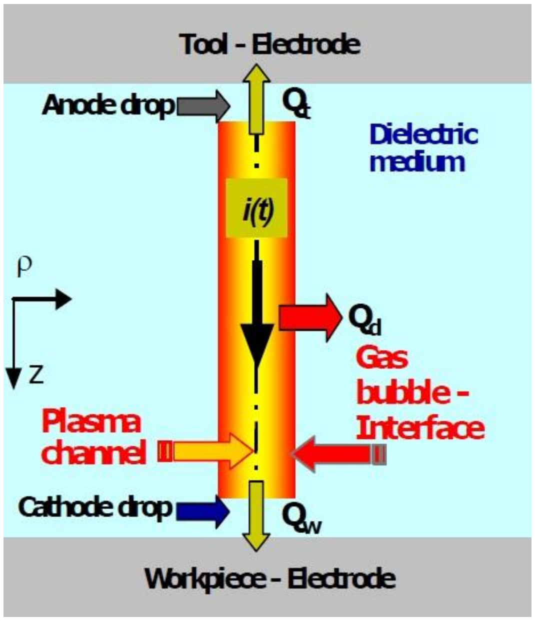

Figure 2. Schematic model of the plasma channel [1]

2. Model creation

Applying COMSOL Multiphysics™ a pseudo 3-D model was created based on the literature data [1]. The model geometry was defined as rotationally symmetric rectangle with represents the work piece. It has a width of 10 µm and a height of 6 µm. The geometry and the main boundary conditions are shown in Figure 3.

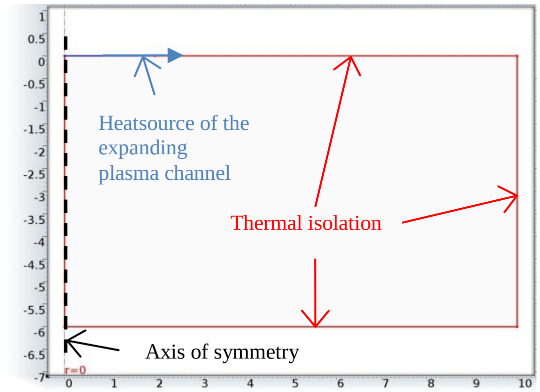

Figure 3. Model geometry and boundary conditions

The temperature emission of the plasma channel is defined as a boundary heat source. All other boundaries are defined as thermal isolations.

The energy which becomes vacant during the discharge is based on the Joule Effect. Because of the very short discharge time the part of the energy, which is emitted to the dielectric medium, can be neglected. So the energy divides into three parts. The parts are emitted into the cathode (18.3%), the anode (8%) and in the plasma channel [3]. The calculation of the heat source q_w on the work piece is shown in equation 1.

$$w = \frac{U(t) * I(t) * F_w}{\pi * (r_n)^2} \tag{1}$$

To calculate the heat source the radius r_n of the plasma channel is needed. The expansion of it is computed for little time steps Δt. The required parameters are shown in table 1. Equation 2 shows the formula for the calculation of the radius [1]. In addition to this a start radius of 2 µm is defined.

$$r_n = \sqrt{\frac{F_P * E_i}{\pi * l * rho * \left\{c_0 * (T_s - T_1) + \frac{c_s - c_0}{2} * \left[(T_s - T_0) - \frac{(T_1 - T_0)^2}{(T_s - T_0)}\right] + h_v + RH_0\right\}} + (r_{n-1})^2} \tag{2}$$

Table 1. Parameters of equation 1 and 2 [1]

Parameter	Description
U	voltage
I	current
Δt	time step
F_W	emitted energy
F_P	energy for the plasma channel
E_i	pulse energy in Δt
l	length of the plasma channel
rho	the density of the dielectric by room temperature T_1
T_S	boiling temperature
T_1	room temperature
T_0	reference temperature
c_S	specific thermal capacitance for T_S of the dielectric medium
c_0	specific thermal capacitance for T_0 of the dielectric medium
h_V	boiling enthalpy
RH_0	binding energy of the dielectric medium

The model simulates a single discharge which is caused by a needle pulse generator. Figure 4 shows smoothed voltage and current curves. These curves are measured data of an experiment with a commercial generator [1].

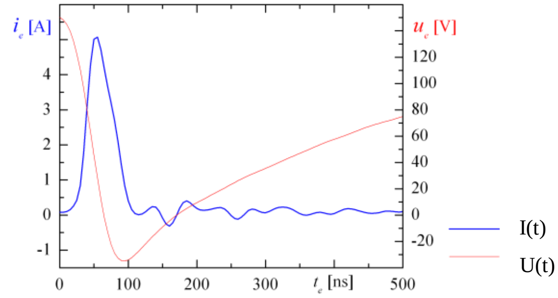

Figure 4. Voltage and current as function of pulse time of a needle pulse [2]

Resulting from the current and voltage function the power of the system can be calculated. The resulting simulated discharge time can be taken from the power curve which is shown in figure 5.

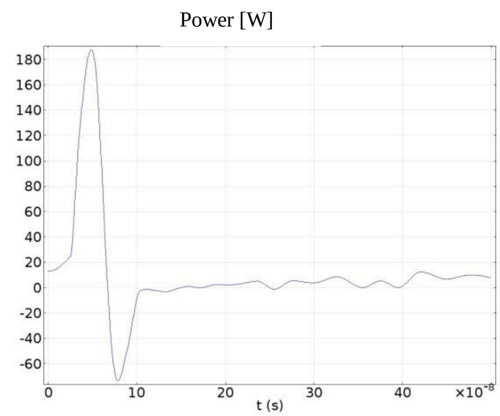

Figure 5. Power as function of pulse time of a needle pulse

The power has a maximum at t=50 ns and a minimum at t=87.5 ns. Therefore the simulated discharge time is defined to this minimum of 87.5 ns.

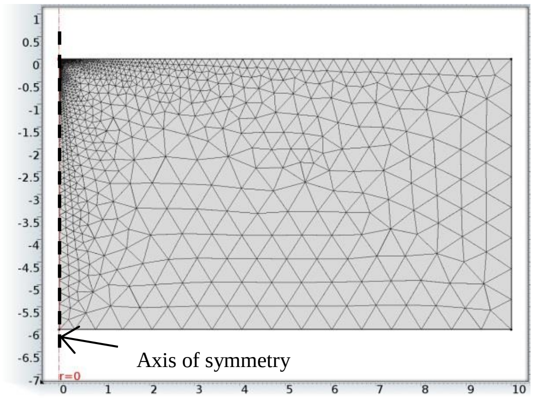

Figure 6. Model geometry and mesh

Figure 6 shows the mesh of the geometry. It was generated free triangular. For the upper left corner an extra mesh size was defined with a maximal element size of 0.0008 µm and a maximal element growing rate of 1.05. The whole mesh consists of 2.947 elements.

3. Results

As first main result figure 7 shows the temperature field at *t*=56 ns. The maximal temperature is nearly 3800 K.

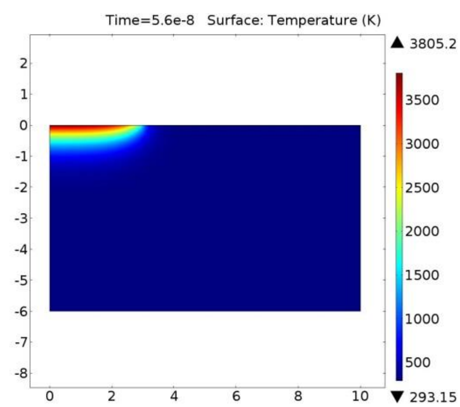

Figure 7. Surface plot of the temperature field at *t*=56 ns

The heat transfer within the work piece overweighs and the temperature inside the work piece decreases. However, because of the heat transfer a large area reaches the melting point. As second result figure 8 shows the temperature field at *t*=65.645 ns. After a discharge time of 65.645 ns a crater with a depth of 0.72 µm and a radius of 2.9 µm is received. The resulting crater was visualized by hiding the areas with a higher temperature than the melting point of the work piece material. The melting point was defined to 1573 K.

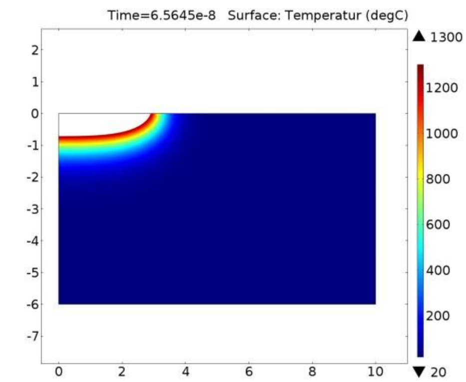

Figure 8. Surface plot of the temperature field and incurred crater after a discharge time of *t*=65.625 ns

Because of the current and voltage curve the power of the system and the heat source decrease to 0 at *t*=67.1 ns. So the heat transfer within the work piece is higher than the heat source of the plasma channel. During the following discharge time the crater shrinks. The figures 9 and 10 show the heat source and heat transfer at the time of *t*=67 ns of the discharge.

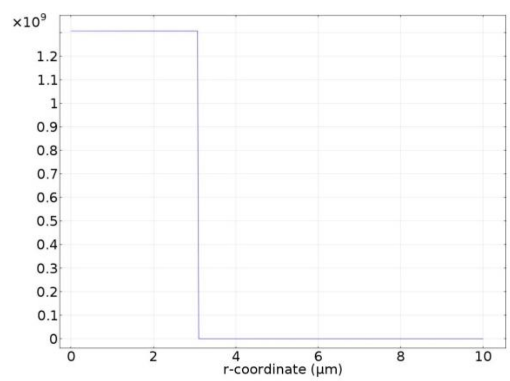

Figure 9. Line graph of the boundary heat source [W/m²] on the work piece surface at *t*=67 ns

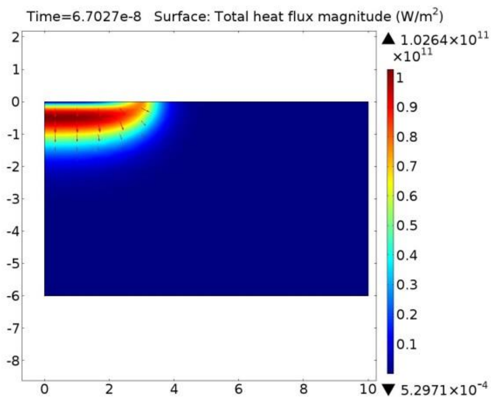

Figure 10. Surface plot of the total heat flux inside the work piece at *t*=67 ns

It's obvious that the heat flux at *t*=67 ns (figure 10) is nearly hundred times as large as the boundary heat source (figure 9). Therefore some of the already molten material has to be expected as re-solidified. Figure 11 shows the resulting final crater geometry.

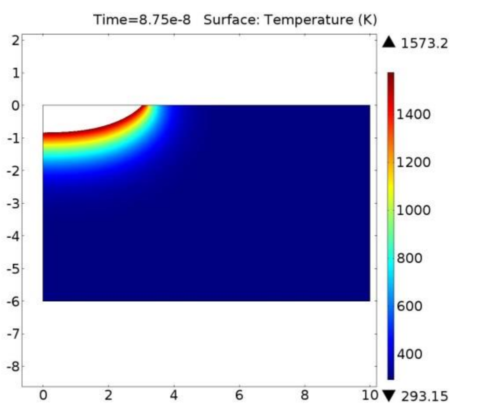

Figure 11. Surface plot of the temperature field and incurred crater generated by one needle pulse

After the needle pulse the crater has a depth of 0.83 µm and a radius of 3.03 µm. The ablated volume is nearly the same as after the discharge time of 65.625 ns.

4. Conclusions

The model presented in this study is a combination of the simulation approaches from Schulze et al. [1] and Marafona et al. [3]. The resulting crater was visualized by hiding the areas with a higher temperature than the melting point of the work piece material. In summary this is a quiet simple method. The model offers quick information for EDM experiments by simple adjustment of the parameters.

Acknowledgements

This project is founded by the Federal Ministry of Economics and Technology, following a decision of the German Bundestag.

References

[1] H.P. Schulze et al., Simulation of thermal effects for electrical discharge machining, Nonconventional Technologies Review, 1, 1 – 3, 2007

[1] H. Zeidler, Schwingungsunterstützte Mikro-Funkenerosion, Dissertation, 2011

[3] J. Marafona et al., A finite element model of EDM based on the Joule effect, International Journal of Machine Tools & Manufacture, 46, 595 – 602, 2006