SIMULATION OF THERMAL EFFECTS FOR ELECTRICAL DISCHARGE MACHINING

Hans-Peter SCHULZE, Marco LEONE, Oliver KRÖNING, Wolfgang SCHÄTZING

ABSTRACT

The literature shows that the eletrical discharge machining is mainly simulated in selected phases. Accordingly the models can be simplified and measurment data can take influence on the calculation of thermal surface problems. Discharge channel growth is the determining factor for the thermal influence of the electrodes surfaces. The paper examines the calculation of the discharge channel radius. Current and voltage curves (for the working gap) are used as source input values to show the thermal stress. The real current and voltage curve were measured during single pulse discharges so that the accurate crater topology can be compared. This detailed modeling is absolutely necessary for analyzing short pulse durations.

KEYWORDS : Electrical discharge machining, thermal effects, simulation, dielectric

1. INTRODUCTION

The simulation of thermal effects for spark erosion is an important work within the analysis of the electrical discharge machining. The simulation permits three important studies.

Firstly, through the real current and voltage paths direct conclusions can be concluded to the surface structure. Secondly, predictions can be made to the surface structure by idealized current and voltage paths. Thirdly, influences of discharge phases can be analyzed by the selection of the time steps.

The model of the discharge channel (plasma channel and gas bubble) corresponds to a cylindrical heat source. A defined part of the pulse energy is yielded about the faces (bases of the discharge channel) onto the electrode surfaces. Another part goes about the generated surface into the dielectric. Another part goes about the generated surface into the dielectric. The residual pulse energy is stored temporarily in the capacitive electrode arrangement or needed for the conservation of the plasma channel.

The simulation to the phase analysis is supposed to be used, the physical parameters are to be used as functions of the temperature then, in particular the enthalpy H(T). During the temporal expansion of the discharge channel and/or plasma channel there are the greatest problems currently. In the paper is shown, as this temporal expansion can be defined and which restrictions through that occur.

2. INFLUENCE OF THE PLASMA CHANNEL BASE

The plasma channel radius propagation is very difficult to determine for the simulation of the thermal-affected zones.

Most models do not consider, that the real plasma channel is not cylinder-symmetric and does build up variously large plasma bases at the electrodes.

According to *Erden* [01] the discharge channel is dependent on the material of the electrodes and the dielectric medium. For long pulse duration is applied

$$r_{pch}(t) = K \cdot W_i^{\,m} \cdot t^n \qquad (1)$$

K, m and n are empirical constants and W_i is the pulse energy. This Eq. (1) applies only when the pulse energy is constant. It is impossible to conclude the constants from the physical and chemical properties. A simplified form of the Eq. 1 was found by *Patel* and *DiBitonto* [02] for the cathode (Eq. 2). In there work the simulation is used to calculate the optimal pulse parameters.

$$r_{pch}(t) = K \cdot t^n \qquad (2)$$

The empirical constants are estimated to K = 0.785 and n = 0.75. These results are to be described hardly suitable the thermal influence of short pulses and/or individual pulse phases.

Ikai and *Hashiguchi* [03] generate an equivalent heat source that is appoint through pulse current and pulse duration. Therefrom they developed the Eq. (3). It is not considered, that the current i(t) is not constant. The Eq. (3) has a range of validity for long pulse duration.

$$r_{pch}(t, I) = 2.04 \cdot 10^{-3} \cdot I^{0.43} \cdot t^{0.44} \qquad (3)$$

The constant pulse current I and the discharge duration t are in Eq. (3). *Sharakhovsky* [04] assumes, that there must be an equivalent radius of the planar heat source for every line of fusion (Solidus line) on the electrode surface. The connection between this Solidus line R_f and the source radius r_q is in Eq. (4) indicated.

$$\mathbf{lg}\, r_q = -0.52 + 0.82 \cdot \mathbf{lg}\, R_f \qquad (4)$$

In this model is accepted, that the model radius of the heat source must not agree with the Solidus Line or Liquidus Line. Already in former models the source radii were considerably larger as measured crater radii and the real plasma channel radii [05], [06].

Finally the model of *Spur* and *Schoenbeck* [07] is supposed because this is designed for short pulse duration.

Starting point is a needle pulse with constant current rise, and same current drop. For the current rise phase applies

$$r_{pch}(t_a, t) = a + b \cdot t \qquad (5a)$$

and for the current drop phase applies

$$r_{pch}(t_a, t) = r_{pch}(t_a, t_a) + c \cdot (t - t_a) \qquad (5b)$$

The current densities computed from the defined radii (Eq. 5) are used for the heat source model.

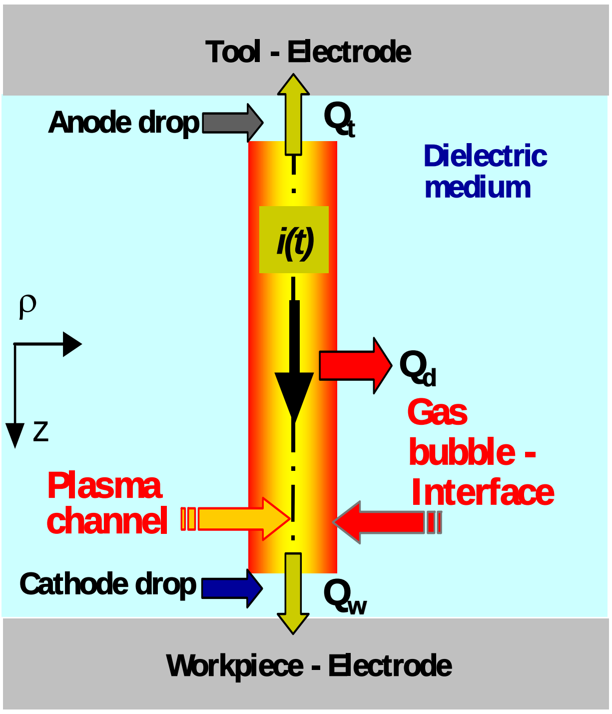

Fig. 1. Model of discharge channel (EDM)

At the beginning similar approaches were used for the developed model (Otto-von-Guericke University Magdeburg) as with *Spur*. Linear current rises depending on the maximum working current are defined for selected time periods.

According to the comparison of the simulated Liquidus Line with the crater parameters the radius increase is adapted according to the deviation.

The simulated results for short pulses are very well usable in order to determine crater topography for different materilas of electrode and pulse parameters. It is a deficit of this first release that the dielectric can not be considered directly.

In the new model it is assumed that in a time interval δt vaporizes a cylindrical volume element of the dielectric and transforms the heat of evaporation.

$$r_{n+1} = \sqrt{\frac{\zeta_1 \cdot \varepsilon_i\left(t_{n,n+1}\right)}{\pi \cdot \ell \cdot \rho(T_1) \cdot \left(c_0 \cdot \left(T_S - T_1\right) + \frac{c_S - c_0}{2} \cdot \left[\left(T_S - T_0\right) - \frac{\left(T_1 - T_0\right)^2}{T_S - T_0} \right] + \Delta h_V + \frac{\Delta_f H^0}{M_{Fl}} \right)} + r_n^2} \quad (6)$$

The radius of the plasma channel cylinder r_{pch} corresponds the maximum radius of the heat source of the plasma channel bases.

In this case material of electrode vaporizes only within this computed radius.

For the time intervals δt_i can be charged about the temporal paths of current and voltage the inserted powers and be determined through that the exact propagation conditions.

The model approach for the discharge channel and/or the plasma channel is in Figure 1 represented.

The discharge channel includes the plasma channel and a gaseous transition region (Gas bubble) to the liquid dielectric.

In Figure 2 the layer model of the cylindrical expansion of the heating is represented.

Under the assumption that the cooling to the dielectric is very small because the gas bubble has a small thermal conductivity the propagation equation can be computed for the plasma channel radius as follows (Eq. (6)).

The form indicated in Eq. (6) contains furthermore the binding energy of the dielectric, that is the decomposition of the dielectric is accepted in the plasma region.

In Eq. (6) are

- ζ_1 the part which is binding in the plasma,
- ε_i the pulse energie in the time period δt_i,
- ℓ the lenght of the plasma channel,
- $\rho(T_1)$ the density of dielectric by room temperature T_1,
- T_s, T_1 and T_0 are boiling temperature, room temperature and reference temperature for 0°C,
- c_S and c_0 the specific thermal capacitance for boiling temperature and reference temperature of the dielectric medium,
- Δh_V the boiling enthalpie and
- $(\Delta_f H^0 / M_{Fl})$ the binding energy of the dielectric medium.

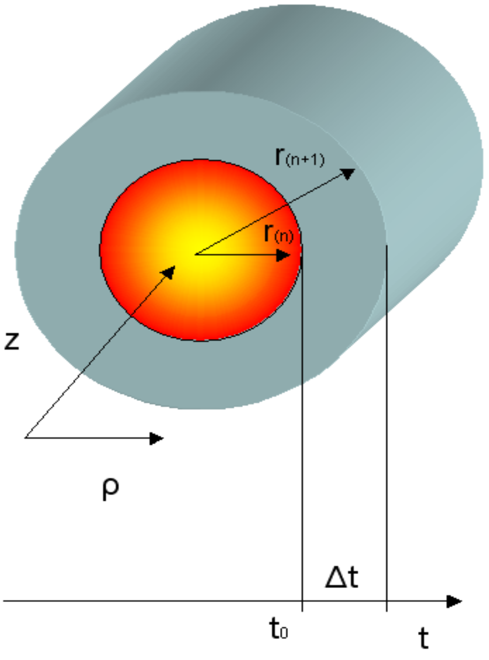

Fig. 2. Layer model for the propagation of plasma channel

3. PLASMA RADIUS PROPAGATION RESULTS

It is very important to measure the crater topology for single discharges because the deviations were to be minimized between simulation and real discharge (Fig. 3).

Therefore from all single discharge craters CLSM images are manufactured in order to exclude effects, as

- the jumping of the plasma channel bases (Fig. 4),
- the multiple igniting of the discharge channel,
- the movement of the plasma channel bases and other.

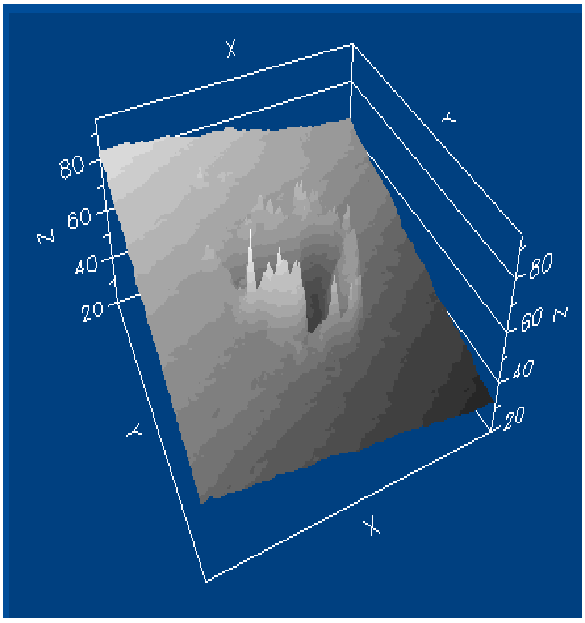

Fig. 3. CLSM for ideal crater topology

In Figure 5 the r_{pch}-courses are simulated for four different approaches.

The first assumption is, the boiling point is reached and the boiling-heat is transformed in the plasma channel.
The measured crater parameters are much smaller, than the simulated plasma channel radius (65 µm) for 5 µs pulse duration. Considering, that the critical temperature (changed pressure conditions) can be reached, a crater radius of 51 µm is measured.

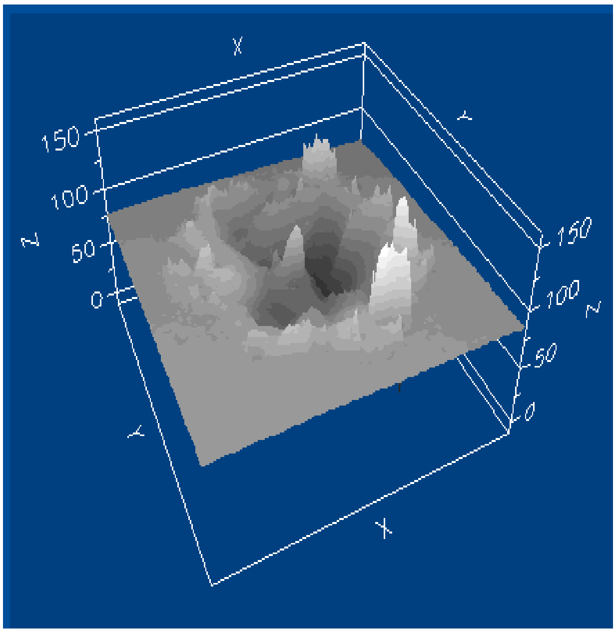

Fig. 4. CLSM – crater topology for single discharge with base jumping or multiple ignition

Also this simulation differs still too strongly of the real condition.
The consideration of the binding energy shows a clear trend into the range of the measured crater parameters.
The maximum temperature of the dielectric does not play then any decisive role more.

For the boiling temperature and the critical temperature are the radii of the Liquidus Line at 33 µm and/or 36 µm.The approach according to Eq. (6) can be used for the propagation of the plasma channel base in order to simulate the thermal interference of the electrode surfaces over all temporal phases of the discharge.

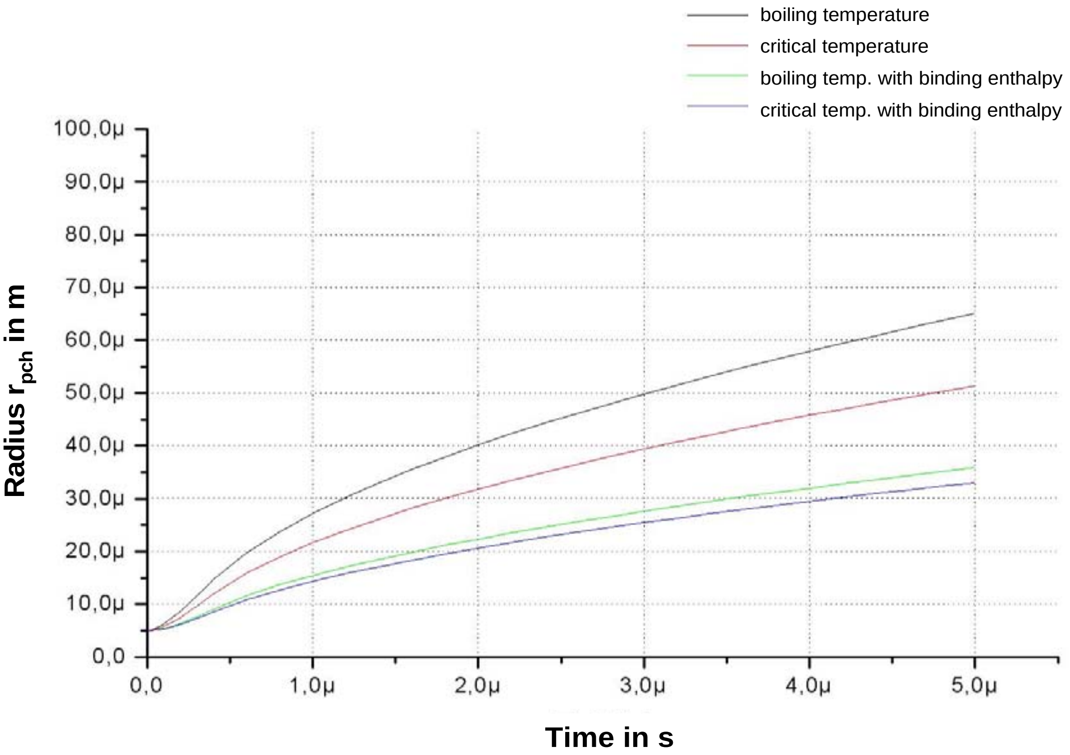

Fig. 5. Dependence of the plasma channel radius on different temperature limits and the binding energy

The accuracy of the plasma radius propagation reduces with that to the determination of the energy part that in the plasma channel is transformed.
At anode and cathode can not be accepted the same initial conditions for the propagation of the plasma channel.

The differences begin in the condition of the pre-ignition phase.
The anode initial radius becomes larger than at the cathode through the early affect of the electrons.

The important voltage drops are certain through impact processes at anode and cathode, that differently and in part very strongly depend on the electrode material. These calculations must occur empirically for these parameters.

4. CONCLUSION

The temporal dependence of the plasma channel radius influences significantly the simulated ranges of the thermal strain of the electrode surface, in particular if discharge phases are supposed to be analyzed.

The comparison of different approaches lets recognize that the binding energies and the temperature dependence of the physical properties can not be neglected.

With the equation (6) the radius propagation can be determined depending on the measured pulse parameters.

The simulation results determined from that tally well with measured crater topology.

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