IMPACT PHENOMENA DURING ELECTRICAL DISCHARGE MACHINING

L. Slătineanu, M. Coteață, O. Dodun, D. Anton, A. Munteanu, S.M. Ilii

1. Laboratory for Machine Manufacturing Technology, Machine Manufacturing Technology Department, Technical University “Gh. Asachi” of Iași, Romania

ABSTRACT

The paper analyses some common aspects of the electrical discharge machining and electron beam machining; the authors tried to search if certain knowledge specific to the electron beam machining could be used in the case of the electrical discharge machining. The effects generated by the electrons at the impact zone with the workpiece material depend on the kinetic energy of the electrons and on the physical properties of the workpiece material. A device able to generate a single electrical discharge between the electrode tool and the test piece, in certain experimental conditions, was built and experimented. The experiments proved the influence exerted by some factors on the size of the crater generated on the workpiece surface by the electrical discharge.

KEYWORDS: Electrical discharge machining, Impact phenomena, Crater forming

1. INTRODUCTION

The electrical discharge machining (EDM) is based on the erosion effect of the electrical discharges in pulse, occurring between an electrode - tool (ET) (that contributes to the macroscopic localization of the process), and the workpiece - electrode (WE), if there is an equipment that provides the adequate conditions for the machining development. The electrodes (the tool and the workpiece) are surrounded by the dielectric fluid during the electrical discharge machining. The machining method does not involve the physical contact between the electrodes /1, 3, 7, 8/. The tool remains a distance away from the workpiece; this means that no mechanical force is exerted on the tool by the machining process.

When the electrode tool is connected to the negative pole of the direct current pulse generator, the electrons appear in the electrical discharge channel and they arrive to the workpiece surface; the phenomena of phase changing, material melting and vaporizing develop, and finally small quantities of workpiece material are removed. One can conclude that the impact phenomena of the electrons with the workpiece superficial layer are the main phenomena which contribute to the developing of the machining.

On the other hand, the same impact phenomena are used within other machining method, namely the electron beam machining. Just within the definition of the electron beam machining, the specialists accept that this machining method uses the thermal and / or chemical effect generated by the high-energy electron beam directed to the impact zone, by the electrostatic and / or electromagnetic fields /4, 6, 7/.

Both in the case of the electron beam machining and the electrical discharge machining, when the volume machining methods are tackled, the material removal develops by successive generations of craters. The surfaces resulted after the electrical discharge machining are a concatenation of craters. On the other hand, the surface obtained as consequence of the electron beam machining (for example, when holes or grooves are machined) are also the results of successive craters generation. Within the both machining methods, the surfaces are created of craters, but also other similitude existing between the electrical discharge machining and the electron beam machining could be an interesting study subject. This means that common as-
pects to the electrical discharge machining and to the electron beam machining could be ana-
yzed. N. A. Marks, D. R. McKenzie and B. A. Pailthorpe /5/ used a two dimensional simulation to study
the phenomena occurring after the ion impact with the target material. They established that
focused collision sequences, sputtering and a thermal spike develops. Of course, the mass of
the electrons is smaller than the ions mass, but an interesting conclusion was that when an
electron-phonon interaction is analyzed, the impact phenomena are slightly damped, but their
main characteristics are unchanged.

2. SIMILAR ASPECTS AND DIFFERENCES BETWEEN THE TWO MACHINING METHODS
WHICH USE THE MATERIAL REMOVAL BY THE ACCELERATED ELECTRONS

Within the electrical discharge machining, the electrons and ions appear in the plasma channel
generated as consequence of the electrical discharge, by the dissociation of the molecules and
atoms along the electrical discharge channel. To increase the material removal rate, the energy
is delivered in electrical pulses and adequate pulse generators are used. The electrons are di-
rected to the workpiece surface layer, due to their connection to the positive pole of the direct
current source.

The kinetic energy of the electrons can be written as:

\[ W = \frac{m_e v_e^2}{2} \quad (1) \]

where \( m_e \) is the electron mass (\( m_e = 9.1066 \times 10^{-28} \) g) and \( v_e \) is the electron speed. The significant
part of the electrons energy is dissipated in the workpiece surface layer, finally determining the
craters generation.

In the case of the electron beam machining, the heated emitter element (for example, the cath-
ode made of tungsten filament) provides a continuous source of thermal electrons, by thermoe-
lectic emission. The electrons are accelerated to the anode connected at the ground potential.
The electric kinetic energy of the electron could be written as:

\[ W = eU, \quad (2) \]

where \( e = 1.602 \times 10^{-19} \) A·s is the charge on electron and \( U \) – the potential difference between the
cathode and anode. On the other hand, the kinetic energy of the accelerated electron which
contributes to the craters generation is given by:

\[ W = \frac{m(v_{ef}^2 - v_{ei}^2)}{2}, \quad (3) \]

\( v_{ef} \) being the final speed of the electron and \( v_{ei} \) – the electron initial speed. Because the final
speed \( v_{ef} \) is much smaller than the initial speed \( v_{ei} \), the first one could be neglected. If the speed
\( v_{ef} \) is very small and the last two relations are considered, the electrons speed \( v_e \) could be de-
determined:

\[ v_e = \sqrt{\frac{2eU}{m}}, \quad (4) \]

If the potential difference \( U = 5-200 \) kV, the electron speed could be \( v_e = 41.945-265.287 \) m/s. If in
the case of the electron beam machining the electrons move in vacuum, in the case of the elec-
trical discharge machining the electrons move within the plasma channel, among the other par-
ticles which move in the contrary direction.
If the potential difference specific to the electrical discharge machining (for example, \( U=70 \) V) is taken into consideration in the relation (4), one can conclude that the electron speed is much smaller \( (v_e=5019 \text{ m/s}) \) than the electron speed within the electron beam. This means that the electron energy is much smaller in the case of the electrical discharge machining and the effects of the impact phenomena with the workpiece material is more reduced than in the case of the electron beam machining.

Other difference could refer to the possibilities to control the energy; in the case of the electron beam machining, the beam energy can be easier controlled by means of the external electrical or magnetic fields. Such control modalities are fewer used in the case of the electrical discharge machining.

An interesting fact is that due to their small dimensions and kinetic energy, the electrons succeed to cross the workpiece superficial layer having the thickness:

\[
\delta = 2.2 \cdot 10^{-12} \frac{U^2}{\rho},
\]  

where \( U \) is the potential difference between the cathode and anode (V), and \( \rho \) – the workpiece material density (g/cm\(^3\)). If the potential difference is \( U=5000 \text{ – 200000 V} \), the depth of electrons free penetration in the surface layer of the metallic workpiece is \( \delta=7.05 \cdot 10^{-8} \text{ – 1.128} \cdot 10^{-2} \text{ cm} \). If the potential \( U \) has a value corresponding to voltage applied usually within the electrical discharge machining (for example, \( U=70 \) V), one can notice that the depth of electrons free penetration is much smaller \((\delta=1.381 \cdot 10^{-9} \text{ cm})\).

After the crossing the layer of depth \( \delta \), the electrons energy is dissipated; the workpiece material temperature increases up to the vaporizing and melting temperatures, so that a micro explosion is produced and the small quantities of the workpiece material are ejected and a small crater is generated.

### 3. EXPERIMENTAL CONSIDERATIONS

To search some aspects specific to the electrical discharge machining, the work scheme graphically represented in the Figure 1 can be considered. Two electrodes (the electrode tool \( ET \) and the workpiece electrode \( WE \)) having the prism shapes were placed in two planes \( P1 \) and \( P2 \) perpendicular each other; in this way, there is a single zone where the distance between the electrodes is minimum. There is a high probability that for a small distance between the electrodes \( ET \) and \( WE \), the electrical discharge appears just in this zone. The electrodes are included in an adequate relaxation circuit (type Lazarenko); thus, there is a capacitor \( C \) with variable capacity (in fact, there is a capacitors battery). The particular aspect of the equipment is that it permits only single electrical discharges (after the discharge of the capacitor, a new charging of the capacitor needs to act a switch). The direct current necessary to the electric discharge is obtained by means of a transformer and a rectifier.

The electrical discharge generates a crater on the workpiece electrode; one can consider that this crater has the shape of a spherical cap, see Figure 2, with the height \( h \) and the width \( B \). The crater volume \( V \) corresponds to the volume of a half of a spherical cap:

\[
V = \frac{1}{2} V_{\text{cap}} = \frac{1}{2} \frac{2}{3} \pi R^2 h = \frac{1}{3} \pi R^2 h
\]  

where \( V_{\text{cap}} \) is the volume of the spherical cap, \( R \) is the radius of the spherical cap and \( h \) is the height of the spherical cap.

Within the experimental researches, the heights \( h \) and the widths \( B \) of the spherical caps were measured by the adequate using of a microscope. In the last equality, the radius \( R \) must be expressed as a function of \( h \) and \( B \). Simple geometrical considerations applied in the case of a circle segment (Figure 3) leads to the relation:
From such a mathematical relation, the radius $R$ could be written as:

$$ R^2 = \frac{B^2}{4} + (R-h)^2 $$  \hspace{1cm} (7)

Taking the last relation in consideration, the volume $V$ is given by:

$$ V = \pi \left( \frac{h}{2} + \frac{B^2}{8h} \right)^2 $$  \hspace{1cm} (9)

On the other hand, it is expected that the size of the volume $V$ be proportional with the size of the energy $W$:

$$ V = k_1 W, $$  \hspace{1cm} (10)

$k_1$ being a coefficient of proportionality.

Some preliminary experiments proved that not all the energy stored in the capacitor is delivered during the electrical discharge and a certain electrical charge is maintained in the capacitor even

**Figure 1:** Experimental research of the impact phenomena within the electrical discharge.

**Figure 2:** Crater generated on the workpiece by the electrical discharge.
after the developing of the electrical discharge. By the measuring of the voltage \( U_i \) existing in the capacitor after the developing of the electrical discharge, the energy \( W_e \) delivered within the electrical discharge should be estimated:

\[
W_e = \frac{C(U_i^2 - U_f^2)}{2}
\]

\( U_i \) being the initial potential difference between the electrodes.

If the relations (10) and (11) are considered, the volume \( V \) becomes:

\[
V = k_1 \frac{C(U_i^2 - U_f^2)}{2}
\]

In accordance with such a relation, the variation of the volume \( V \) must is direct proportional with the capacity \( C \).

By the using of the equipment schematically presented in Figure 1, some experiments were made, for different sizes of the electric capacity \( C \) and potential difference \( U_i \). The experimental conditions and the results are succinctly presented in the table 1. By the using of the relation (8), the experimental volumes \( V \) of the craters were calculated; the sizes thus obtained were included in the column 8 of the table 1. The workpiece was made of high speed steel (containing 0.8 % carbon, 17 % tungsten, 5.1 % cobalt, 4.1 % chromium and 1.2 % vanadium) and the electrode tool – of copper.

![Figure 3: Correlations among the crater dimensions.](image)

**Table 1: Experimental results.**

<table>
<thead>
<tr>
<th>Exp. no.</th>
<th>Capacity ( C ), ( \mu \text{F} )</th>
<th>Initial voltage ( U_i ), V</th>
<th>Final voltage ( U_f ), V</th>
<th>Potential difference, ( U ), V</th>
<th>Crater height, ( h ), mm</th>
<th>Crater width, ( B ), mm</th>
<th>Crater volume, ( V ), mm(^3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1000</td>
<td>40</td>
<td>20</td>
<td>20</td>
<td>0.60</td>
<td>0.27</td>
<td>0.0947</td>
</tr>
<tr>
<td>2</td>
<td>1000</td>
<td>80</td>
<td>21</td>
<td>59</td>
<td>1.08</td>
<td>0.51</td>
<td>0.3087</td>
</tr>
<tr>
<td>3</td>
<td>10200</td>
<td>40</td>
<td>23</td>
<td>17</td>
<td>1.33</td>
<td>0.76</td>
<td>0.4724</td>
</tr>
<tr>
<td>4</td>
<td>10200</td>
<td>80</td>
<td>24</td>
<td>56</td>
<td>2.14</td>
<td>1.08</td>
<td>1.229</td>
</tr>
</tbody>
</table>

The experimental results were processed by means of specialized software /2/; thus, the following type power function was determined:

\[
V = 0.007932C^{-0.347}U^{0.458}.
\]
By analysing the relation (13), one can notice that the potential difference $U$ exerts a more important influence on the volume $V$ of the crater, in comparison with the influence exerted by the capacity $C$, because the size of the exponent $U$ is greater than the size of the exponent attached to $C (0.458>0.347)$. On the other hand, the size of the exponent corresponding to the voltage $U$ is smaller than the exponent 2 corresponding to the voltage in the relation (12). This means that not all the energy of the electrical discharge contributes to the crater generation in the workpiece surface layer; indeed, a quantity of the discharge energy is dissipated on the so-called electrode tool and in the space round of the discharge channel.

4. CONCLUSIONS

Both the electrical discharge machining and the electron beam machining are based on the impact phenomena of the accelerated electrons with the workpiece surface layer. The kinetic energy specific to the electron beam machining is greater, since the potential difference used for the electrons acceleration is greater. The main consequence of the impact phenomena are the generation of craters on the workpiece surface, as consequence of the energy dissipation and heat developing; small quantities of the workpiece material are melted, vaporized and ejected out of the workpiece. The volume of the crater is influenced by the energy of the electrical discharge, by means of the capacity of the electrical discharge circuit and the potential difference applied to the electrodes.

5. REFERENCES