Nonconventional Technologies Review
Romania, June, 2013

THEORETICAL STUDIES ON ELECTRODISCHARGE MACHINING WITH ROTATING ELECTROD TOOL

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ABSTRACT: Electrical discharge machining is a process that still raises many problems related to productivity, accuracy and tool consumption. This paper presents a theoretical research concerning the influence of rotational motion of the tool electrode on the electrical discharge machining process development. First, we have studied the influence of the motion on the debris` evacuation from the gap, then we analyzed the modification of the tool electrode removed layer.
KEY WORDS: Electrodischarge machining, rotating electrode tool

1. INTRODUCTION

Electrical discharge machining is one of the most used non-traditional machining methods. It is used especially for hard metals or other types that would be very difficult to handle by traditional means.

The tool consists of either a massive electrode that has the same shape with the work piece, or a wire that follows the contour. The first solution is known as die-sinking EDM –or Sinker EDM, or volume EDM- and the second – Wire EDM.

The sinker equipment does not need complicated motions, the electrode tool only shifting vertical and its shape being copied on the work piece.

Due to the manufacturing mechanism which consists of repeated electrical discharges between tool-electrode and the work piece, besides manufacturing the material belonging to the work piece, there will occur an unwanted sampling on the tool surface. There have been made a lot of researches in order to diminish this wear and the solutions brought are sometimes being implemented by machine construction factories belonging to the field.

Several authors have made theoretical and practical researches regarding these implementations, therefore the purpose of the present paper is to express some of authors' theoretical studies concerning electrical discharge machining with rotating electrode tool.

The authors considered the case of a disc electrode that rotates around a horizontal axis and in the same time moves linear on vertical.

2. ROTATIONAL MOTION INFLUENCE ON THE EVACUATION PROCESS OF EROSION PRODUCTS

There are several reasons why, during the process, a high concentration of erosion products might appear in the working gap, nonetheless the final result of this agglomeration is given by modifying the electrical discharge characteristics including consequences regarding productivity, impulse use efficiency, manufacture stability and quality of the resulted surface.

The main factors that lead to workspace agglomeration are:

- poor work zone wash
- improper energetic regime
- Moreover, the poor work zone wash might occur due to different situations:
- a high-viscosity dielectric fluid
- insufficient debit of the dielectric fluid
- working area wider than the washing possibilities' extent
- geometry of Transfer Object attack surface does not permit washing properly

There are generally used some channels–either through OT, or OP-in order to improve the quality of the wash, and, by the means of these channels, the dielectric fluid is brought to the working area. Furthermore, a pulsatory regime that consists of the transfer object periodical retraction is used, so that gap is properly washed.

This solution requires a high manufacturing price (in addition to the fact that in some cases it is not even possible) – given the supplementary operation (drilling of the OP or OT) and the productivity decrease generated once additional time is introduced.

Another solution for improving the quality of the wash resides in a supplementary OT movement whenever possible. It has been noticed that introducing a rotation movement for the OT mends the manufacturing qualities [1], [2], [3], [4], [5], which is why in the present paper processing precision with rotating electrode is highlighted.

Past research [6], [7], [8], [9], [10], regarding the influence of rotation movement on technological parameters has demonstrated that this has a low influence on the erosion process, and the highest influence is manifested during evacuation phase when the erosion products are being eliminated from the erosive gap.

More than one hypothesis that approximates real conditions is mandatory in order to express the movement of a particle, which is the result of the erosion through the gap.

These approximations are necessary given the extreme and time-varying conditions found at the erosive gap.

We will consider that over the studied segment, the liquid flow is laminar, having a constant velocity

$$v = \omega * R$$

where ω represents the angular velocity[rad/sec] and R is the radius belonging to OT[mm]. Furthermore, we will ignore the other particles` existence and the eventual interactions between those and the considered particle.

The study must start at the same time the velocity of the particle coincides with the dielectric fluid velocity (regarding the module and the orientation) because the initial velocity of a separated particle from OT is very high in comparison with the fluid velocity and has an arbitrary orientation.

During the erosion process, there are several forces that act on a certain particle (considering an inertial reference system):

Force of gravity.

$$\vec{G} = m \cdot \vec{g}, \quad [2]$$

considering **m** the mass of the particle

Archimedes` force

$$\vec{F}_A = \frac{\rho_1}{\rho_p} \cdot \vec{G}, \quad [3]$$

where ρ_1 and ρ_p are the liquid`s and particle`s densities.

resistance force given by the viscosity of the dielectric fluid ,

$$F = -c * v_{relat} \quad [4]$$

where **c** is the resistance coefficient and v_{relat} is the relative movement velocity towards the dielectric fluid.

The Second Law of Thermodynamics is expressed below :

$$\vec{G} + \vec{F}_A + \vec{F}_v = m \cdot \vec{a} \quad [5]$$

where “a” is the acceleration gained by the particle on which the mentioned above forces act.

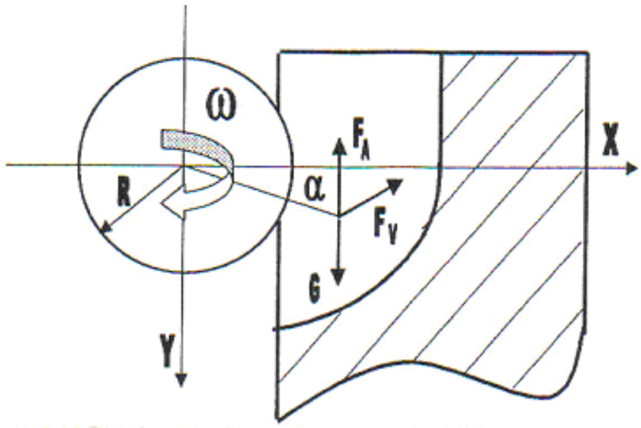

Figure 1. The forces that act on the particle of material; identical direction of rotational move and feed

Solving the equation [5] can be done in two different manners:

a) rotating OT the same direction the erosive feet (cw) (fig 1)
b) the rotation is counter feet of the erosion. (ccw)

In the first case (a), by projecting the equation on Ox and Oy axes of the Cartesian system from fig 1; referring the relative velocity of the particle to its absolute velocity and the absolute velocity of the fluid, we obtain the system [6]; whereas in case (b), the resulting system is represented as in equation [7]

$$\frac{d^2x}{dt^2} + \frac{c}{m} \cdot \frac{dx}{dt} - \frac{c}{m} \cdot \omega \cdot y(t) = 0$$

$$\frac{d^2y}{dt^2} + \frac{c}{m} \cdot \frac{dy}{dt} - \frac{c}{m} \cdot \omega \cdot x(t) - g \cdot \left(1 - \frac{\rho_1}{\rho_p}\right) = 0 \quad [6]$$

$$\frac{d^2x}{dt^2} - \frac{c}{m} \cdot \frac{dx}{dt} - \frac{c}{m} \cdot \omega \cdot y(t) = 0$$

$$\frac{d^2y}{dt^2}-\frac{c}{m}\cdot\frac{dy}{dt}-\frac{c}{m}\cdot\omega\cdot x(t)-g\cdot\left(1-\frac{\rho_1}{\rho_p}\right)=0 \quad [7]$$

In order to solve the system, Maple soft has been used, which gives us the graphic solution in some particular cases. Thereby, the particle initial position and velocity are being defined with the use of [8] system where r_0 and α_0 define the initial position of the studied particle and depend on the transfer object radius, on the working gap and also on the depth of the channel being processed.

$$\begin{cases} x(0)=r_o*\cos\alpha_0 \\ v_x(0)=-\omega*r_o*\sin\alpha_0 \\ y(0)=r_o*\sin\alpha \\ v_y(0)=\omega*r_o*\cos\alpha_0 \end{cases} \quad [8]$$

The particle mass can be calculated considering its volume and density; whereas the resistance coefficient depends not only on the particle profile shape and size,but also on the dielectric fluid density ρ_1, according to:

$$c=\frac{1}{2}\cdot C\cdot S\cdot\rho_1 \quad [9]$$

C being a proportionality coefficient, while S is the total area of the resulted surface by projecting the body on a perpendicular plan to the velocity vector.

The particles obtained by electrical erosion are usually spherical; their radius depending on the impulse time and material of the OP. For short durations of the impulse, we can consider the medium particle`s radius is 7 μm and its density will be accepted as being equal with the steel`s density (7.8 kg/dm^3).

Given the hypothesis according to which the movement is laminar, coefficient C is suggested to be chosen 0.4.Also, we will consider a medium value for ρ_1=0.85 kg/dm^3 ; the usual densities being in the range 0.815-0.865 0.85 g/cm^3.

As a result, c/m ratio will have the value:

$$\frac{c}{m}=\frac{\frac{1}{2}\cdot 0{,}4\cdot\pi\cdot r_p^2\cdot\rho_1}{\frac{4}{3}\cdot\pi\cdot r_p^3\cdot\rho_p}=2{,}33516 \quad [10]$$

The angular velocity ω will be calculated taking into consideration the transfer object`s rotational speed n:

$$\omega=\frac{n\cdot\pi}{30} \quad [11]$$

The movement equations include the following factor:

$$g\cdot\left(1-\frac{\rho_1}{\rho_p}\right)=9{,}81\cdot\left(1-\frac{0{,}85}{7{,}8}\right)=8{,}74 \quad [12]$$

It is clear that the only modifications that occur in system [7] compared to system [6] are given by the sign that can be found in front of the factor c/m·dy/dt which becomes a PLUS out of a MINUS; all the other factors being identical.

As for ω, r_0 and α_0 parameters: the values are given below due to scientific literature:

For the rational speed belonging to 0-100 rpm range; the angular velocity will be in between 0 and 10.472 rad/s.

OT radius values are usually limited under 100 mm for constructive reasons.

α_0 angle ranges between 0 and a maximum valueα_{0maxim} = arccos(R+ δ-h)/ (R+ δ) [13]

where R is the OT radius, δ is the size of the gap (being almost 0.05 mm for finishing) and h is the processed channel depth (between 0 and 5 mm).

Given the fact that ω can have more than one value, several graphics drawn by Maple soft will be studied in some of the cases, because the differences are not major considering the discussed time ranges (chosen so that the particle remains in the working gap).

The trajectories (two of them being presented below in figure 2) can be seen that have different shapes. However, according to fig 3 and 4 where there are presented the chosen trajectories, the dependencies x=x(t) and y=y(t) are approximately linear.

Based on these graphics, the trajectories of the particles have been drawn inside the working gap; determining the particle-OP wall collision points.

As shown in the algorithm belonging Figure 5, the following step is determining the displacement, collision speed, and acceleration (considering a uniformlyacceleratedmotion).

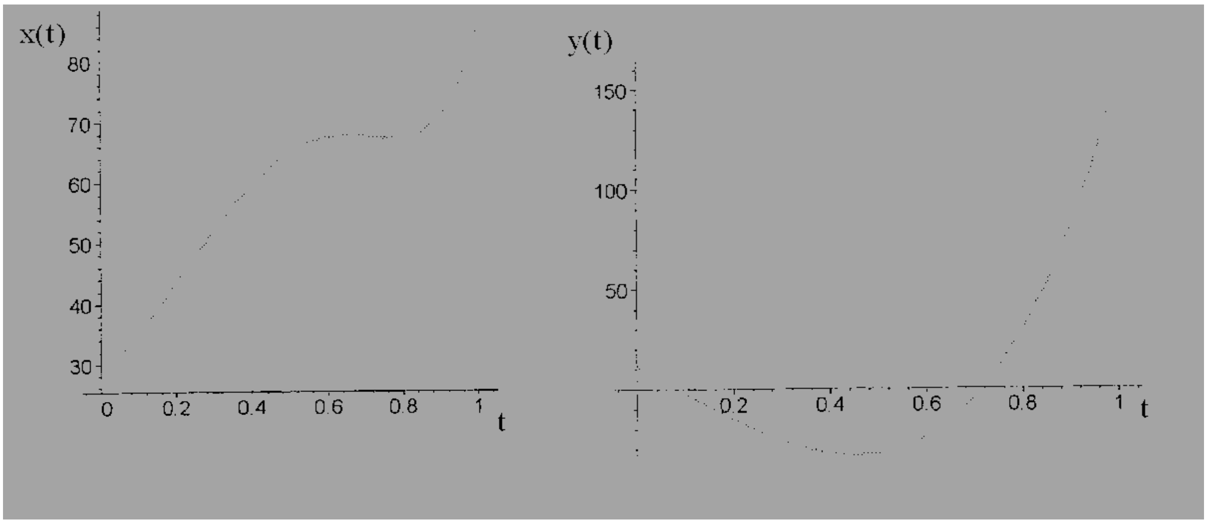

Figure 2. The trajectory of the debris

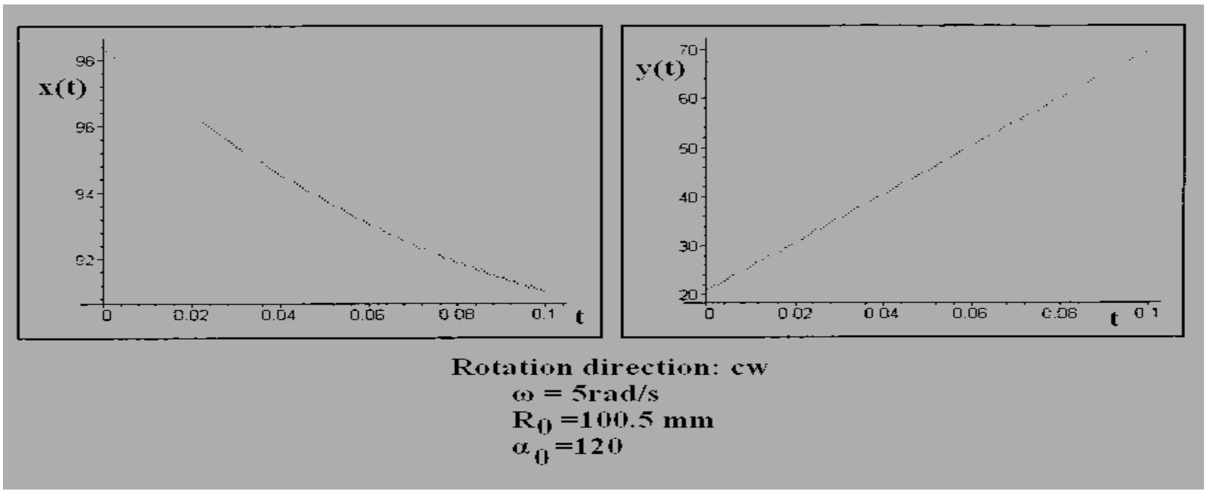

Figure 3. Particle displacement versus time graph, cw rotation

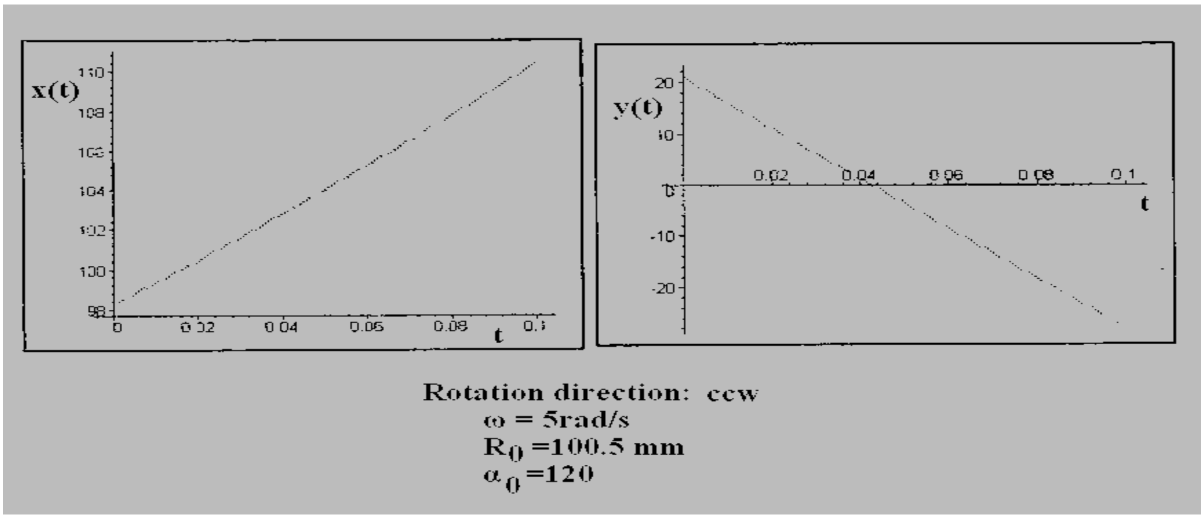

Figure 4. Particle displacement versus time graph, ccw rotation

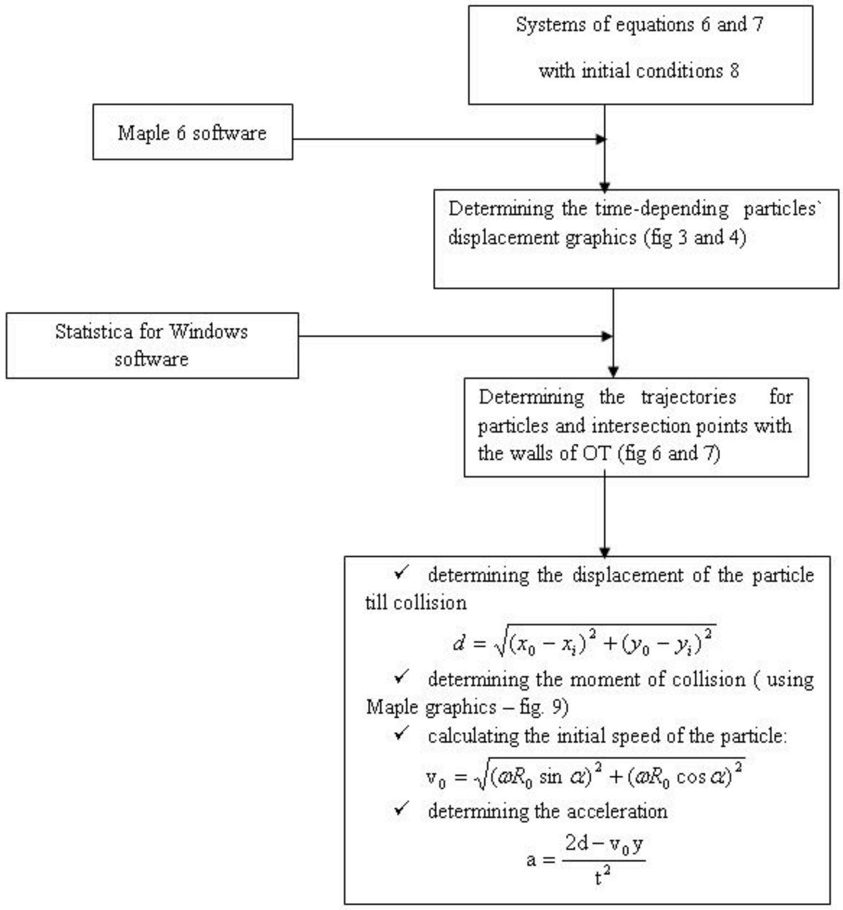

Figure 5. Algorithm for determining the kinematics values

Figures 6 and 7 reveal the motion graphics and the calculated or graphically determined sizes, values that lead us to conclusions regarding the erosion products' behavior in different circumstances.

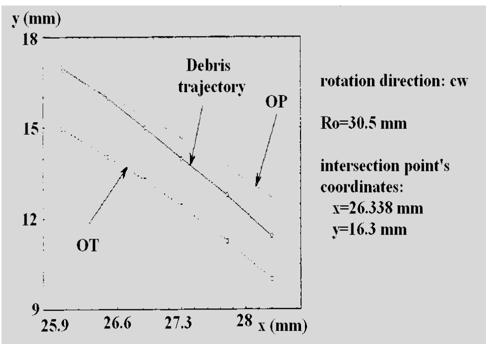

Figure 6. Debris trajectory

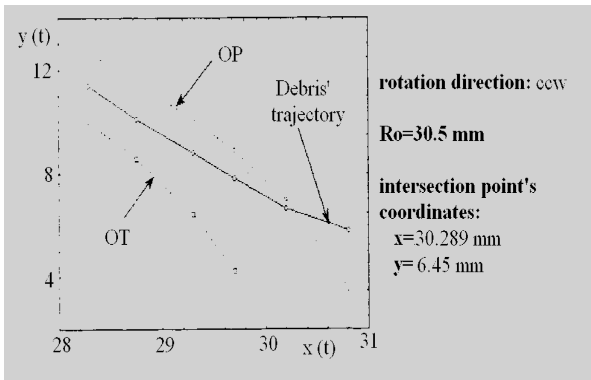

Figure 7. Debris trajectory

There are several ideas that can be concluded after studying the graphics and the tables from above:

Case	xo [mm]	y0 [mm]	xi [mm]	yi [mm]	d [mm]	t [s]	vox [mm/s]	voy [mm/s]	v0 [mm/s]	a [mm/s2]
1	28.28	11.42	26.17	16.7	5.68	0.038	57.1	141.4	152.5	159.28
2	28.28	11.42	29.94	7.6	4.16	0.025	57.1	141.4	152.5	1112
3	98.3	20.89	96.38	30.2	9.51	0.02	104.48	491.52	502.5	2700
4	98.3	20.89	100.47	10.33	10.78	0.019	104.48	491.52	502.5	6828.2
5	28.28	11.42	26.338	16.33	5.28	0.018	114.2	282.8	305	1296.3
6	28.28	11.42	30.289	6.45	5.361	0.017	114.2	282.8	305	1211.1
7	98.3	20.89	95.92	31.5	10.87	0.012	208.9	983	1005	3057
8	98.3	20.89	100.05	12.02	9.07	0.009	208.9	983	1005	617.28

Figure 8. The kinematic calculated values

- increased radius of OT use leads to enlarging the displacement made by the particle until collision with OT takes place (or, when the initial position of the sphere is nearby the exit of the gap)
- at low angular velocities it is noticed that the acceleration increases (as an absolute value) once the rotation is counter feet; whereas the acceleration increases when it is done in the same direction with the feet; when the angular velocities are high.
- between the considered cases, the highest velocity occurs in case 4 (6828 mm/s^2), almost 10 times higher than the minimum value (617,28 mm/ s^2), from case 8.

As a conclusion, if looking forward to increase the displacement of the particle until it collides with the wall of the OP, there can be made several recommendations:

✓ to use a large radius OT
✓ to use ccw rotation for low angular velocities and the cw rotation when having high angular velocities.

Those two steps increase the efficiency of the erosion products` evacuation process; which leads to a remarkable improvement not only for the precision characteristics but for all the manufacturing ones.

3. THE INFLUENCE OF THE ROTATIONAL MOTION ON THE DEPTH OF THE WEAR LAYER

To determine the influence of the rotational motionupon the depth of the worn layer from the surface of the transfer object we have considered the case of processing a channel (with the width b) with a disc electrode having the initial radius R.

If the transfer object is not rotating, the wear will affect a portion of a circular crown (ABCD in figure 9), corresponding to angle α [rad], to which size depends on the depth of the channel, the gap size and the OT radius, as seen in the following formula:

$$\alpha = \arccos\frac{R+\delta-h}{R+\delta} = \arccos\left(1-\frac{h}{R+\delta}\right) \quad [14]$$

For calculating the weared layer volume (V) we will consider a medium value of the weared layer depth, H, so that the final radius of the disc on this sector must be R_f. In this case we can write:

$$V = \frac{\pi\cdot\left(R^2-R_f^2\right)\cdot b\cdot\alpha}{2\pi} = \frac{b\cdot\alpha}{2}\cdot\left(R-R_f\right)\left(R+R_f\right) = \frac{b\cdot\alpha}{2}\cdot H\cdot\left(2R-H\right)$$

[15]

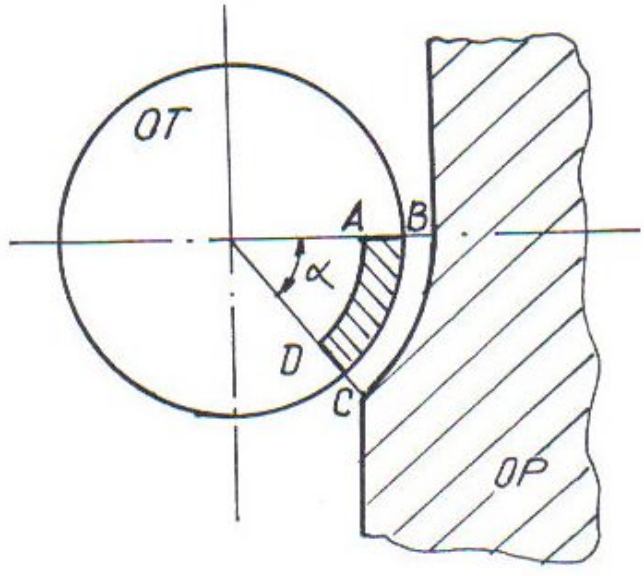

Figure 9. Circular OT manufacturing

When the electrode has a rotation movement with the rotational velocity *n* [rpm] the wear will be distributed on a wider surface, and due to the fact that the volume has to be the same (in the same amount of time) the new medium wear layer depth will be H_1. In this case the circular crown radius will be equal to α+ ωt, where ω is the angular velocity of the disc and will be calculated using relation [11]. The used volume will then be:

$$V = \frac{\pi\cdot\left(R^2-R_f^1\right)\cdot b}{2\pi}\cdot\left(\alpha+\omega\cdot t\right) = \frac{b\cdot\left(\alpha+\omega\cdot t\right)}{2}\cdot H1\cdot\left(2R-H1\right)[16]$$

Given the fact that the volume is identical in both situations ([14] and [15]), after dividing we get the following equation:

$$\alpha\cdot H\cdot(2R-H) = \alpha+\omega\cdot t)(2R-H1)\cdot H1 \quad [17]$$

The dependency H1=f(H) can be rapidly obtained using Maple 6 software.

The graphic representation for some particular cases has been considered more useful given the complex analysis that should be made otherwise, considering the formula given by the programme.

In order to be able to compare H and H1 values, taking into consideration that we are processing the same channel, there have been considered some random values for ω, R, t, h and δ and by means of Maple 6, there have been drawn the graphics for H1=f(H) and it can be observed that they are approximately linear, on the already considered segments. Consequently, for a better understanding regarding the depth decrease of the worn-out layer; the ratio Hmax/H1max is given for a few cases in figure 9 and also in the spreadsheet from figure 10.

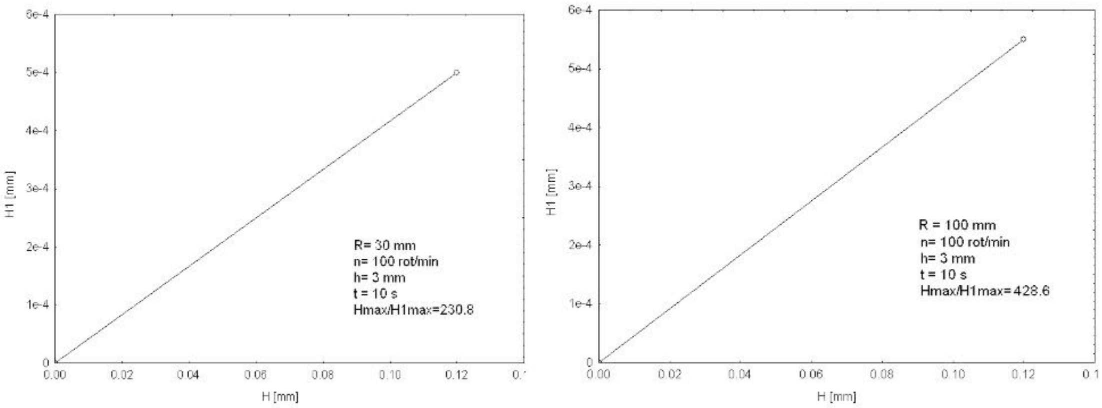

Figure 10. Depth decrease of the worn-out layer

#	1 R	2 N	3 COS_ALFA	4 ALFA	5 T	6 OMEGA	7 C1	8 C2	9 R2	10 H_H1
1	30.000	50.000	.900	.450	10.000	5.233	52.783	3167.000	60.000	115.380
2	100.000	50.000	.970	.245	10.000	5.233	52.578	10515.67	200.000	214.280
3	30.000	100.000	.900	.450	10.000	10.467	105.117	6307.000	60.000	230.770
4	100.000	100.000	.970	.245	10.000	10.467	104.912	20982.33	200.000	428.570
5	30.000	50.000	.833	.585	10.000	5.233	52.918	3175.100	60.000	88.230
6	100.000	50.000	.950	.317	10.000	5.233	52.650	10530.07	200.000	166.660
7	30.000	100.000	.833	.585	10.000	10.467	105.252	6315.100	60.000	172.400
8	100.000	100.000	.950	.317	10.000	10.467	104.984	20996.73	200.000	333.300

Figure 11. Spread sheet

We can observe that no matter the situation, increasing the rotational velocity and the radius lead to significant decrease of the wear layer medium depth.

For cases where there has been considered an increased depth of the processed channel (5 mm instead of 3 mm), the decrease of the wear layer medium depth is smaller than in the previous cases

4. THE INFLUENCE OF THE ROTATIONAL MOTION ON THE DEPTH OF THE WEAR LAYER

As a conclusion, inducing the transfer object a rotational motion influences the manufacturing quality in electric erosion process regarding two aspects:

- improving the erosion products` evacuation process
- wear distribution over a wider area while reducing the linear wear speed

Therefore an experimental research by the use of a rotating electrode is considered to be fair, using the conclusions obtained in the theoretical study: while having the same radiuses and rotational velocities, but a smaller channel width.

In consequence, when having the rotational electrode, even with an identical profile with a static electrode, will occur different values of colinear wear velocity $v_T$andof wear layer dimensions which leads to modifying not only the linear relative local wear but also the feet speed in order to be improved.

- to use a large radius OT
- to use ccw rotation for low angular velocities and the cw rotation when having high angular velocities.

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