A THEORETICAL STUDY ABOUT THE INFLUENCE OF PULSE PARAMETERS ON THE DYNAMICS OF THE EDM PRPOCESS

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ABSTRACT

Starting from a macroscopic regard on the active gap evolution during the electrical discharge machining, a theoretical model is built, describing the relations between the main pulse parameters and the erosion speed. The results of this study make possible a fuzzy approach of the EDM process.

KEYWORDS: EDM, pulse, dynamics, fuzzy

1. EVOLUTION OF THE ACTIVE GAP

Figure 1 presents the elements defining the evolution of the active gap between the tool-electrode (TE) and the workpiece (WP), during an infinitesimal lapse of time dt. It may be accepted that the speed v_a of the tool-electrode is invariable during dt. The WP and TE surfaces are eroded with dx_{WP} and dx_{TE} respectively, in Ox direction. The TE takes down with v_a.dt and the active gap between TE and WP increases from s (at t) to s+ds (at t+dt). These infinitesimal variations are related as follows:

$$s + ds = dx_{TE} + (s + dx_{WP} - v_a.dt)$$

or:

$$ds = dx_{TE} + dx_{WP} - v_a.dt \qquad (1)$$

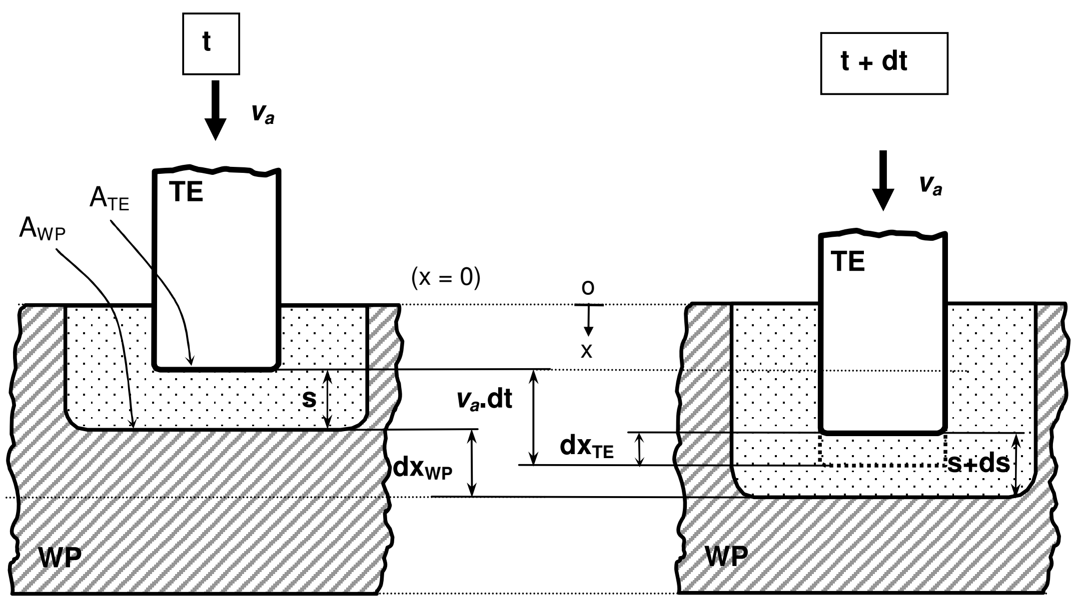

Fig. 1 Evolution of the active gap between the TE and the WP

The infinitesimal displacements dx_{WP} and dx_{TE} are expressed in function of the elementary volumes dV_{WP} and dV_{TE} eroded during dt and the constant areas A_{WP} and A_{TE} of the eroded surfaces:

$$dx_{WP} = \frac{dV_{WP}}{A_{WP}} \qquad (2)$$

$$dx_{TE} = \frac{dV_{TE}}{A_{TE}} \qquad (3)$$

where : dV_{WP}, dV_{TE} - the elementary volumes eroded during dt at the WP and TE,
A_{WP} , A_{TE} – the areas of the active surfaces of WP and TE.
The elementary volume dV_{WP} can be expressed in function of the volume eroded by a single discharge:

$$dV_{WP} = V_{iWP}.f_p.dt \qquad (4)$$

where : V_{iWP} – the eroded volume by a single discharge, at the surface of the workpiece,
f_p – the frequency of erosion discharges.
The eroded volume by a single discharge can be expressed as follows [1, 2]:

$$V_{iWP} = c.\eta.W_i \quad [mm^3/pulse] \qquad (5)$$

c = proportionality constant,
η = efficiency constant,
W_i = energy of a single discharge with erosion effect [J].
The energy of a single discharge with erosion effect is:

$$W_i = U_d.I_d.t_{ii} \quad [J] \qquad (6)$$

where:
U_d – the tension during the discharge process (20…25V),
I_d - the current of the electric discharge [A],
t_{ii} = the current pulse time [s].
The current pulse time can be expressed as follows:

$$t_{ii} = \eta_i \cdot T_p = \eta_i \cdot \frac{1}{f_p} \qquad (7)$$

where:
T_p - average period of erosion pulses [s],
$f_p = \frac{1}{T_p}$ - average frequency of erosion pulses [Hz],
$\eta_i = \frac{t_{ii}}{T_p}$ - pulse rate of current pulses, considering the average period of erosion pulses.
Equations (7), (6), (5) permit to express V_{iWP}:

$$V_{iWP} = c \cdot \eta \cdot \eta_i \cdot \frac{U_d \cdot I_d}{f_p} \qquad (8)$$

and (8), (4) lead to:

$$dV_{WP} = c \cdot \eta \cdot \eta_i \cdot U_d \cdot I_d \cdot dt \qquad (9)$$

Equations (9) and (2) define the elementary erosion of the WP surface in Ox direction, in the gap of time dt:

$$dx_{WP} = \frac{c \cdot \eta \cdot \eta_i}{A_{WP}} \cdot U_d \cdot I_d \cdot dt \qquad (10)$$

Similar to the previous approach, it is possible to express the wear of the tool electrode in Ox direction, starting from equation (3):

$$dV_{TE} = V_{iTE}.(f_p + f_M).dt \qquad (11)$$

where:
V_{iTE} - the eroded volume by a single discharge, at the surface of the tool electrode,
f_p – the frequency of erosion discharges,
f_M - the frequency of break up discharges.
The eroded volume by a single discharge can be expressed as follows [1, 2]:

$$V_{iES} = c'.\eta'.W_i \quad [mm^3/pulse] \qquad (12)$$

where:
c' = proportionality constant,
η' = a constant, similar to the efficiency constant η,
W_i = energy of a single discharge with erosion or break up effect [J].
The amounts of energy of erosion and break up discharges are appreciated as similar:

$$W_i = U_d.I_d.t_{ii} \quad [J] \qquad (13)$$

The duration of a current pulse can be expressed as follows:

$$t_{ii} = \eta_i \cdot \frac{1}{f_p + f_M} \qquad (14)$$

with:
f_p - average frequency of erosion pulses [Hz],

f_M- average frequency of break up pulses [Hz],

$\eta_i = \frac{t_{ii}}{T_{av}}$ - pulse rate of current pulses, considering a well-balanced average period T_{av} of the erosion and break up pulses.

V_{iTE} can be expressed from equations (14), (13), (12):

$$V_{iTE} = c' \cdot \eta' \cdot \eta_i \cdot \frac{U_d \cdot I_d}{f_p + f_M} \quad (15)$$

and (15),(11) lead to:

$$dV_{TE} = c' \cdot \eta' \cdot \eta_i \cdot U_d \cdot I_d \cdot dt \quad (16)$$

Equations (16) and (3) define the elementary erosion of the TE surface in Ox direction, during the gap of time dt:

$$dx_{TE} = \frac{c' \cdot \eta' \cdot \eta_i}{A_{TE}} \cdot U_d \cdot I_d \cdot dt \quad (17)$$

Using in equation (1) the partial results (10),(17) it is possible to express the elementary variation ds of the active gap, during dt:

$$ds = \frac{c \cdot \eta}{A_{WP}} \cdot \eta_i \cdot U_d \cdot I_d \cdot dt + \frac{c' \cdot \eta'}{A_{TE}} \cdot \eta_i \cdot U_d \cdot I_d \cdot dt - v_a \cdot dt \quad (18)$$

Two constants can be defined:

$$K_{WP} = \frac{c \cdot \eta}{A_{OP}} \qquad K_{TE} = \frac{c' \cdot \eta'}{A_{ES}} \quad (19)$$

Equation (18) becomes:

$$ds = (K_{OP} + K_{ES}) \cdot \eta_i \cdot U_d \cdot I_d \cdot dt - v_a \cdot dt \quad (20)$$

A global constant is defined:

$$K = (K_{OP} + K_{ES}) \quad (21)$$

(20), (21) lead to the differential equation describing the evolution of the active gap s:

$$\frac{ds}{dt} = K \cdot \eta_i \cdot U_d \cdot I_d - v_a \quad (22)$$

Considering the process parameters invariants in a finite lapse of time [0, t], the right part of (22) equation can be considered as a constant. In this case, the solution is:

$$s(t) = \int (K \cdot \eta_i \cdot U_d \cdot I_d - v_a) \cdot dt \quad (23)$$

$$s(t) = C + (K \cdot \eta_i \cdot U_d \cdot I_d - v_a) \cdot t \quad (24)$$

The integration constant C is calculable taking into consideration the initial condition:

$$s = s_0 \quad \text{when} \quad t = 0 \quad (25)$$

where s_0 is the breadth of the gap in the first moment of the considered lapse of time.

Equations (24) and (25) permit to express the temporal evolution of the active gap:

$$s(t) = s_0 + (K \cdot \eta_i \cdot U_d \cdot I_d - v_a) \cdot t \quad (26)$$

It can be seen that the axial movement v_a acts in the sense of decreasing the gap. The first term in the brackets acts in the opposite sense. That term represents in fact the speed of increasing the active gap, due to the erosion phenomena at the surfaces of WP and TE. It could be named “global erosion speed”, noted v_e:

$$v_e = K \cdot \eta_i \cdot U_d \cdot I_d \quad (27)$$

Equation (26) can be written as follows:

$$s(t) = s_0 + (v_e - v_a) \cdot t \quad (28)$$

This equation expresses in an obvious form the dynamic equilibrium condition of the EDM process: the gap rests unchanged ($s = s_0$) if the tendency of increase (v_e) due to the erosion process is balanced by the axial movement of the tool electrode (v_a). The EDM process is dynamic equilibrated if the internal feedback (process feedback) is permanently compensated by the external feedback (realized by an external control system) [1, 2, 3].

In (18), the factors of dt in the first two terms represent the speeds of progression of the surfaces of the WP and TE

- the speed of the workspace :

$$v_{WP} = \frac{c \cdot \eta}{A_{WP}} \cdot \eta_i \cdot U_d \cdot I_d = K_{WP} \cdot \eta_i \cdot U_d \cdot I_d \quad (29)$$

- the speed of the tool electrode:

$$v_{TE} = \frac{c' \cdot \eta'}{A_{TE}} \cdot \eta_i \cdot U_d \cdot I_d = K_{TE} \cdot \eta_i \cdot U_d \cdot I_d \quad (30)$$

Equation (28) can be transformed as follows:

$$s(t) = s_0 + (v_{WP} + v_{TE} - v_a) \cdot t \quad (31)$$

where: $v_{WP} + v_{TE} = v_e$ (32)

The meaning of the speeds v_{WP}, v_{TE} *and* v_a is illustrated in Fig.2

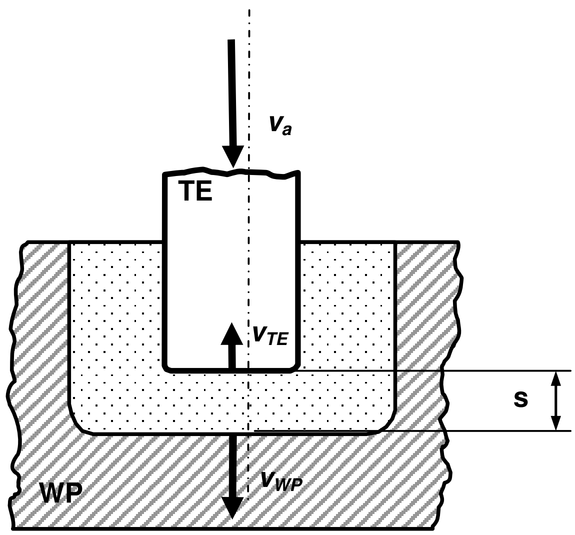

Fig. 2 ***The meaning of the speeds v_{WP}, v_{TE} and v_a***

2. DYNAMICS THE INFLUENCE OF THE PULSE PARAMETERS ON THE PROCESS

The EDM process proceeds in a stable way if the active gap is maintained unchanged. The discharges in spark form are possible if the amount of the active gap belongs to an interval (s_{min}, s_{max}). This represents the selectivity propriety [1, 2], which is illustrated qualitatively in Fig.3 as a dependence of the productivity (Q_p) versus the gap amount.

The optimal value of gap (s_{optim}) corresponds to a maximum probability to get an efficient discharge.

This condition of stability of the EDM process is introduced in equation (26), describing the temporal evolution of the active gap:

$s = s_0 = s_{optim} =$ constant

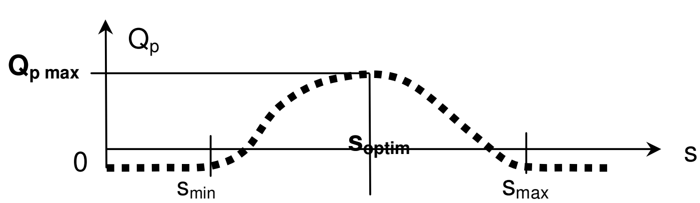

Fig. 3 Dependence of the productivity (Qp) versus the gap amount

The equation (26) becomes:

$$K \cdot \eta_i \cdot U_d \cdot I_d - v_a = 0$$

or:

$$v_a = K \cdot \eta_i \cdot U_d \cdot I_d \qquad (33)$$

This last equation shows in synthetic form the correlation between the electric pulse parameters, the material constants, the specific constants of the phenomena taking place in the gap, the characteristics of the EDM equipment and of the automatic control system, leading to a stable EDM process.
The material constants, the constants of the phenomena in the gap, the characteristics of the equipment and control system are included in the K global value.

This constant contains a large amount of unknown information. That is why an analytic description of the K value is very difficult or even impossible to be done. However, the equation (33) can be helpful in studying the correlation between electric and dynamic parameters, by using fuzzy techniques [3, 4].
This method allows finding out relations between the components of a system starting only from qualitative observation. The conclusions of such an analysis have to be adjusted and validated by real and/or simulated experiment.
Figure 4 shows the ideal that means pulses having as a result to remove material from the WP and TE surfaces. The main parameters of discharge pulses are specified [1, 2, 3].

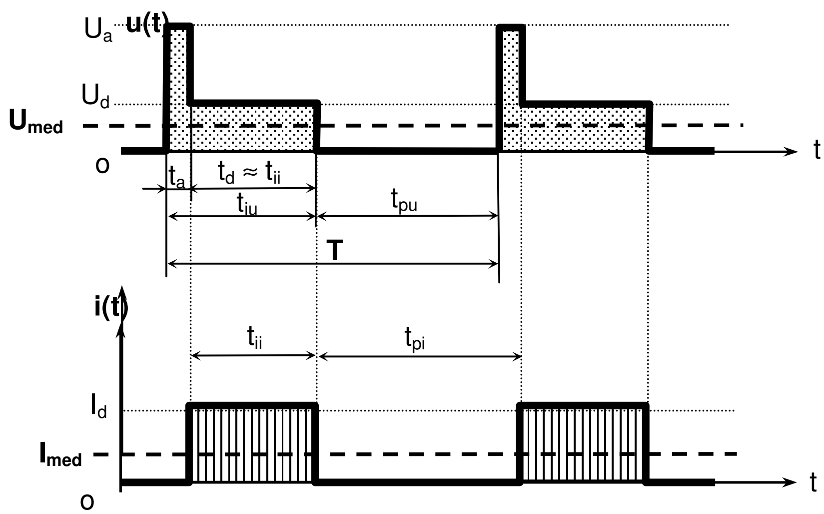

Fig.4 ideal that means pulses having as a result to remove material from the WP and TE

T	period of pulses	[s]
f = 1/T	frequency of pulses	[Hz]
t_a	breakdown delay	[s]
t_{iu}	tension pulse time	[s]
t_{pu}	pause time between tension pulses	[s]
t_{ii}	current pulse time	[s]
t_p	pause time between current pulses	[s]
U_a	breakdown tension	[V]
U_d	discharge tension	[V]
U_{av}	average value of gap tension	[V]
I_d	discharge current	[A]
I_{av}	average value of gap current	[A]

The duration of the top of tension pulses is considered equal with the duration of current pulse ($t_d = t_{ii}$). The average value of the gap tension is:

$$U_{av} = \frac{1}{T} \cdot \int_0^T u(t) \cdot dt \approx \frac{1}{T}\left(U_a \cdot t_a + U_d \cdot t_{ii}\right) = U_a \cdot \frac{t_a}{T} + U_d \cdot \frac{t_{ii}}{T} \qquad (34)$$

Following constants are introduced:
- the pulse rate of current pulses:

$$\eta_i = \frac{t_{ii}}{T} \qquad (35)$$

- pulse rate of the brackdown top

$$\eta_{Ua} = \frac{t_a}{T} \quad (36)$$

The average gap tension is:

$$U_{av} = U_a \cdot \eta_{Ua} + U_d \cdot \eta_i \quad (37)$$

The discharge tension U_d is expressed in function of the average gap tension U_{av}, easier to be found out by measurement:

$$U_d = \frac{U_{med} - \eta_{Ua} \cdot U_a}{\eta_i} \quad (38)$$

In a similar way and by the same reason, the discharge current I_d is expressed in function of the average value of the gap current I_{av}:

$$I_{av} = \frac{1}{T} \cdot \int_0^T i(t) \cdot dt \approx \frac{1}{T} \cdot I_d \cdot t_{ii} = \frac{t_{ii}}{T} \cdot I_d = \eta_i \cdot I_d \quad (39)$$

$$I_d = \frac{I_{av}}{\eta_i} \quad (40)$$

Equations (33), (38), (40) allow to express the correlation between the process parameters, using easy measurable average value:

$$v_a = K \cdot \frac{1}{\eta_i} \cdot I_{av} \cdot \left(U_{av} - \eta_{Ua} \cdot U_a\right) \quad (41)$$

3. CONCLUSIONS

The equation (41) allows evaluating the qualitative influence of the pulse parameters on the dynamics of the EDM process.
The conclusions of this analysis are synthesized in Table 1.
These correlations could be a starting point for generating a fuzzy model of the EDM process. The contents of Table 1 represent a good logic basis for the inference (reasoning) phase in a fuzzy approach [3, 4]

Table 1

IF	I_{av}	high	THEN	v_a	high
	I_{av}	low		v_a	low
	η_i	high		v_a	low
	η_i	low		v_a	high
	U_{av}	high		v_a	high
	U_{av}	low		v_a	low
	U_a	high		v_a	low
	U_a	low		v_a	high
	η_{Ua}	high		v_a	low
	η_{Ua}	low		v_a	high

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