

## GASEOUS PHENOMENA FROM THE WORKING GAP INFLUENCING MACHINING RATE AT ULTRASONIC AIDED EDM

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**Abstract:** The paper deals with hydro-dynamic gaseous phenomena of cavitation nature which occur mainly during the stretching semiperiod of dielectric liquid from the gap determined by capillarity and ultrasonic oscillation of electrode tool. These operate on increasing of machining rate through decreasing of life time gas bubble duration formed around plasma channel of discharge comparing to classic EDM. Some microtopographies together with craters dimensions obtained under conditions of ultrasonic or without ultrasonic assistance are also presented in order to analyze the effect of gaseous phenomena in the gap.

**Keywords:** electrodischarge machining, ultrasonics, cavitation.

### 1. INTRODUCTION

Gaseous phenomena ultrasonically induced at electrodischarge machining aided by ultrasonic longitudinal vibrations of electrode (EDM+US) bring major advantages in finishing processes, where the gap is very narrow, less than 10  $\mu\text{m}$ . At first these phenomena appears as secondary ones, but they contribute to evacuation improving of removed particles from the gap, and essentially, to material removing process as it will be highlighted.

The life duration of gas bubble formed around plasma channel of the discharge plays an important part concerning the access of hydraulic forces of dielectric liquid access to EDM spot and consequently in material removal mechanism [1], [2], [3], [4].

### 2. CAVITATIONAL PHENOMENA AT US AIDED EDM

Some specific conditions are to fulfill in order to produce cavitation. The limit of acoustic pressure from which cavitation occurs, i. e. *cavitation threshold* depends on real working conditions characterized by following parameters: hydrostatic pressure size, liquid nature, viscosity, density, temperature and mostly, liquid purity, respectively the existing of cavitation nuclei.

Concerning parameters from above, experimental data of different researches vary very much. Esche [5] reported that at 20 KHz, acoustic pressure must be greater than 0.02...0.316 MPa to produce cavitation.

The maximum acoustic pressure  $p_{ac}$  generated by ultrasonics is determined:

$$p_{ac} = 2 \pi f_{US} A \rho c_s \quad [\text{Pa}] \quad (1)$$

where:

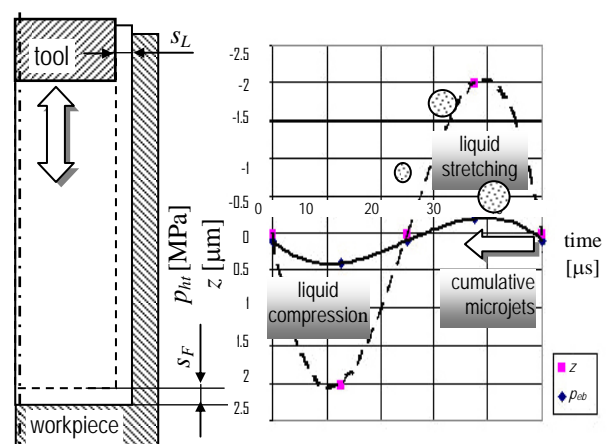
$f_{US}$  is ultrasonic frequency of longitudinal oscillations of electrode [Hz];

$A$  - oscillations amplitude [m];

$\rho$  - working liquid density [ $\text{kg}/\text{m}^3$ ];

$c_s$  - sound velocity in working liquid [m/s].

In our experimental researches conditions, cavitation occurred when working at 0.1 MPa hydrostatic pressure, with ultrasonic longitudinal vibrations of electrode having a frequency of 20 kHz and an amplitude of 1...2  $\mu\text{m}$ , in P3 oil that has a density of 840  $\text{kg}/\text{m}^3$  and a kinematic viscosity of 2.5...4.5 cSt at 20 °C. Acoustic pressure calculated by formula (1) was 0.15...0.3 MPa.



**Fig. 1. Variation of elongation and pressure in working gap at ultrasonic aided EDM**

Due to capillary phenomena in the working gap, the period of ultrasonic electrode oscillation ( $T_{US}$ ) comprises a semiperiod of dielectric liquid *compression* and a semiperiod of *stretching* one (fig. 1). The cavitation phenomena take place in the second semiperiod when total hydrostatic pressure ( $p_{ht}$ ) becomes negative.

The following formula emphasizes the two capillary phenomena within an oscillation period:

$$P_{ht} = p_{ac} \sin \omega t + p_h \quad [\text{MPa}] \quad (2)$$

where:  $p_h$  is hydrostatic pressure in working gap [Pa];

$$\omega = 2\pi f_{US} \text{ [s}^{-1}\text{]} \quad (3)$$

Cavitation does not occur in compression semiperiod because of high value of  $p_{ht}$ , which becomes positive as the formula (2) and figure 1 point out. In this time interval, gas bubbles from the gap are dissolved, diminishing the number of cavitation nuclei.

At EDM finishing, the gas bubbles from the working gap have dimensions of  $\mu\text{m}$  order. It can be established the own frequency ( $f_0$ ) of a bubble using Minnaert formula [5]:

$$f_0 = \frac{1}{2\pi R_0} \sqrt{\frac{3\psi}{R_0} \left( p_h + \frac{2\sigma}{R_0} \right)} \quad [\text{Hz}] \quad (4)$$

where:

$R_0$  is initial radius of gas bubble before liquid stretching [m]

$\psi$  is adiabatic exponent of gas from bubble;

$\sigma$  is liquid surface tension [N/m].

Ultrasonic  $f_{US}$  frequencies lower than  $f_0$  lead to cavitation and on the contrary, superior ultrasonic frequency determines a growing of bubble volume and oscillatory motion. In case of EDM finishing gap, frequency  $f_0$  of bubbles is inferior to the most used  $f_{US}$  frequency 20 and 40 kHz. Thus the bubbles contained in the gap can be cavitation nuclei, of millions order, their number increasing when machining greater surfaces. The advantage of EDM+US finishing extended surfaces, difficult to machine through classical EDM is based on this phenomenon.

Gas bubbles have a high growing rate, reaching a great dimension in a short time ( $T_{US}/2$ ), the stretching semiperiod (fig.1). But soon after, they get an instability state, i. e implosion. This is the result of  $p_{ht}$  increase at the final of an oscillation period. At lower

frequencies ( $f_{US}=20\text{kHz}$ ), increasing of bubble volume is greater than in case of higher frequencies ( $f_{US}=40\text{kHz}$ ), due to the fact they have much time to develop within a semiperiod.

At the beginning of the development bubble time, when the bubble walls are very close, approximately  $1 \mu\text{m}$ , because of high electric field of  $500\dots600 \text{ V/cm}$  created by contrary electric loads from the opposite walls, electric discharges occur, which can locally ionize the working medium. The necessary condition to produce these discharges is that pressure of gas within the bubble must be reduced at around  $0.002 \text{ MPa}$ , according to K. Negiski [5]. The light radiation can be extended in ultraviolet favorizing photochemical and electrochemical reactions in agreement to Frenkel theory [5].

On this basis, two consequences in removal mechanism at EDM+US can be identified:

(1) False electric discharges between electrode-tool surface and electric loads from the gap can occur which determine a decrease of interelectrodes energy discharges. Thus, energy from plasma channel of discharge is diminished determining machined roughness decrease;

(2) The cracking phenomena in dielectric liquids are favorized contributing to lowering of electrode-tool wear [1].

During the stretching semiperiod because of rapid development of bubbles, probability of discharges produced in gaseous medium increases. Therefore, EDM process takes place with low current density in plasma channel because inertia forces, which act against channel development, are reduced reported to those from dielectric liquid. This is an important phenomenon favorizing EDM finishing process.

The implosion time  $\tau$ , located at final of each oscillation period during cumulative microjets stage (fig. 1) is much lower than that of development one and depends on  $\beta$  report of bubble radii before and after contraction:

$$\tau = R_m \sqrt{\frac{3\rho}{2p_h}} \int_{\beta}^1 \frac{\beta^{\frac{3}{2}}}{(1-\beta)[\beta^2 + (\beta+1)\frac{1+3\sigma}{p_h R_m}]} d\beta \text{ [s]} \quad (5)$$

where:

$$\beta = R_f / R_m$$

$R_m$  is maximal radius before contraction [m];

$R_f$  is final radius after contraction [m].

Particularly, in case of bubble shutting down ( $\beta=0$ ), Rayleigh [5] found the formula:

$$\tau = 0,915R_m \sqrt{\frac{\rho}{p_h}} \quad [s] \quad (6)$$

Using P3 oil, at maximum frontal finishing gap,  $s_f=0.01 \mu\text{m}$  and  $p_h = 0.1 \text{ MPa}$ , according to formula (6), it results  $\tau=0.8 \mu\text{s}$ .

Taking also into account the values of temperature developed during implosion, approximately  $10.000 \text{ C}$ , this thermal phenomenon can be assimilated with effect of EDM finishing pulse. This is among others a supplementary removal mechanism contributing to machining rate increase and machined surface roughness decrease at EDM+US finishing.

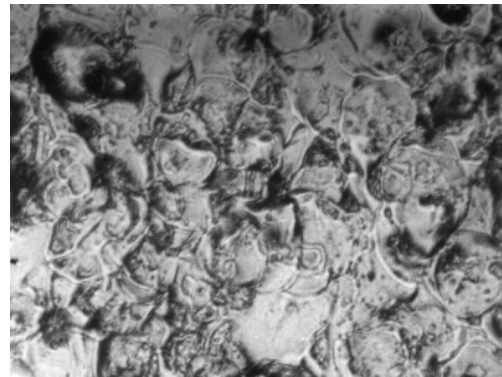
In agreement, with the assumption from above, Hammit noticed [5] that in general microcraters diameters produced by local high temperatures, combined with great pressure developed by bubbles implosion are lower than  $5 \mu\text{m}$ , with a maximum occurrence frequency at around  $2 \mu\text{m}$ , no matter if material was Cd, carbon steel or stainless steel. Comparatively EDM craters are situated within the interval  $5...30 \mu\text{m}$  [1]. In case of frontal gap at EDM finishing, because the solid walls are so close, the shock waves and microjets produced by implosion are oriented parallel to machined surface.

The pressure developed in *cumulative microjets phase* is of  $100 \text{ MPa}$  order and microjets speed is around sound velocity in dielectric liquid.

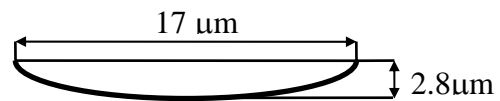
The peaks of surface microgeometry have a low shear resistance and are removed by cumulative microjets, thus resulting in optimum conditions [1], a decreasing of machined surface roughness at EDM+US finishing comparing to classic EDM in the same working conditions.

### 3. MICROGEOMETRY COMPARISON AT CLASSIC AND ULTRASONIC AIDED EDM FINISHING

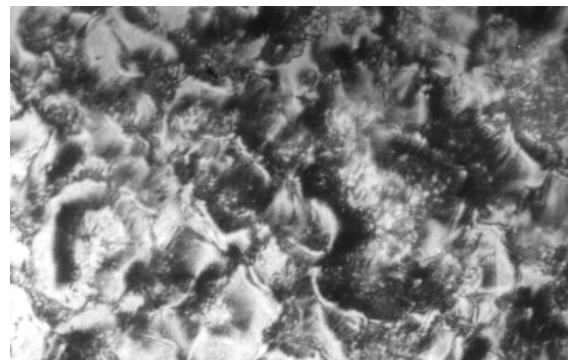
Some photographs of microgeometry taken with integrated system camera-microscope Neophot 2 - Zeiss with a magnitude  $\times 500$  and the profile of the craters determined by the surface measurement instrument are presented underneath.



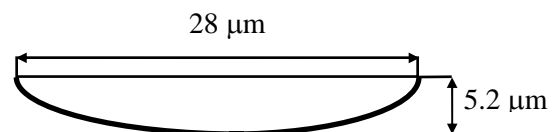
**Fig. 2. Microtopography at classic EDM finishing (x500); I=1; C=1; no flushing**



**Fig. 3. Transversal dimensions of craters at classic EDM (mean values); I=1; C=1**



**Fig. 4. Microtopography at US aided EDM finishing (x500); I=1; C=1;  $P_{cUS}=300 \text{ W}$ ; no flushing**



**Fig. 5. Transversal dimensions of craters at classic EDM (mean values); I=1; C=1;  $P_{cUS}=300 \text{ W}$**

Legend: I - supplying current step;  
C - condenser capacity step (at relaxation generator of Charmilles D4 machine);  
 $P_{cUS}$  – consumed power on ultrasonic chain

Comparative analysis of microgeometry obtained in case of relaxation pulses with and without ultrasonic assistance (fig. 2, 4) and also correspondent crater mean dimensions in cross section (fig. 3, 5) point out the effect of cavitation phenomena occurred at EDM+US.

As it can be noticed, the volume of craters at EDM+US is greater than in case of classic EDM in the same working conditions, i.e. the machining rate was enhanced. We also mention that for microgeometry presented in fig. 4 and 5, the consumed power on acoustic chain was relative high. This parameter can be optimized to achieve also a decrease of surface roughness in the same time [3].

This increasing of machining rate at EDM+US is basically explained in terms of life duration of gas bubble ( $t_b$ ) formed around plasma channel. At classic EDM, lifetime of bubbles is much greater than pulse time. In finishing conditions, when working with a single pulse time  $t_i = 10 \mu\text{s}$  and hydrostatic pressure  $p_{ht} = 0.1 \text{ MPa}$ , the bubble collapses after approximately  $180 \mu\text{s}$  [6]. These data were much later confirmed by ultra speed camera (more than  $10^6$  frames / second) [7]. Thus hydraulic forces of dielectric liquid find a great volume of material melted by discharge resolidified. This is a main cause of low machining rate at classic EDM.

Schulze at al. reported that the consecutive discharge, which occurs in the proximity due to ionization of working medium, is able to shorten the gas bubble life time produced by previous discharge [7]. This decreasing of bubble life time depends very much on delay time, which in case of classic finishing is relative high, more than  $100 \mu\text{s}$  due to very low pulse energies.

On the contrary, at EDM+US, bubbles resulted around plasma channel during stretching semiperiod collapse after  $25 \mu\text{s}$  maximum time - comparable with pulse time interval - if working with usual frequency,  $f_{US} = 20 \text{ kHz}$ . This explains very much the increasing of machining rate growing, up to 500% [1], [2], [3], [4]. Thus almost all material melted by discharge is removed through dielectric flushing.

#### 4. CONCLUSIONS

Machining rate growing, up to 500%, could be explained by shortening the life time bubble formed around the plasma channel. In case of EDM+US with ultrasonic frequency of 20 kHz, this is less than  $25 \mu\text{s}$ . In classic EDM this is more than  $150 \mu\text{s}$  after the pulse end, mainly due to long delay time of ignition in case of finishing conditions. This leads to molten volume increasing removed by

hydraulic forces from the gap, which can faster access the EDM spot.

These assumptions are in agreement with experimental data, the photographs of microtopographies resulted from electrodischarge machining aided or nonaided by ultrasonics, which emphasize that the volume of craters produced by discharges under cavitation conditions ultrasonically induced are much greater.

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