

TECHNOLOGICAL PERFORMANCES INCREASE AT ULTRASONICALLY AIDED EDM IN CONNECTION WITH VALORIZATION OF INTANGIBLE ASSETS

Niculae Marinescu¹, Daniel Ghiculescu² and Viorel Vulturescu³

¹ Politehnica University of Bucharest, Romania, niculae.marinescu@yahoo.com

² Politehnica University of Bucharest, Romania, daniel.ghiculescu@upb.ro

³ Politehnica University of Bucharest, Romania, yvultur@yahoo.com

ABSTRACT: The paper deals with technological performances increase at electrical discharge machining aided by ultrasonic longitudinal vibrations of electrode-tool (EDM+US), in terms of machining rate and machined surface roughness. Some experimental data are presented in relation with finite element modelling of EDM+US material removal process. The machining rate could be increased by growing the probability to overlap the pulse time on cumulative microjets stage (CMS) – the effect of ultrasonically induced cavitation in the frontal gap. The surface roughness could be decreased through optimization of a key-parameter of working mode, the consumed power on ultrasonic chain. All these technological improvement with market impact on EDM users segment, very sensitive to cost level, are feasible if the organization applying this hybrid technology (EDM+US) valorizes the connected intangible assets, operable through some main competencies, technology, supplying, marketing, innovation, quality assurance, continuous costs decrease provided by accumulated know-how and patents series in EDM field.

KEY WORDS: electrical discharge machining, ultrasonics, intangible assets.

1. INTRODUCTION

The actual technological progress in electrical discharge machining, considered as classic, apparently reaching a maturity stage within its life cycle is absolutely remarkable. Surveying the state of the art, two main research directions are highlighted: (1) ultra-miniaturization of machined surface, the so-called micro and even nano EDM; the fabrication of tool-electrodes with diameters of nm order of magnitude through electrochemical machining (ECM) as well as feed system using piezoactuators with the same order of magnitude were approached [1]; (2) improved surface quality of EDMed surfaces; ultra-small craters with diameters of nm diameter are obtained [2]. Understanding of the behaviour of dielectric liquid at breakdown produced by plasma channels with nm order of magnitude diameters is fundamental at this process scale [3] in connection with comparison between wet and dry electrical processes [4, 5]. These achievements are characterized by machining rate increase, joined with lower costs compared to other advanced technologies [1].

Ultrasonic assistance of micro-EDM and finishing (the topic of this paper) is a very important research direction, able to spectacular increase the technological performances. The intangible assets of an organization doing cutting edge research in EDM field represent a capital of utmost importance, essentially built on accumulated know-how, one of the most significant intangible assets.

2. TECHNOLOGICAL PERFORMANCES

Experimental data obtained at EDM+US supported the increase of technological performances through ultrasonic aiding at EDM finishing modes. Disk shape samples from X210Cr12 were machined comparatively on Romanian ELER 01 machine with and without 20 kHz longitudinal ultrasonic oscillations of the tool (fig. 1). Disk shape electrode-tool from copper with diameter of 25 mm and height of 3 mm was used. The ultrasonic chain included the tool at its end.

The working parameters were: current step, $I=3A$, positive (tool) polarity; injection pressure, $p_{hl}=0.04$ MPa (through workpieces); consumed power on ultrasonic chain, $P_{CUS}=90$ W; oscillations amplitude, $A=2$ μm , producing ultrasonic cavitation in the gap.

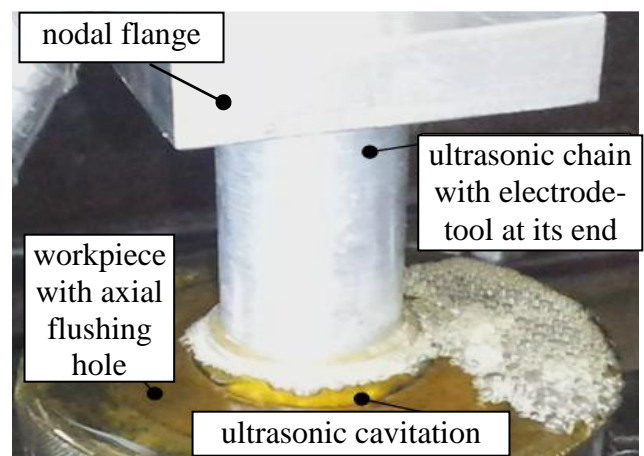


Figure 1. Detail of working zone at EDM+US tests

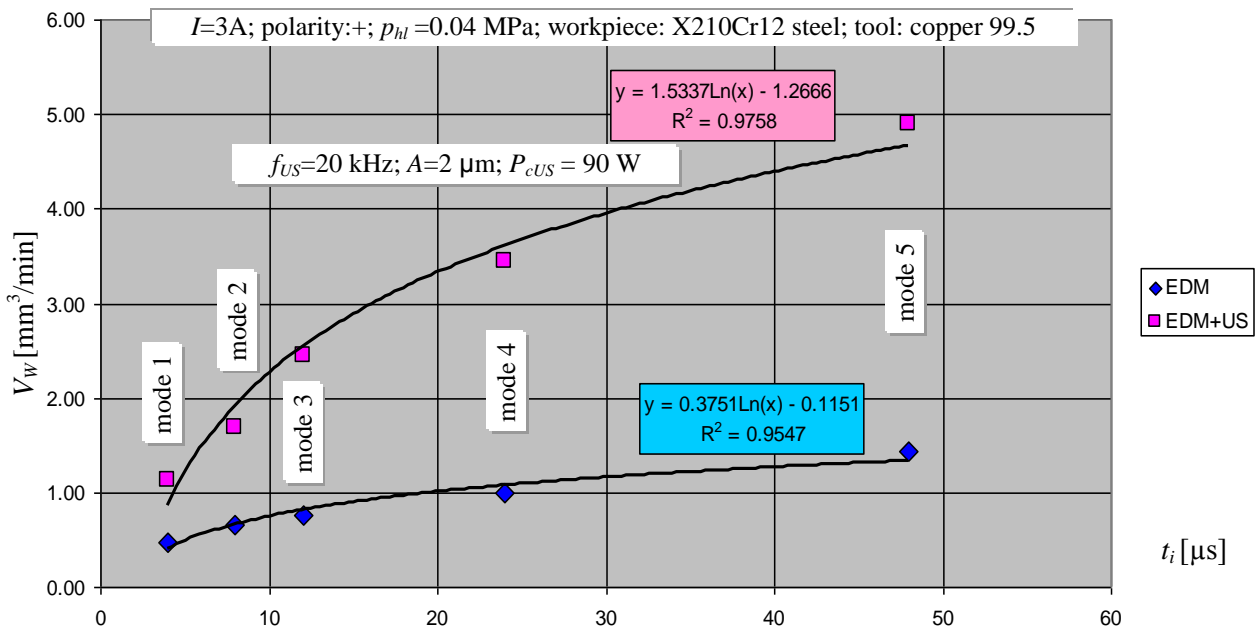


Figure 2. Machining rate (V_w) as function of pulse time (t_i) at EDM+US and classic EDM, finishing modes

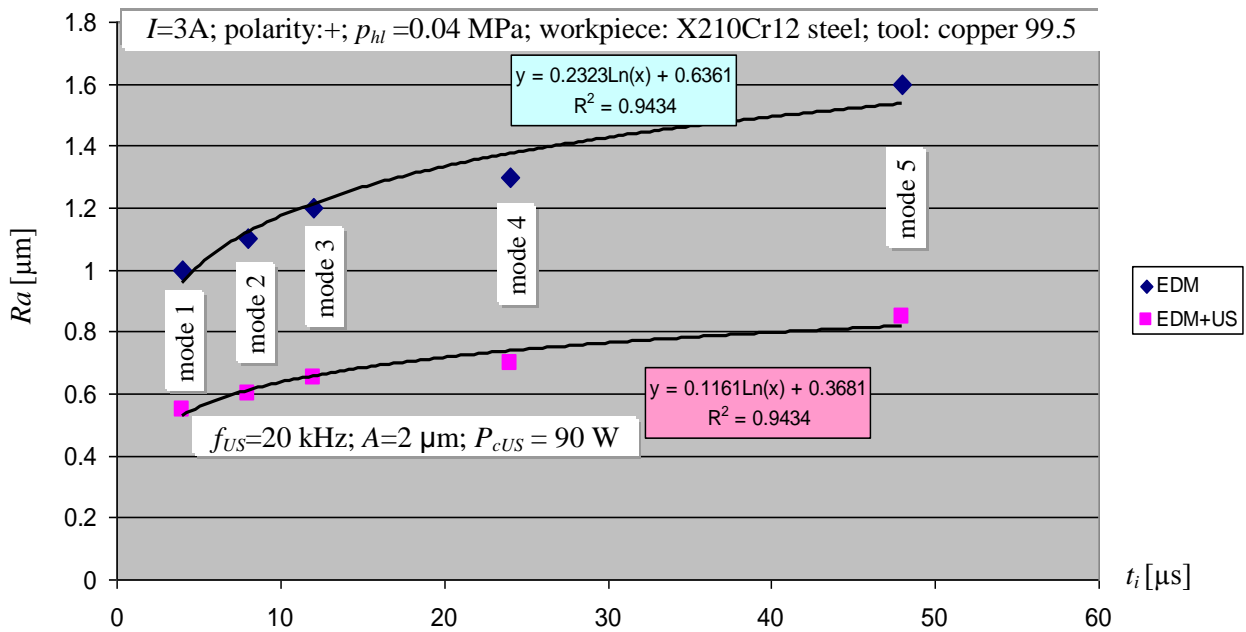


Figure 3. Machined surface roughness (R_a) as function of pulse time (t_i) at EDM+US and classic EDM, finishing modes

In fig. 2, machining rate (V_w) as function of pulse time (t_i) obtained at EDM+US and classic EDM, is presented comparatively, using five finishing working modes: mode 1, $t_0=2$ µs, $t_i=4$ µs; mode 2, $t_0=4$ µs, $t_i=6$ µs; mode 3, $t_0=6$ µs, $t_i=12$ µs; mode 4, $t_0=12$ µs, $t_i=24$ µs; mode 5, $t_0=24$ µs, $t_i=48$ µs. Similarly, machined surface (R_a) as function of pulse time (t_i) is presented in fig. 3.

As it can be noticed, ultrasonic aiding produced greater V_w gain at longer pulse time, i.e. more than three times, respectively at t_i longer than 12 µs.

The decrease of R_a due to ultrasonic assistance is maintained approximately constant, at 45-47%, with

a slightly greater decrease of longer pulse time, i.e. at t_i longer than 12 µs.

Some samples of machined surfaces microgeometry resulted from classic EDM and EDM+US finishing under specified below working conditions are presented comparatively in fig. 4, 5. These were taken by Reichert Univar microscope and Buehler OmniMet Enterprise software.

Their corresponding profiles of microcraters produced by discharges under conditions of classic EDM and EDM+US finishing, whose depth was determined by Taylor-Hobson surface instrument, are presented in fig. 6, 7.

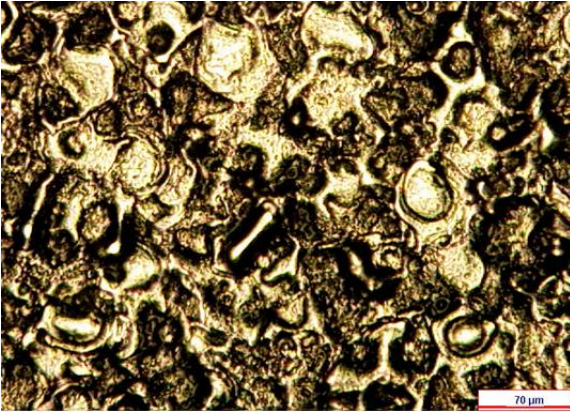


Figure 4. EDM microtopography with $Rz=5.2\mu\text{m}$, $I=3\text{ A}$, $t_i=24\mu\text{s}$, $t_o=12\mu\text{s}$, positive (tool) polarity

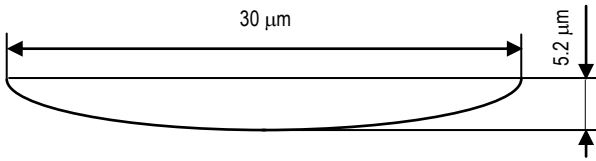


Figure 6. EDM average dimensions of crater, $I=3\text{ A}$, $t_i=24\mu\text{s}$, $t_o=12\mu\text{s}$, polarity +

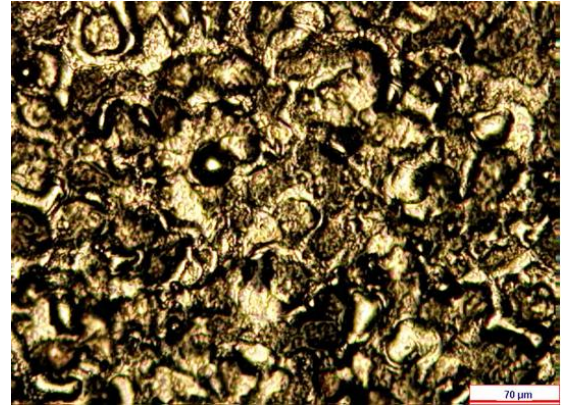


Figure 5. EDM+US micro-topography with $Rz=2.8\mu\text{m}$, $I=3\text{ A}$, $t_i=24\mu\text{s}$, $t_o=12\mu\text{s}$, positive polarity, $P_{cUS}=90\text{ W}$

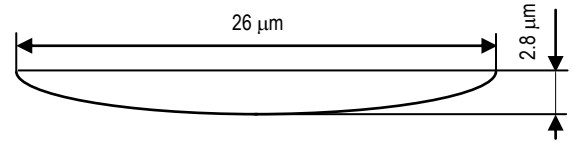


Figure 7. EDM+US average dimensions of crater, $I=3\text{ A}$, $t_i=24\mu\text{s}$, $t_o=12\mu\text{s}$, polarity +, $P_{cUS}=90\text{ W}$

As it can be noticed, the average crater dimensions are lower at EDM+US than those from classic EDM. Despite the fact, the machining rate is increased at ultrasonic aiding, resulting a greater volume removed by discharge, the crater dimensions are reduced, and implicitly the machined roughness Rz , due to the effect of cumulative microjets stage (CMS) by surface micropeaks shearing. This is the consequence of shock waves oriented along the working gap, generated by CMS, which occurs at each final of any ultrasonic period, developing high pressures of 100 MPa order of magnitude [6]. All these assumptions will be sustained below by modelling the material removal mechanism of EDM+US, using finite element method (FEM).

3. MODELLING OF EDM+US MATERIAL REMOVAL MECHANISM

Comsol Multiphysics, Heat Transfer in Solids, Time Dependent with Parametric Sweep as pulse time were used for thermal removal modelling (first component of EDM+US removal mechanism) to determine boiling isothermal and melting isothermal positions in X210Cr12 samples after discharge in different finishing modes in case of EDM, and respectively, EDM+US. In case of classic EDM, the overheating model [7], generally agreed, indicates that the material boiling, just after the pulse end is the main mechanism of material removal. The gas bubble formed around plasma channel has much longer life time than pulse time confirmed by images of high speed framing camera [8], the melted material being already solidified after its breakdown.

In case of EDM+US, melting was considered the main mechanism of material removal since collective implosion of the gas bubbles from the gap, i.e. CMS stops the discharge and facilitates the access of dielectric liquid at the EDM spot, the material being still in liquid state.

An advanced model with time dependent radii of plasma channel and gas bubble was used. For this reason, a parametric 2D axis symmetric model was created with plasma channel and gas bubble time dependent radii as it presented in fig. 8.

For the calculation of plasma channel radius (r_{pc}) as function of pulse time (t_i), the next relation was used:

$$r_{pc} = 0.004695 \cdot \sqrt{t_i} \quad [\text{m}] \quad (1)$$

This is based on K. Inoue' model [9], found to be closest to the experimental data by our previous researches [6].

Parameters			
Name	Expression	Value	Description
rwp	15[mm]	0.015 m	radius of workpiece
hwp	10[mm]	0.01 m	height of workpiece
rms	0.25e-6	2.5E-7	radius of solidified material
acr	15e-6	1.5E-5	radius of initial crater
bcr	5.2e-6	5.2E-6	depth of initial crater
ti	24e-6	2.4E-5	pulse time
rgb	$-2e7 \cdot t_i^2 + 187.02 \cdot t_i + 7e-7$	-0.007031	radius of gas bubble
rpc	$0.004695 \cdot t_i^{0.5}$	2.3E-5	radius of plasma channel

Figure 8. Parameters assigned for the thermal removal model with time dependent radii of plasma channel and gas bubble

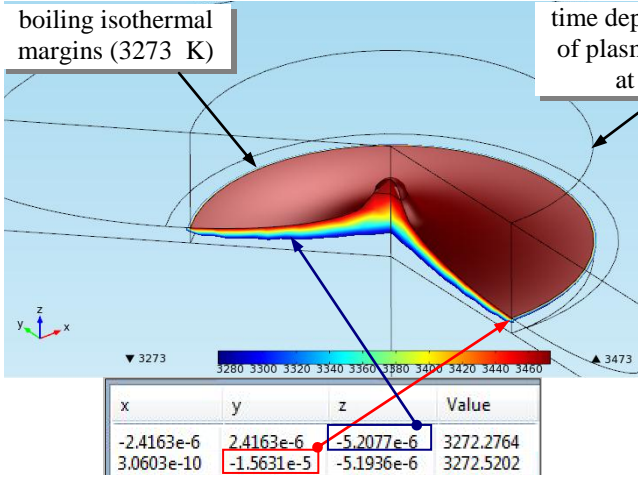


Figure 9. Temperature distribution (K) and boiling isothermal coordinates [m] in X210Cr12 after $t_i=24\mu s$ when the pulse ends at classic EDM

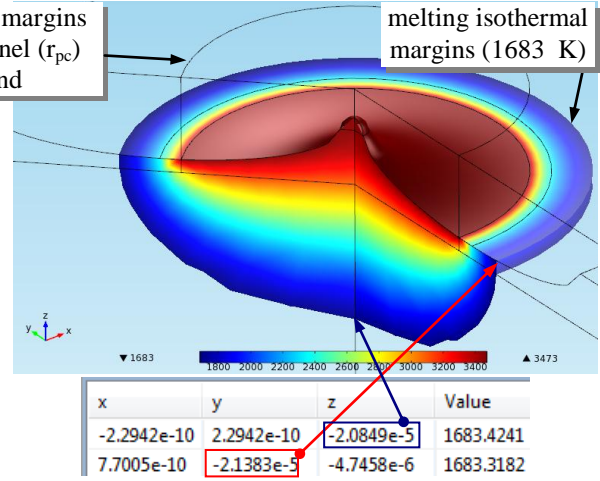


Figure 10. Temperature distribution (K) and melting isothermal coordinates [m] in X210Cr12 after $t_i=6\mu s$ when cumulative microjets stage occurs at EDM+US

For the calculation of gas bubble radius (r_{gb}) formed around the plasma channel, some data provided in [8] led to the following relation:

$$r_{gb} = -2 \cdot 10^7 \cdot t_i^2 + 187.02 \cdot t_i + 7 \cdot 10^{-7} \quad [\text{m}] \quad (2)$$

The following boundary conditions were considered: constant 3473K temperature on cathode spot (circle with r_{pc} radius), thermal isolation on area covered by gas bubbles (circle with r_{gb} radius), and convection cooling on workpiece periphery immersed in dielectric liquid with 313K.

The FEM results of time dependent thermal removal models briefly described above are presented comparatively for EDM and EDM+US in fig. 9, 10. The temperature distribution from fig. 9, the dimensions of boiling isothermal indicates roughly the volume removed by discharge in case of classic EDM in good agreement with experimental data from fig. 6. At EDM+US, the temperature distribution indicates that volume (V) removed by discharge is more than 7 times greater (fig. 10), calculated with formula:

$$V = \frac{4\pi \cdot y^2 \cdot z}{6} \quad [\mu\text{m}^3] \quad (3)$$

This situation is factual only when pulses are overlapped on CMS. When overlapping occurs randomly (present tests), the overlapping probability is estimated at 40%, when using pulses longer than $12 \mu s$, and delay time of around $100 \mu s$. Therefore the increase of machining rate is around 3 times as experimental data highlighted, although this is affected by many other factors.

The hydraulic mechanical removal (the second component of EDM+US mechanism of material removal) was modelled using Structural Mechanics Module of Comsol with time dependent variant.

Additional parameters were assigned to this current model, as they are presented in fig. 11.

Name	Expression	Value	Description
modulE	2.1e11	2.1E11	Young' modulus of X210Cr12
tus	1e-6	1.0E-6	duration of shock wave
pus	116[MPa]	1.16E8 Pa	ultrasonic cyclic load of CMS

Figure 11. Parameters assigned for the hydraulic mechanical removal model

Boundary conditions were: pressure p_{US} created by CMS in each ultrasonic period, considered as fatigue load, on one flank of the microgeometry profile, along the frontal working gap; fixed constraint on the workpiece inferior part since a clamping force was applied on its superior (frontal) surface part.

The fatigue load produced by cumulative microjets shock waves oriented parallel to machined surface can reduce its roughness - removing the coloured material represented in fig 12 - if an optimum value of p_{US} (e.g., 116 MPa) is attained like in this case.

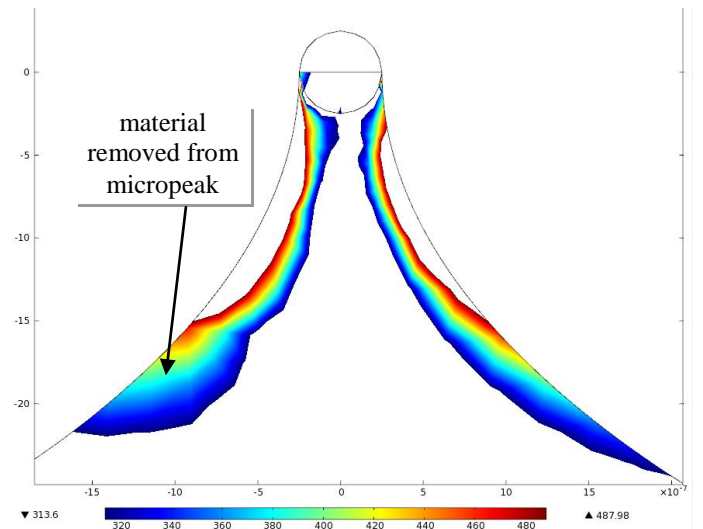


Figure 12. Von Mises stress [MPa] on sample microgeometry from X210Cr12, higher than ultimate tensile strength of fatigue pulsing cycle, $\sigma_o=313 \text{ MPa}$

4. VALORIZATION OF INTANGIBLE ASSETS CONNECTED TO COMPETENCIES

The technological performances describe above belong to a consortium that participates in the actual Partnership Research Program, developing a project focused on achieving an equipment and technology based on EDM+US. The project consortium includes, beside other partners, a Small and Medium Enterprise (SME), which has a long experience in the EDM research field. So, this SME owns important performances, but it is also the beneficiary of this project results as transfer of knowledge.

A method of evaluation of intangible assets (IA) – aiming at their valorization – in connection with competencies related to Producer Matrix (PM) [10] was applied in case of mentioned above SME, denoted (*O*) – after involving in this research program. This evaluation is primarily focused on PM competencies in connection to IA, aiming at sustainable competitive advantage (SCA), in the area of EDM+US.

The level of PM competencies results from the relative position against the main competitors from Germany (A), Great Britain (B), and Switzerland (C). The relative profiles of effectiveness competencies for enterprise *O* and its competitors are presented in fig. 13. The operating competencies, more specific, *technology* competencies with 50% weight is over 0.5 as well as *supply* one; *marketing* competencies (weight 10%) should be at much higher level, closer to relative level of 0.5; but all are increased in comparison with previous evaluation at this project start [11]. The essential system competencies, i.e. *innovation* (weight of 25%) that is situated much over 0.5 level (SME *O* has many patents in the EDM field, also as research project results), as well as *quality assurance* (weight, 20%), are much improved against evaluation from [11].

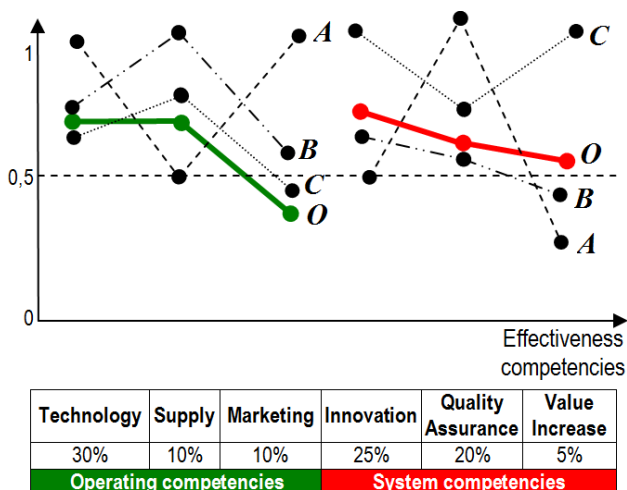


Figure 13. Competitors profiles of effectiveness competencies

The weights assigned to operating and system competencies are appropriate to such an advanced technologic field, where innovation is strongly related to technology that must keep the pace to the development rhythm of this sector that is passing over the launching development stage of its life cycle, with trends of entering the nanoEDM range as it was specified in introduction.

The competitors profile for competencies focused on unit cost decrease is presented in fig. 14. Organization *O* has some competencies of medium importance over the 0.5 level. The development of EDM aiding by ultrasonics has much lower costs than other technologies, especially those applied in the range of micro and nowadays, nano. A Romanian SME has the advantage against Western European competitors of lower costs of *production factors*. The other two competencies are situated lower than 0.5, because they are not usual attributes of SMEs.

A first aggregate mark of operational and system competencies, (N_{os}) of SME *O* was determined using the following relation and the data from fig. 13:

$$N_{os} = \sum w_i C_{osi} \quad (4)$$

$$= 30\%TC + 10\%SC + 10\%Mk + 25\%IC + 20\%QA + 5\%VI = 0,64$$

where: w_i is the weight assigned to a certain operational or system competency [%]; C_{osi} – level of corresponding competency on the scale 0-1; TC, SC, Mk, IC, QA, VI are the levels on scale 0-1 for respective competencies: *technology*, *supplying*, *marketing*, *innovation*, *quality assurance*, and *value increasing*.

A second aggregate mark of competencies focused on costs, (N_{fc}) of SME *O* was determined using the following relation and the data from fig. 14:

$$N_{fc} = \sum w_i C_{fci} \quad (5)$$

$$= 50\%CC + 30\%CCD + 15\%PFC + 5\%ES = 0.45$$

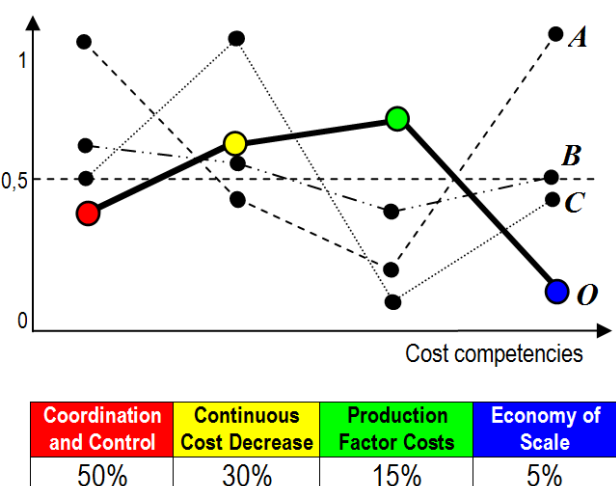


Figure 14. Competitors profiles of costs focused competencies

where: w_i is the weight assigned to a certain costs focused competency [%]; C_{fei} – level of corresponding competency on the scale 0-1; CC, CCD, PFC, ES are the levels on scale 0-1 for respective competencies: *coordination and control, continuous cost decrease, production factor costs, economy of scale*.

Similar aggregate marks were calculated for the competitors A, B, and C. The PM coordinates for all competitors were calculated with relations, $y=N_{os}$, $x=1/(kN_{fc})$, where $k=10$. Thus, the four competitor's positions are presented in Producer Matrix (fig. 15).

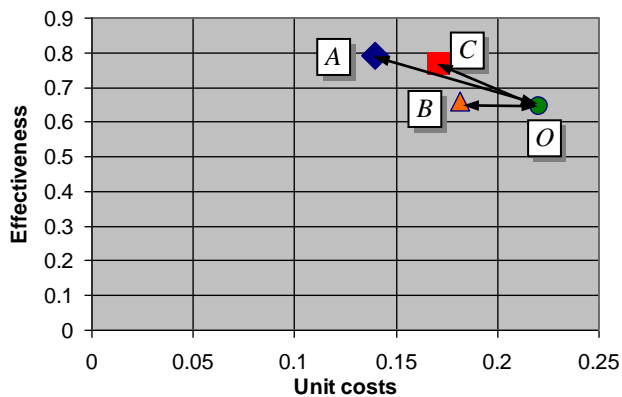


Figure 15. Competitors positions in Producer Matrix

5. CONCLUSIONS

The technological performances in terms of machining rate and surface roughness presented above need optimum value of ultrasonic pressure created by cumulative microjets stage. This corresponds to the power consumed on ultrasonic chain, which is 90 W in this case. This is a key-parameter strongly dependent by real working conditions, highlighted by FEM results. But this has to be attained experimentally, in strong relation to know-how of organization. This is an example of best practice of intangible assets valorization related to specific competencies of operation and system. The competencies focused on costs are naturally increased by EDM+US approaching. Thus, the distances of Romanian organization against its competitors was decreased in Producer Matrix by participation at Partnership research project.

6. ACKNOWLEDGEMENT

Research financed through the projects: Joint Applied Research Project supported by MEN-UEFISCDI, project no. PN-II-PT-PCCA-2013-4-0236, Contract no. 222/2014; „MINERVA – Cooperation for elite career in doctorate and post-doctorate research: POSDRU/159/1.5/S/137832, project cofinanced from European Social Fund through Human Resources Development Sectoral Operational Program 2007-2013.

7. REFERENCES

1. Benilov, A., Skryshevsky, V., Robach, Y., Cabrera, M., Micro and nano electrical discharge machining in microfluidics and micro nanotechnology, *International Journal of Material Forming*, April, Vol. 1, Issue 1, pp. 1315-1318, (2008).
2. Kunieda, M., Hayasaka, A., Yang, X.D., Sano, S., Araie, I., Study on Nano EDM Using Capacity Coupled Pulse Generator, *CIRP Annals - Manufacturing Technology*, Vol. 56, Issue 1, pp. 213-216 (2007).
3. Kalyanasundaram, V., Virwani, K.R., Spearot, D.E., Malshe, A.P., Rajurkar, K.P., Understanding behavior of machining interface and dielectric molecular medium in nanoscale electro-machining, *CIRP Annals*, Vol. 57, Issue 1, pp. 199-202, (2007).
4. Jahan, M.P., Malshe, A.P., Rajurkar, K.P., Experimental Investigation and Characterization of Nano-scale Dry Electro-machining, *Journal of Manufacturing Processes*, Vol. 14 (4), pp. 443-451, (2012).
5. Jahan, M. P., Virwani, K. R., Rajurkar, K. P., Malshe, A. P., A comparative study of the dry and wet nano-scale electro-machining, *Procedia CIRP*, Vol. 6 pp. 626 – 631, (2013).
6. Ghiculescu, D., Marinescu N.I, Varga, G., Nanu, S., FEM study of thermal front dynamics at micro-electrical discharge machining aided and not aided by ultrasonics, *Nonconventional Technologies Review* Vol. XVIII, Nr. 3, pp. 43-48, (2014).
7. F. Van Dijck, R. Snoeys, Theoretical and Experimental Study of the Main Parameters Governing the Electrodischarge Machining Process, *Mecanique*, Vol. 301-302, pp. 9-16 (1975).
8. H.-P. Schulze, G. Wollenberg, R. Herms, K. Mecke, Gas bubble morphology in small working gaps at spark erosion, *2004 Annual report Conference on Electrical Insulation and Dielectric Phenomena*, Boulder, Colorado, USA, 16-20, October, pp. 534 – 537, (2004).
9. Kiyoshi Inoue, *Fundamental of Electrical Discharge Machining*, Society of Non – Traditional Technology, Tokyo, (1977).
10. D. Faulkner, C. Bowman, *Elements of competitive strategy*, Teora, Bucharest, (2000).
11. Vulturescu, V., Ghiculescu, D., Marinescu, N., Mitroi, M., Integrated method for evaluation of intangible assets applied to research SMEs from nonconventional field, *Nonconventional Technologies Review*, Vol. XVIII, No. 4, pp. 117-122, (2014).