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MODELING OF DISCHARGE ENERGY IN ELECTRICAL DISCHARGE MACHINING BY THE USE OF GENETIC PROGRAMMING

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Abstract: *Being able to model machining process can save enormous funds and time, which will result in cheaper and more efficient production. In this paper discharge energy, which is in EDM directly transformed into thermal energy, is used as a primary machining process and because of that it presents a main point of interest in modeling procedure. Link between discharge energy and output results of machining process is found using genetic programming as a type of artificial intelligence.*
Key words: *EDM, discharge energy, machining parameters, genetic programming*

Modelovanje energije pražnjenja u elektroerozivnoj obradi pomoću genetskog programiranja. *Mogućnost modelovanja procesa obrade može uštedeti velika sredstva i vreme a krajnji rezultat je jeftinija i efikasnija proizvodnja. U ovom radu je energija pražnjenja, koja se u elektroerozivnom procesu direktno pretvara u toplotnu energiju, korišćena kao primarni parametar obrade i zbog toga predstavlja žižu interesa u procesima modelovanja. Veza između energije pražnjenja i izlaznih parametara procesa obrade je formirana koristeći genetsko programiranje kao vrste veštačke inteligencije.*
Ključne reči: *EDM, energija pražnjenja, parametri obrade, genetsko programiranje*

1. INTRODUCTION

Everybody who worked with EDM knows that the only requirement for machining to take place is that both the tool and the workpiece have to be electro conductive. By meeting this requirement, arcing between the tool and the workpiece can take place. This will result in ionization of small volume of dielectric around arcing zone, reaching a temperature up to 40.000 °C, consequentially heating workpiece surface to 10.000 °C. Small area on workpiece surface, under the influence of this high temperature, is melted and when electric arc is cut off a strong pressure wave is generated. Melted material is then washed off from workpiece surface and flushed away with dielectric fluid. Described process is repeated until desirable results are met.

Machining ability of workpiece depends on its thermal properties and not its hardness like in conventional machining processes. Because of this EDM is preferable choice in processes like machining hard materials, mould making, precision machining or individual production. As can be noted from above mentioned, EDM is rarely used in mass production. Machining each part with different demands is very challenging and in order to keep minimum cost it requires a profound knowledge of process parameters and their influence on final result. This would mean that one should spend large amount of funds and time on becoming familiar with process of EDM to exploit it properly. In order to make EDM more accessible, various forms of simulations are created. Many of these simulations are based on artificial intelligence, which is gaining ever more popularity among scientific and technical circles. Following trends, this article presents modeling of EDM process and finding relationships between process parameters and process outputs based on experimentally obtained results. Genetic programming, a type of artificial intelligence, is used as a tool for finding those relationships.

Parameters used to describe quality of EDM process are: productivity, which is expressed through material removal rate, accuracy represented by dimension tolerances and type of shape of workpiece, and finally surface integrity expressed through machined surface roughness. In this article all three of these parameters will be modeled, and at the end an extensive conclusion about effectiveness of this method will be presented.

2. DISCHARGE ENERGY

In EDM discharge energy is directly transformed into thermal energy and it becomes an instrument for machining. Discharge energy E_e is calculated as the mean value of electrical energy per one impulse which is transformed into heat, and can be expressed by the following equation:

$$E_e = \int_0^{t_e} u_e(t) \cdot i_e(t) \cdot dt \cong U_e \cdot I_e \cdot t_e \qquad (1)$$

where U_e is discharge voltage, I_e is discharge current and t_e is discharge duration.

In proper machining conditions, electrical discharge occurs instantaneously and is independent from other electric values. With this fact in mind ignition delay time can be neglected, $t_d \approx 0$, meaning that the discharge duration is equal to pulse duration, $t_e \cong t_i$. By this simplification the final expression for discharge energy has more practical form:

$$E_e = U_e \cdot I_e \cdot t_i \quad (2)$$

As can be seen from Eq. (2), the discharge energy is influenced by the discharge voltage, discharge current, and pulse duration. Their influences are interconnected and depend on the rest of the machining parameters [1].

The discharge voltage depends only on materials of workpiece and electrode. For every combination of workpiece and electrode there is a specific value of discharge voltage. This value can range from 15 to 30 V [2,3] and cannot be influenced under the given machining conditions.

Parameter which directly impacts the discharge energy is discharge current. But this impact is limited by the current density at the electrode. Stability of impulse discharge will be threatened in case when the current density oversteps the limit for the given machining conditions (approximately 10÷25 A/cm^2) [4,5]. By exceeding this threshold, the continuous current flow will be established, and arcing or short circuiting will take place. This event will lengthen the time of deionization of the discharge channel, and consequentially reduce the efficiency of EDM.

Direct control of discharge energy can be achieved by varying the pulse duration. However, arbitrarily regulation of process parameters is limited. Experience has taught us that pulse duration must be limited for a particular discharge current. Otherwise, an electric arcing occurs which damages both tool and workpiece [6].

Experiment number	***Discharge current*** I_e (A)	***Pulse duration*** t_i (µs)	***Current density*** γ (A/cm^2)	***Discharge energy*** E_e (µJ)	***Material removal rate*** V_w (mm^3/min)	***Gap distance*** a (mm)	***Surface roughness*** R_a (µm)
1	1	1	0.5	20	0.86	0.055	1.8
2	1	2	0.5	40	1.28	0.055	1.9
3	1	5	0.5	100	2.35	0.06	2.1
4	1	7	0.5	140	1.97	0.06	2.3
5	5	1	2.5	100	3.22	0.09	3.9
6	5	2	2.5	200	4.16	0.095	4.2
7	5	5	2.5	500	6.47	0.10	5.1
8	5	7	2.5	700	4.31	0.105	5.1
9	9	2	4.5	360	7.71	0.13	8.2
10	9	5	4.5	900	14.89	0.14	8.8
11	9	7	4.5	1260	9.49	0.155	9.0
12	9	10	4.5	1800	5.24	0.155	9.8
13	13	2	6.5	520	6.13	0.165	9.2
14	13	5	6.5	1300	18.71	0.18	9.4
15	13	7	6.5	1820	10.71	0.20	9.7
16	13	10	6.5	2600	6.62	0.21	10.3
17	20	5	10	2000	24.49	0.20	10.2
18	20	7	10	2800	31.82	0.22	10.4
19	20	10	10	4000	26.70	0.23	10.8
20	20	20	10	8000	17.11	0.24	11.2
21	30	7	15	4200	39.92	0.23	10.8
22	30	10	15	6000	53.30	0.24	11.3
23	30	20	15	12000	56.82	0.25	11.8
24	30	50	15	30000	40.48	0.26	12.5
25	50	10	25	10000	46.36	0.28	11.8
26	50	20	25	20000	66.83	0.30	12.5
27	50	50	25	50000	72.92	0.31	13.2
28	50	100	25	100000	60.60	0.33	13.4

Table 1. Experimental data used in modeling procedure

3. EXPERIMENT

Experimental investigation was conducted on EDM machine tool ″FUMEC – CNC 21″ of South Korea. The work material used in the experiment was manganese-vanadium tool steel, ASTM A681 (0,9% C, 2% Mn, and 0,2% V), hardness 62 HRc. The tool was made of electrolytic copper with 99,9% purity, 20×10 mm cross-section. The dielectric was petroleum and natural flushing was used [1].

The range of the discharge current was I_e=1÷50 A (current density 0,5÷25 A/cm^2), while the pulse duration was chosen from the interval t_i=1÷100 µs to accommodate the chosen current. The rest of the parameters of electric impulse were held constant, according to manufacturer's recommendations.

During the experiment input parameters were varied and the resulting machining parameters of EDM process were monitored and recorded [7]. Measured parameters were material removal rate V_w, gap distance ***a*,** and surface roughness R_a.

Material removal rate (ratio of removed material volume and the effective machining time) was measured indirectly, by monitoring the machining time for the set eroding depth. The depth and time of eroding were monitored using the machine tool CNC control unit. The machining accuracy of EDM was monitored through the change of side gap distance. Gap distance was calculated as the half of difference between the tool and workpiece contour dimensions. Measurements were conducted using electronic calipers. Surface integrity was assessed by measuring surface roughness and research of the surface layer properties. ″PERTHOMETER S5P″ of Mahr, Germany was used to measure the arithmetic average deviation of the assessed *profile* (ISO 4287). Experimental data are shown in Table 1.

4. GENETIC PROGRAMMING

Evolutionary algorithms, with genetic programming being a subclass, as their name is suggesting are based on principles of evolution and natural selection. Each solution to the problem is considered to be one individual which is evaluated by fitness function. Results of evaluation are directly determining each individual's probability of mating and thus transferring his genetic material onto next generation [8].

5. MODELING PROCEDURE

Fitness function which will be used to evaluate quality of generated solution is mean square error function:

$$\Delta = \frac{1}{28}\sum_{i=1}^{28}\left(P(i) - D(i)\right)^2 \qquad (3)$$

where P is experimentally obtained value and D is modeled value for every parameter.

For practical realization of model software GPdotNET was used [9].

At the beginning six random constants were generated from the interval 0÷10. These will be used in equations forming as supporting members. Not to be confused, those constants don't have to be in final solutions. They are just available there for algorithm to use them. Sometimes solutions are found to be better without some constants. Number of individuals in every generation was 500. Elite count was 16, which means that from every generation 16 individuals with best fitness were automatically moved to next generation. Whole modeling procedure lasted for 500 generation. During that time evolution operators were executed with probabilities: 0,7 for crossover to happen, mutation 0,1, 0,2 for reproduction and 0,05 for permutation. Only arithmetic operators, respectively "+", "-", "*" and "/", are used to form membership functions.

Experiment number	***Material removal rate*** V_w (mm^3/min)	***Gap distance a*** (mm)	***Surface roughness*** R_a (µm)
1	0,904829	0,047841	1,774416
2	0,797056	0,053609	1,865592
3	1,682975	0,059967	2,045031
4	0,906295	0,061781	2,369622
5	1,656256	0,083007	4,035409
6	4,789811	0,093201	4,395282
7	6,655974	0,104839	4,880491
8	5,728006	0,108389	5,091111
9	7,526026	0,137209	8,556323
10	11,04414	0,15328	8,962838
11	10,20863	0,15777	9,238136
12	5,157758	0,162075	9,514302
13	7,931261	0,158927	8,942481
14	18,38405	0,177094	9,158567
15	12,32222	0,181979	9,438222
16	7,019762	0,186482	9,687872
17	24,08892	0,208637	10,12729
18	32,10425	0,21407	10,48132
19	28,23901	0,218878	10,7287
20	17,22119	0,226906	11,19571
21	40,69907	0,246097	11,44995
22	52,49966	0,251262	11,73371
23	57,0317	0,259253	12,15443
24	39,20718	0,270295	12,94534
25	45,11767	0,291234	11,81118
26	67,11118	0,29935	12,21899
27	71,9187	0,308659	12,79981
28	61,55513	0,318856	13,60713

Table 2. Values of modeled parameters for every experiment

6. RESULTS

Dependence between experimental results and results obtained by genetic programming modeling for material removal rate, gap distance and surface roughness, are shown in Fig 1-3.

σ_{Vw} (%)	σ_a (%)	σ_{Ra} (%)
12,0	**4,6**	**2,6**

Table 3. Values of average percent deviation of results

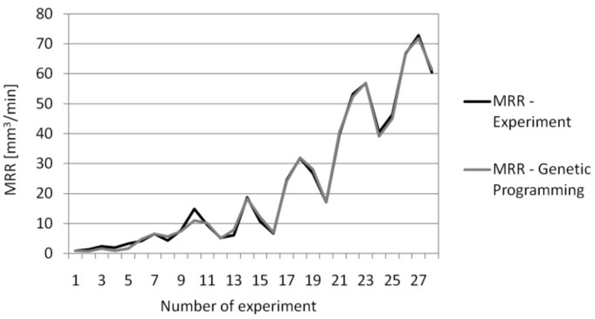

Fig. 1. Dependence between material removal rate (MRR) values

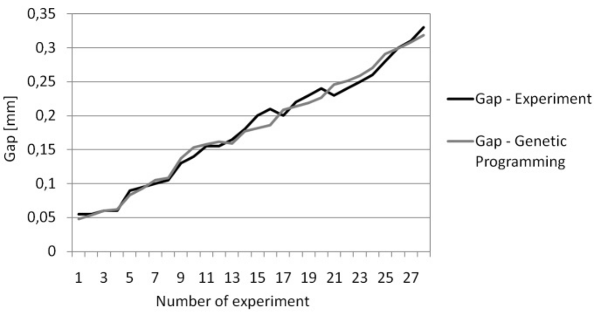

Fig. 2. Dependence between gap distance values

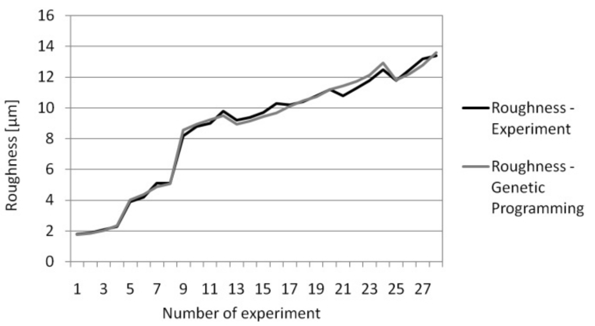

Fig. 3. Dependence between roughness surface values

Specific values of parameters obtained with genetic programming model are shown in Table 2. And numerical values of average percent deviation (σ), for modeled results from experimentally obtained results, are shown in Table 3.

7. CONCLUSION

According to Fig. 1-3 it is clearly visible that modeling ability of genetic programming is on very high level of precision. One of the most important advantages of this type of modeling is that specific equations are obtained and models can be used independently. Because of the scarcity of space and slight complexity of generated membership functions, they are not shown within this paper. They are although available on request from corresponding author. For later research more experiments are suggested. It is speculated that this would enable to yield more accurate results without drastically prolonging computational time. Also more workpiece materials could be investigated to crosscheck model validity.

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