The Influence of EDM Parameters in Finishing Stage on Surface Quality using Artificial Neural Network

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Abstract: In this work, the influence of different EDM parameters (pulse current, pulse voltage, pulse on-time, pulse off-time) in finishing stage on the surface roughness (R_a) as a result of copper electrode application to a workpiece (cold work steel DIN1.2379) has been investigated**.** Design of the experiment was chosen as full factorial. Statistical analysis has been done and artificial neural network has been used to choose proper machining parameters in order to reach certain surface roughness. The experiment results indicated a good performance of the proposed method in optimization of such a complex and non-linear problems.

Keywords: Artificial Neural Network, Hot Work Steel, Surface Roughness

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1 INTRODUCTION

Electrical discharge machining (EDM) is one of the most extensively used nonconventional material removal processes. Its unique feature of using thermal energy to machine electrically conductive parts regardless of hardness has been its distinctive advantage in mould manufacturing, die, automotive, aerospace and surgical components. In addition, EDM does not make direct contact between the electrode and the workpiece eliminating mechanical stresses, chatter and vibration problems during machining. Today, an electrode as small as 0.1 mm can be used to ‘drill’ holes into curved surfaces at steep angles without drill wander [1].

The origin of electrical discharge machining (EDM) dates back to 1770 when an English scientist Joseph Priestly discovered the erosive effect of electrical discharges. Pioneering work on electrical discharge machining was carried out in 1943 during World War II by two Russian scientists, B.R. and N.I. Lazarenko at the Moscow University (Lazarenko, 1943). The destructive effect of an electrical discharge was channelized and a controlled process for machining materials was developed [2].

Ozlem et al. [3] showed a developed technique for surface roughness modeling in EDM. They have evaluated different EDM parameters such as current, pulse on-time, pulse off-time and arc voltage on roughness value in finishing and roughing machine stages by using the genetic algorithm and genetic expression programming (GEP) methods. Results obtained from this experimental work have been compared with roughness values modeled by using the genetic algorithm method where the results showed less than 10% error.

Yang et al. [4] proposed an optimization methodology for the selection of the best process parameters in electro discharge machining. Regular cutting experiments were carried out on die-sinking machine with different conditions of process parameters. The system model was created using counter-propagation neural network and experimental data. This system model was employed to simultaneously maximize the material removal rate as well as minimize the surface roughness using simulated annealing scheme.

In this work, the influence of different EDM parameters (pulse current, pulse voltage, pulse on-time, pulse off-time) in finishing stage on the surface roughness (R_a) as a result of copper electrode application to a workpiece (hot work steel DIN1.2344) has been investigated. Statistical analysis has been carried out on surface roughness data gathered from the test. Appropriate artificial neural network (ANN) has been designed for the prediction of roughness in finishing stage of hot work steel DIN1.2379. Finally for decreasing the error in ANN, a hybrid model (a combination of statistical analysis and ANN model) has been used.

2 EXPERIMENTATION

In this section, there will be a brief description of the equipment and material used to carry out the EDM experiments. Also, the design factors used in this work will be outlined.

2.1. Equipment used in the experiments

Die-sinking EDM machine used in this experiment was Roboform 40 manufactured by Charmilles Technologies Machine. It has 4 axial movements (linear movement in X, Y and Z axis and rotational movement about Z axis). Movement resolution of EDM machine was 0.5 micron. The photograph of Die-sinking EDM machine is shown in Fig. 1.

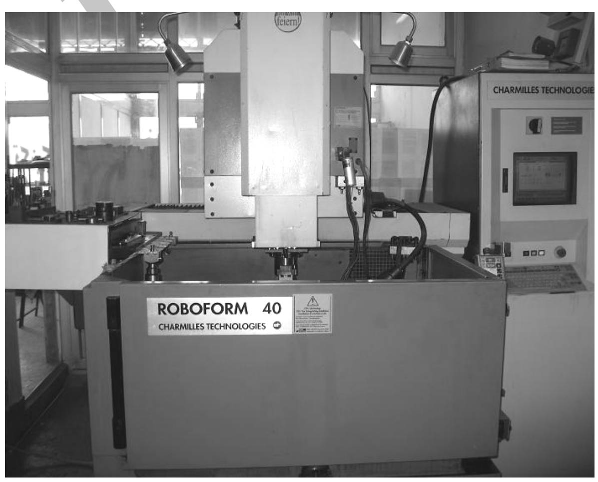

Fig. 1 Utilized Die-sinking EDM machine

Table 1 Details of work piece, tool and dielectric fluid

Electrode	Work piece	Dielectric fluid
Copper (electrolytic grade) Dimension: cylindrical shape with a diameter of 10mm (10mm×10mm×25 mm)	Cold Work Steel : DIN 1.2379 Composition—C: 1.53 %; Cr:12%;Mo: 0.85%; V: 0.85%; Mn: 0.4%; Si: 0.35%; rest iron Dimension: cylindrical shape with a diameter of 40mm and thickness of 5mm	(Kerosene)

A Perthometer (produced by Mahr Co, Model M2) was used in this study for measuring the surface roughness, where the accuracy of this equipment was 0.001 mm.

2.2. Material used in the experiment

A new set of instrument (electrode and workpiece) for each experiment has been used, where the machining state has been shown in Table 1.

3 DESIGN OF THE EXPRIMENT

The purpose of the present experiment was surface roughness evaluation in EDM finishing stage of hot work steel DIN 1.2344 and proposing an appropriate ANN for the prediction of surface roughness. For this purpose, different workpieces have been selected to be drilled for the depth of 0.2 mm. The corresponding EDM machining process is shown in Fig. 2.

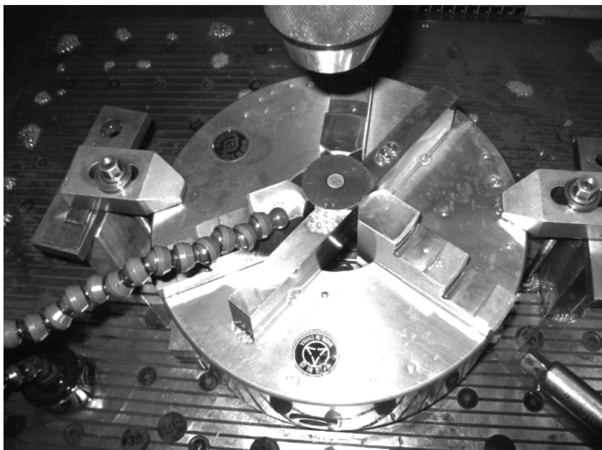

Fig. 2 EDM machining process

The most important parameters in EDM process are pulse current (I), pulse voltage (V), pulse on-time (T_{on}) and pulse off-time (T_{off}) [4], [5]. This study employed a full EDM factorial design because ANN model needed a lot of data to obtain an appropriate model for surface roughness prediction.

The relation between pulse current and surface roughness is demonstrated in a curve [6], [7], where the pulse currents of 4 to 8 Ampere were selected for EDM finishing and as a result, pulse currents of 4, 6, 8A were used. However, pulse voltages of 40, 60, and 80 V were used based on available pulse voltages in EDM machine.

The relation between pulse on-time and surface roughness is demonstrated in a curve [6], [7], where the pulse on-times of 25, 50, and 100µs were used. The relation between pulse off-time and surface roughness is demonstrated in a curve [3], [6], where the pulse-off duration is equal to the pulse-on, thus pulse off-times of 25, 50, and 100 µs were used.

Therefore, in this study, 81 experiments were done on the workpieces. The parameters explained above were used as experimental variables and they defined the roughness values occurring on the workpiece surface. There are various simple surface roughness amplitude parameters used in industry. In the measurement stage, the sampling length (L_c=0.8 mm), measuring length (L_m= 4 mm) and traverse length (L_t= 5.6 mm) were taken, respectively. Surface roughness (R_a) created on each part as a result of each EDM experiment was measured three times and its average value was calculated and applied in the ANN and hybrid model.

4 RESUALTS AND DISCUSSION

All of the 81 surface roughness values measured as a result of the EDM process based on parameters such as the discharge current, pulse on-time, pulse off-time and gap voltage are presented in Table 2.

Figure 3 shows the estimated response surface for the surface roughness parameter, according to the design parameters of pulse current (I) and pulse voltage (V) whilst the pulse on-time (T_{on}) and pulse off-time (T_{off}) remain constant in its central value, which is 62.5 µs.

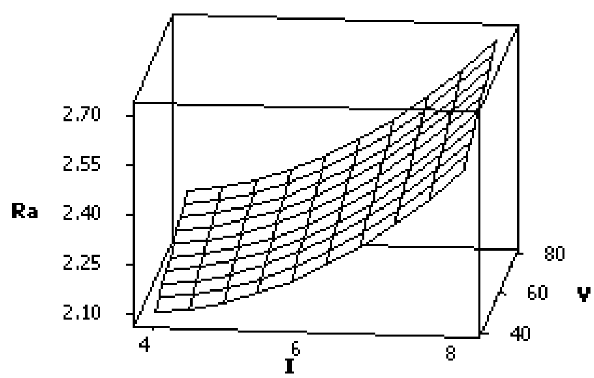

Fig. 3 Estimated response surface of Ra vs. I and V

Figure 3 shows that with an increase in the amount of intensity, surface roughness increases, while with increasing in the amount of voltage, surface roughness increases. Moreover, intensity in comparison to voltage, influences more effectively on surface roughness.

Table 2 Results of the EDM experiment

No	I (A)	V (v)	T_{on} (µs)	T_{off} (µs)	R_a (µm)	No	I (A)	V (v)	T_{on} (µs)	T_{off} (µs)	R_a (µm)	No	I (A)	V (v)	T_{on} (µs)	T_{off} (µs)	R_a (µm)
1	4	40	25	25	1.91	28	6	40	25	25	1.96	55	8	40	25	25	2.27
2	4	40	25	50	1.87	29	6	40	25	50	1.91	56	8	40	25	50	2.13
3	4	40	25	100	1.80	30	6	40	25	100	1.84	57	8	40	25	100	2.04
4	4	60	25	25	2.00	31	6	60	25	25	2.05	58	8	60	25	25	2.35
5	4	60	25	50	1.97	32	6	60	25	50	2.02	59	8	60	25	50	2.27
6	4	60	25	100	1.94	33	6	60	25	100	2.00	60	8	60	25	100	2.23
7	4	80	25	25	2.02	34	6	80	25	25	2.05	61	8	80	25	25	2.38
8	4	80	25	50	2.07	35	6	80	25	50	2.12	62	8	80	25	50	2.35
9	4	80	25	100	2.11	36	6	80	25	100	2.15	63	8	80	25	100	2.40
10	4	40	50	25	2.24	37	6	40	50	25	2.29	64	8	40	50	25	2.58
11	4	40	50	50	2.21	38	6	40	50	50	2.27	65	8	40	50	50	2.55
12	4	40	50	100	2.15	39	6	40	50	100	2.21	66	8	40	50	100	2.49
13	4	60	50	25	2.29	40	6	60	50	25	2.37	67	8	60	50	25	2.67
14	4	60	50	50	2.26	41	6	60	50	50	2.33	68	8	60	50	50	2.62
15	4	60	50	100	2.22	42	6	60	50	100	2.30	69	8	60	50	100	2.56
16	4	80	50	25	2.34	43	6	80	50	25	2.43	70	8	80	50	25	2.73
17	4	80	50	50	2.30	44	6	80	50	50	2.38	71	8	80	50	50	2.68
18	4	80	50	100	2.28	45	6	80	50	100	2.35	72	8	80	50	100	2.62
19	4	40	100	25	2.55	46	6	40	100	25	2.66	73	8	40	100	25	3.03
20	4	40	100	50	2.40	47	6	40	100	50	2.51	74	8	40	100	50	2.86
21	4	40	100	100	2.24	48	6	40	100	100	2.33	75	8	40	100	100	2.65
22	4	60	100	25	2.60	49	6	60	100	25	2.72	76	8	60	100	25	3.10
23	4	60	100	50	2.44	50	6	60	100	50	2.55	77	8	60	100	50	2.91
24	4	60	100	100	2.27	51	6	60	100	100	2.37	78	8	60	100	100	2.70
25	4	80	100	25	2.66	52	6	80	100	25	2.77	79	8	80	100	25	3.16
26	4	80	100	50	2.51	53	6	80	100	50	2.61	80	8	80	100	50	2.97
27	4	80	100	100	2.32	54	6	80	100	100	2.43	81	8	80	100	100	2.76

Fig. 4 shows the estimated response surface for the surface roughness parameter, according to the design parameters of pulse on-time (T_{on}) and pulse off-time (T_{off}) remains, while the pulse current (I) and pulse voltage (V) remain constant in their central value, which are I=6 and V=60.

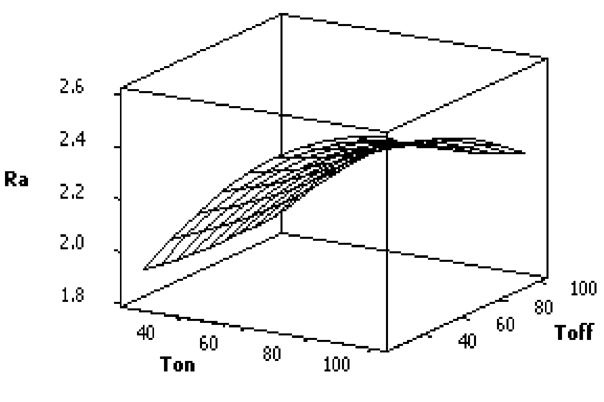

Fig. 4 Estimated response surface of Ra vs. T_{on} and T_{off}

Fig. 4 shows that with an increase in the amount of T_{on}, surface roughness increases, while with an increase in the amount of T_{off}, surface roughness decreases. Moreover, T_{on} in comparison to voltage, influences more effectively on $T_{on.}$ Considering figures 4 and 5, it can be concluded that intensity and T_{on} have the most significant effects on surface roughness.

5 DESIGN OF THE ARTIFICIAL NEURAL NETWORK MODEL

Artificial neural network (ANN) has been designed for the prediction of Ra, MRR and EWR. For designing and training of ANN model, the programming in MATLAB software was used, where the training procedure was as follows:

1. Defining the inputs and outputs of the network
2. Defining error function of the network
3. Obtaining the trained output data for input vector data
4. Comparing real outputs with test outputs

5. Correcting ANN weights based on error value
6. Repeating "Correct ANN weights based on error value" to reach minimum error [8].

The input parameters considered in the experiments included discharge current (I), voltage (V), pulse-on time (T_{on}) and pulse-off time (T_{off}). The output parameter considered in experiments included surface roughness (R_a), where the architecture of ANN model is shown in figure 5.

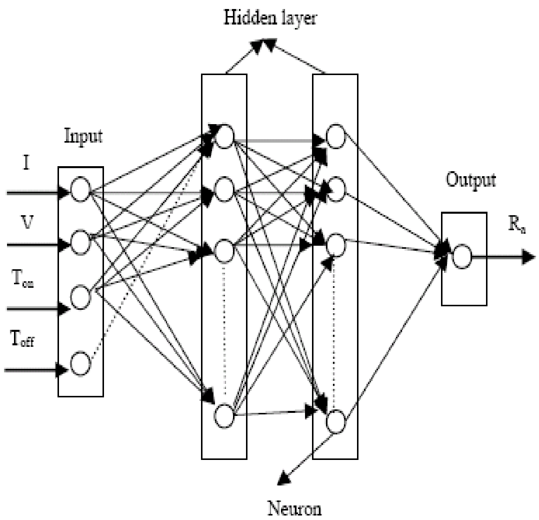

Fig. 5 Architecture of ANN model

Error function network used mean square error (MSE) procedure as shown in the following equation [5]:

$$MSE = \frac{1}{2N}\sum_{i=1}^{N}\sum_{j=1}^{m}\left(T_j - O_j\right)^2 \qquad (1)$$

Where N is the all number of training pattern (definition of epoch in Matlab programming), m is the number of output nodes; T_j is the target output of the j^{th} neuron and O_j is the estimated value of the j^{th} neuron. The number of data is 81, hence 9 out of 81 were chosen for testing of the network and 72 for training the network. The choose of the number of neurons in hidden layers, transportation function of each neuron, learning method and training method was based on trial and error to obtain minimum error.

The designed ANN had 4 inputs, 13 neurons in first hidden layer, 13 neurons in second hidden layer and 1 neuron in output layer. The training of network used Levenberg-Marquadt (back propagation) method. The value of MSE was used to be 0.0001. In this situation Mean prediction error has a minimum value and network architecture is in the best situation. The maximum, minimum and mean prediction error with different architectures network for selection neurons has been shown in Table 3.

Table 3 Different architectures network for ANN model

Serial no	Network architecture	Minimum prediction Error (%)	Maximum prediction Error (%)	Mean prediction Error (%)
1	4-12-12-1	0.05	7	2.6
2	4-13-13-1	0.03	2.6	0.7
3	4-14-14-1	0.3	16	7.3
4	4-15-15-1	0.1	7	4.6
5	4-16-16-1	0.02	5.5	1.7
6	4-17-17-1	0.8	5.5	1.7
7	4-18-18-1	0.3	2	1.3
8	4-19-19-1	0.4	82	5

5 CONCLUSION

In this work, the influence of different EDM process parameters (current, pulse on-time, pulse off-time, arc voltage) on the surface roughness while utilizing copper electrode to cold work steel DIN1.2379, has been investigated. Design of the experiment was chosen full factorial in finishing stage, followed by statistical analysis of the results. The outcome of the analysis is as follows:

- With increasing the amount of intensity in finishing stage of machining, surface roughness increases. With increasing the amount of voltage also, surface roughness increases. Moreover, intensity in contrast to voltage influences more effectively on surface roughness.
- With increasing the amount of T_{on} in finishing stage of machining, surface roughness increases. With increasing in the amount of T_{off}, surface roughness decreases. Moreover, T_{on} in comparison to voltage, influences more effectively on T_{on}.
- Intensity and T_{on} have the most significant effects on surface roughness in finishing stage of machining.

Finally, to predict the surface quality, ANN has been employed where the following results are obtained:

- Application of ANN to predict surface roughness is a scientific method which avoids complex traditional trial and error methods.
- By using ANN, proper training of network and giving values for current, pulse on-time, pulse off-time and arc voltage, accurately predicts the surface roughness.
- Designed ANN has mean error of 0.7 percent and maximum error of 2.6 percent, while this error level is quite satisfactory for surface roughness measurement.

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