International Journal of Science and Engineering Applications
Volume 7–Issue 10,391-395, 2018, ISSN:-2319–7560

Optimization and Modeling of Electrical Discharge Machining Using Response Surface Methodology Part-I

Rania Ahmad Elrifai
Benghazi University, Industrial and Manufacturing System Engineering
Benghazi, Libya

Abstract: To improve and optimize the response of Electrical Discharge Machining process, the various input machining control parameters are to be set at an optimal value. As FW4 is a newly developed hot die material widely used in Forging Dies manufacturing. The optimal selection of the machining conditions is one of the most important aspects to be taken into consideration in the Electrical Discharge Machining (EDM) of FW4. In this paper, an attempt has been to develop and optimize mathematical model of relating Material Removal Rate (MRR) and the machining parameters (current, pulse -on time, voltage). Experiments are designed and the correlating the desired response and the control parameters are established using Response Surface Methodology (RSM), finally (RSM) is applied to search the optimal parametric values for the optimal response. Using RSM, maximum Material Removal Rate obtained is 30.5541mm³/min which is 0.3641less in magnitude than experimentally measured value, Thus, the result proves RSM to be optimization technique which can be used to optimize Electrical Discharge Machining Processes.

key words: Electrical Discharge Machining (**EDM**); Response Surface Methodology (**RSM**); ANOVA; Material Removal Rate.

1. INTRODUCTION

EDM is a common technique used in industry for high-precision machining of all types of conductive materials such as: metals, metallic alloys, graphite, some ceramic materials, and any hardness[2]. FW4 is a welded steel, that is the most important and applicable welded material on the basis of chromium . Using welded material increases the lifetime of forging moulds more than 150% and periodical replacement time of moulds up 200% as compared to moulds made of ordinary steel tool . Also it causes a decrease in materials and mould`s expenses to 62% the hardness of the weld metal will be controlled in the scale of 30-50 HRC, the weld metal will be resistant in hot strength, high temperature , wear and thermal fatigue crack [1]. At present , EDM is a widespread technique used in industry for high-precision machining of all types of conductive materials such as : metals, metallic alloys ,graphite ,or even some ceramic materials,of any hardness[2]. EDM is nontraditional machining process based on removing material from part by means of successive electrical discharges occurring between an electrode and a work piece immersed in a dielectric fluid[2]. The photographic view of the Schematic diagram of machine and machining has been shown in figure.1 (a) and (b) respectively. The other details of the experimentation and design of experimenthave been shown in Table 1.

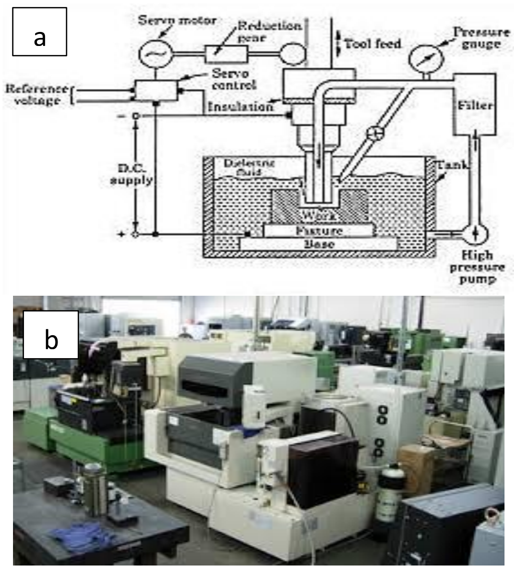

Figure 1: (a) Schematic diagram of Electrical Discharge Machining process; (b) Machining

Optimization of machining process first requires a mathematical model to be established to correlate the desired response and the process control parameters. Thereafter an optimization technique is applied to find optimal setting of control parameters to drive the desired response, since EDM is complex machining process , in order to achieve the economic objective of this process , optimal conditions have to be determined and so mathematical models need to established ; therefore, Statistical - Mathematical models are always used by scientists to describe the correlation between characteristics and machining output results, and setting or input parameters . Regression Analysis are the most important and major modeling methods , employed in the EDM process modeling[4]. Regression analysis is regarded as powerful tool for representing the relation between input parameters and process response [5]. Mathematical model for electrical discharge machining of WC-Co, SIC and conductive ceramic on the basis of experiments designing techniques . They introduced the obtained - mathematical model ,using regression analysis [5-8]. The effects of electrode tool material and electrical discharge machining were studied input parameters such as: current, pulse-on time, on AISI D3 EDM characteristic, by the use of variance analysis and experiments designing techniques[9]. They reported that the graphite electrode, having highest material removal rate and precise dimension and low tool wear ratio, is the most appropriate material for steel machining [9]. Estimated Regression Coefficients for MRR are been used data in uncoded units that they used for make relation between input parameters and EDM process such as peak current, pulse-on time and voltage and the process output has been modeled, using the techniques of Design Of Experiment (DOE) method, multi linear regression techniques and Response Surface Methodology (RSM) [10]. Also effect of input parameters on characteristic of machining FW4 steel has been analyzed . The result of this research, leads to desirable process output, finally optimization of input parameters and output of process.

2. MATERIALS AND METHODS

2.1 Material

The material used for work piece was FW4 welded tool steel. To prepare FW4 samples ,first a sheet of common steel was used as a base ,and the welding process was done using a forge weld semi-automatic MIG welding station. Welding process occurs by the systematic deposition of weld layers achieving a build -up of 3-5 mm per layer with "covered welding wires of FW4", in in several pulses, separating welding dost from the basic sheet, raw block of FW4 steel are prepared. Raw blocks were cut to circular tables 20 mm height by wire EDM and then ground to parallel faces, EC-16 graphite tool electrode material has particle size from 3 to5 micron. Graphite tools were cut from 20mm dia. Rod and machined by using a very accurate CNC lath. Table1 shows the samples and tools physical and mechanical properties[11].

Table 1: Workpiece and electrodes physical properties

Properties of FW4 (work piece)		Properties of EC-16 (Tool)	
Density	7.7623(1000kg/m3)	Bulk density	1018(g/cm2)
Melting Point	2670℃	Specific resistance	1650(μhom-cm)
Poisson Ratio	0.34	Flexural strength	750 (kg/cm2)
Hardness	4505 HRC	Shore hardness	70
Elastic Modulus	210(Gpa)		
Thermal Conductivity	27.2(W/m.k)		

In this study, an attempt is made to establish the input-output relationship of Material Removal Rate (MMR) of the transportation processes parameters by pipeline. It is important to note that selection of the range of the operating parameters is an important consideration. There are a large number of factors to consider within the EDM process ,put in this work peak current (I), pulse -on time (T_{on}) and voltage (v) have only been taken into account as design factors . The reason why these three factors have been selected as design factors is that they are the most widespread and used amongst EDM researchers.

Table 2: Factors and selected for the experiments

No	Factors	Units	Levels		
			-1	0	+1
1	Current	A	8	16	24
2	Pulse - on time	μs	12.8	25	50
3	Voltage	V	160	180	200

2.2. Method

The choice and the implementation of an experimental design type is an important decision. A single integrated package performs the ED and RSM in Minitab16 software. A response variable (Material Removal Rate (MMR)). The experimental design is implemented using RSM in two steps:

1. **Full Factorial Design (FFD)**
2. **Central Composite Design (CCD)**

In order to study the effect of EDM process parameters of FW4 material on the volumetric metal removal rate , second -order polynomial response can be fitting into the following equation (1):

$$Y=\beta 0+\beta 1X+\beta 2\Phi+\beta 3\Psi+\beta 12X\Phi+\beta 13X\Psi+\beta 23\Phi\Psi+\beta 11X^2+\beta 22\Phi^2+\beta 33\Psi^2 \quad (1)$$

Where Y is the response and X,Φ, ψ are the quantitative variables .β1,β2 and β3 represent the linear effect of X,Φ and ψ respectively , β11,β22 and β33 represent the quadratic effects of X,Φ and ψ,β12,β13 and β23 represent linear - by- linear interaction between "X and Φ" "X and ψ , "Φ and ψ, respectively .these quadratic models work quite well over the entire factor space and the regression coefficients were computed according to least -square procedure. For the three variables the design required with eight star points (cube points), six axial points to form central composite design with five center points for replication to estimate the experimental error. The design was generated and analyzed using MINITAB16 statistical package. The levels of each factor were chosen as −1, 0, + 1 in coded form to have a central composite design as shown in Table 3.

International Journal of Science and Engineering Applications
Volume 7–Issue 10,391-395, 2018, ISSN:-2319–7560

Table 3: Randomized design table for three parameters (uncoded) and outputs

No	Current (A)	Pulse-on time(µs)	Voltage(v)	MRR(mm³/min)
1	16	12.8	180	12.5013
2	16	31.4	180	19.6183
3	8	12.8	200	7.4420
4	8	50	200	9.5043
5	16	31.4	180	19.6183
6	24	12.8	200	15.8079
7	16	31.4	180	19.6183
8	8	50	160	4.6120
9	24	50	200	30.9180
10	16	31.4	180	19.6183
11	16	12.8	160	12.1110
12	24	50	160	24.322
13	24	31.4	180	19.6183
14	16	31.4	180	19.6183
15	16	31.4	160	23.3422
16	24	31.4	180	22.4833
17	16	31.4	200	9.3188
18	8	50	180	20.2945
19	16	31.4	180	19.6183
20	16	12.8	160	3.7549

3. Mathematical modeling and statistical analysis by using response surface methodology

Table 4: shows the p-values that determine whether the effects are significant or insignificant.

Source	Df	Seq SS	Adjss	AdjMS	F	P
Regression	9	953.25	953.25	105.92	470.18	0.00
Linear	3	708.43	708.43	236.13	1048.3	0.00
Current	1	516.52	516.52	516.52	2292.9	0.00
Pulse	1	6144.6	6144.6	6144.6	642.16	0.00
Voltage	1	47.250	47.250	47.250	209.75	0.00
Square	3	167.91	167.91	55.971	248.46	0.00
Current*current	1	132.48	36.546	36.546	162.23	0.00
Pulse*pulse	1	32.258	35.207	35.207	156.29	0.00
Voltage*voltage	1	3.177	3.177	3.177	14.10	0.00
Interaction	3	76.904	76.904	25.635	113.80	0.00
Current*pulse	1	74.432	74.432	74.432	330.41	0.23
Current*voltage	1	0.367	0.367	0.367	9.35	0.01
Pulse*voltage	1	2.105	2.105	2.105	*	*
Residual Error	10	2.253	2.253	.225		
Lack- of-fit	5	2.253	2.253	0.451		
Pure Error	5	0.000	0.000	0.000	1048.3	
Total	19	955.49			2292.9	

Table 5: Estimated Regression Coefficients for MMRmm³/min)

Term	Coef
Constant	63.6345
Current	1.83650
Plus	0.277772
Voltage	-0.923390
current*current	-0.0569603
plus*plus	-0.0103424
voltage*voltage	0.00268710
current*plus	0.0204989
current*voltage	0.00133852
plus*voltage	0.00137907

After identifying the significant effects (main and two-way interactions) in the analysis of variance table, a look at the estimated effects and coefficients table. Table 3 shows that all the p-values associated with each individual model term are all significant and < 0.05. The p-values indicate that quadratic effect are significant. The p-values indicate that just one two-way interaction are significant. Equation(2) shows the model for predictions and calculating **MRR**:

$$\mathbf{MMR} = 63.6345+1.8366\,\mathbf{I}+0.2778\,\mathbf{T_{on}}-0.9234\mathbf{V}-0.0570\mathbf{I}^2-0.0103\mathbf{T_{on}}^2+0.002710\,\mathbf{V}^2+0.0205\,\mathbf{I}^*\,\mathbf{T_{on}}+0.\mathbf{0013}\,\mathbf{I}^*\,\mathbf{V}+0.00134\,\mathbf{T_{on}}\,{}^*\mathbf{V} \qquad (2)$$

Where:

I = current,

T_{on} = pulse -on time and

V = voltage.

To check on the obtained results, probability plot is also used to identify the appropriate distribution. The Normal probability plot. Various fits, histograms and order distributions are shown in Figure3. It can be seen from the probability plots, that the normal distribution is the best one, since all data fall within the 95% confidence interval.

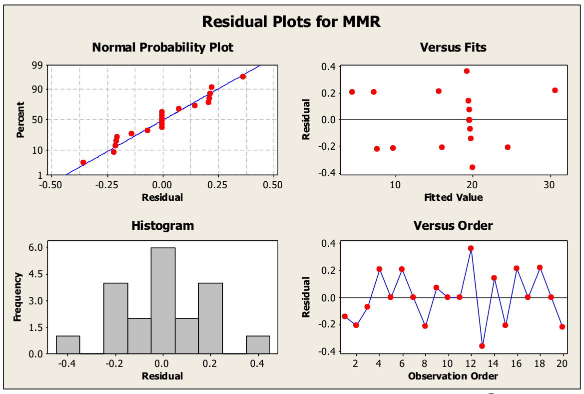

Figure 3: Probability plots for MMR(mm³/min)

4. Results and discussion for the effects of process variables on Material Removal Rate (MRR), based on RSM.

Since the model have enough characteristics for changing data we can study the effect of input parameters on the machining characteristics by graphs on the basis of models and predict response change`s value on middle surface of input changes.

4.1 Effect the input parameters on MRR

Material Removal Rate in EDM process is an important factor because of its vital effect on the industrial economy. Figures3,4 and 5 show the response surface and contour of MRR versus current, pulse-on time and voltage. Increasing the current, pulse-on time and voltage values lead to an increase in the amount of Material Removal Rate. But the most influential factors are peak current and pulse-on time, also the MRR increase gradually with the voltage. In this process, the spark energy affects the material removal speed and energetic sparks increases the material removal rate Energy of each spark, according to its electrical concepts, is a function of spark current, pulse-on time and voltage.

The Figures 3(a) and 5(a) show that in all the currents, the MRR decreases after a particular T_{on}. The major reason for the decrease in MRR is high gap pollution and low energy density during pulse-on time. In the view point of industrial economy it is desirable to obtain higher values of MRR, should be identified (Figures3,4,5).

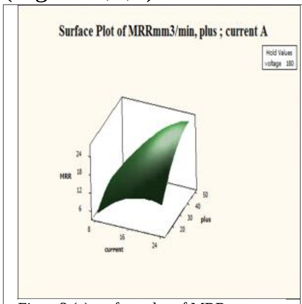

Figure3 (a):surface plot of MRR mm³/min ,pulse(µm), current(A) v=180)

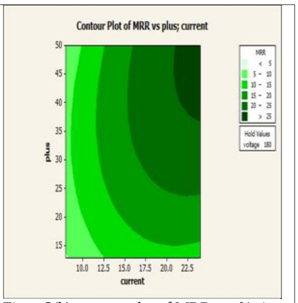

Figure3(b):contour plot of MRR mm³/min ,pulse(µm), current(A)(v=180)

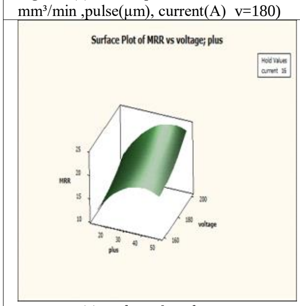

Figure 4: (a):surface plot of MRR mm³/min, pulse(µm), voltage(v). I=16A)

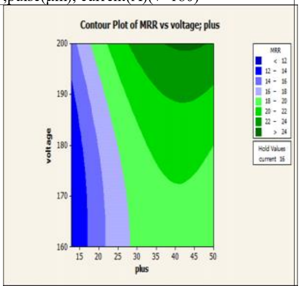

Figure4(b): contour plot of MRR mm³/min , pulse (µm), voltage(v). (I=16A)

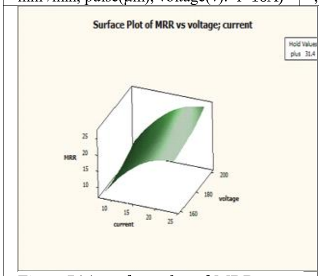

Figure5(a):surface plot of MRR mm³/min ,current(A), voltage(v).Ton =31.4µm

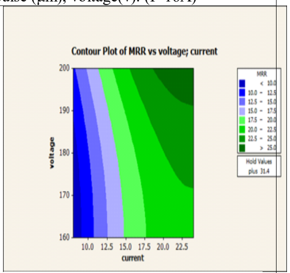

Figure5(b): contour plot of MRR mm³/min, voltage(v). current(A). Ton =31.4µm

Figures 3,4,5: show surface and contour plots

5. Optimization Using RSM (Response Surfaces Methodology)

Many designed experiment involve determining optimal conditions that will produce the "best" value for the response. Depending on the design type (factorial, response surface, or mixture), the operating conditions that you can control may include one or more of the following design variables: factors, components, process variables, or amount variables.

For example, in product development, we may need to determine the input variable settings that result in a product with desirable properties (responses). Since each property is important in determining the quality of the product, you need to consider these properties simultaneously. For example, we may want to increase the yield and decrease the cost of a chemical production process.

Optimal settings of the design variables for one response may be far from optimal or even physically impossible for another response. Response optimization is a method that allows for compromise among the various responses.

Minitab provides two commands to help we identify the combination of input variable settings that jointly optimize a set of responses. These commands can be used after we have created and analyzed factorial designs, response surface designs, and mixture designs.

Response Optimizer Provides we with an optimal solution for the input variable combinations and an optimization plot. The optimization plot is interactive; we can adjust input variable settings on the plot to search for more desirable solutions.

Overlaid contour shows how each response considered relates to two design variables (factorial and response surface designs) or three continuous design variables (mixture designs), while holding the other variables in the model at specified levels. The contour plot allows we to visualize an area of compromise among the various responses.

6. Optimization Of EDM Process Using RSM

The present research work optimize the desired response and control parameters using Minitab software Figure (6) shows the RSM output of the best measured response of maximum MRR as 30.5541 mm³/min. Response optimization by RSM has been obtained by two values the lower and the upper from the table of experiments were run , then the optimization parameters are current as 24A, pulse as 50 **µs** ,voltage 200v with desirability 98.65%.

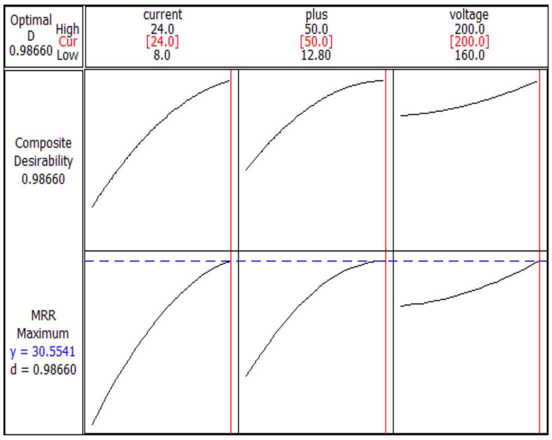

Figure 6: shows the optimal values of input parameters and the response (MMR)

7. Conclusion

In this paper, an experimental investigation was performed to consider the machining in EDM process of FW4 welded steel and the following results were concluded :

1. RSM provides a cost effective soft computing technique for optimizing machining operations.

2. Results show that the central composite design (CCD) is a powerful tool for providing experimental diagrams and statistical-mathematical models, to perform the experiments appropriately and economically.
3. In this paper, an attempt was made to consider the effect of voltage, pulse-on time, and current on material removal rate in EDM process . According to the ANOVA results, voltage, pulse-on time, and current are the not significant parameters on Material Removal Rate whereas interaction voltage and current are the most significant.
4. Based on the optimization results, it has been found that 200V as voltage, 50µs as pulse-on time, 24 A as current .
5. The optimization value of material removal rate found very close to the experimental value of experimental value at optimum level of input process parameters.
6. Based on the test results predicated using RSM ,this technique can be accommodated within an intelligent manufacturing system for automated process planning .

REFEENCES

[1] www.corewire.com

[2] Fonda, P., Wang, Z., Yamazaki, K, Akutsu, Y., 2007, A fundamental study on Ti–6Al–4V's thermal and electrical properties and their relation
to EDM productivity, J. Mater. Process. Technol.,

[3] Mukherjee, I., Ray, P.K., 2006, A review of optimization technique in metal cutting process, Computer & Industrial Engineering, 50: 15-34.

[4] Hewidy, M.S., El-Taweel, T.A., El-Safty, M.F., 2005, Modelling the machining parameters of wire electrical discharge machining of Inconel 601 using RSM, J. Mater. Process. Technol., 169: 328–336.

[5] Puertas, I., Luis, C.J., Álvarez, A., 2004, Analysis of the influence of EDM parameters on surface quality, MRR and EW of WC–Co, J. Mater.
Process. Technol., 153–154: 1026–1032.

[6] Puertas, I., Luis, C.J., 2004, A study on the electrical discharge machining of conductive ceramics, J. Mater. Process. Technol., 153–154: 1033–1038.

[7] Puertas, I., Luis, C.J., Villa, G., 2005, Spacing roughness parameters study on the EDM of silicon carbide, J. Mater. Process. Technol., 164–65:1590–1596.

[8] Luis, C.J., Puertas, I., 2007, Methodology for developing technological tables used in EDM processes of conductive ceramics, J. Mater. Process. Technol., 189: 301–309.

[9] Khoshkish, Ashtiani, Goreyshi, Effects of Tool electrode material on electrical discharging machining process of hardened tool AISI D3, Iran Conference of Manufacturing Engineering.

[10] George, P.M., Raghunath, B.K., Manocha, L.M., Warrier, A.M., 2007, EDM machining of carbon–carbon composite—a Taguchi approach, J. Mater. Process. Technol., 153-154: 920–924.

[11] www.MVI.com

[12] Montgomery, D.C., 1997, Design and Analysis of Experiments, Wiley, NewYork. World Academy of Science, Engineering and Technology Vol:28 2009-04-29.

★★★★★★