Optimization of Surface Roughness in EDM For AISI M2 High Speed Steel Using Response Surface Methodology

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Abstract

The modelling and optimization of machining parameters are very important for machining processes in manufacturing industries. The present study provides the models for the functional relationship between various process parameters and the output response of electric discharge machine. The experimental work is done on AISI M2 high speed steel. Surface roughness is one of the most important factor which is to be considered during machining in manufacturing and it influences the quality and performance of product. So minimization of surface roughness is of maximum importance. It is also desirable and realistic if finished part do not need further any operation to meet the required optimum level of surface quality. For that optimization of parameters is essential. Four significant machining parameters, discharge current(Amp),gap voltage(volt),pulse on time(µs) and duty cycle(%) have been selected and number of combinations are made and then experiments are conducted on it. The RSM model was developed to predict the surface roughness in EDM. The developed model could be used for the selection of levels in EDM process for saving the machining time and product cost can be achieved by utilizing the model.

Keywords

Electrical Discharge Machine, AISI M2, Surface Roughness, Response Surface Methodology

I. Introduction

The Electrical Discharge Machining, commonly known as EDM is a non-conventional machining method and electro-thermal erosion process which is used to remove material by a number of repetitive electrical discharges of small duration and high current density produced by a pulse generator between the work piece material and the electrode tool which are submerged in dielectric medium. EDM is an important and cost-effective method of machining extremely tough and brittle electrically conductive materials. In EDM, since there is no direct contact between the work piece and the electrode, hence there are no mechanical forces existing between them. Any type of conductive material can be machined using EDM irrespective of the hardness or toughness of the material. EDM has a high capability of machining the precise cavities of dies and moulds. However, the surface quality aspect of EDMed component is important to meet the requirements of component performance, longevity and reliability [1]. In order to increase the machining efficiency of EDM the value of surface roughness must be minimized. As there are number of process parameters in EDM machine, the optimization of these process parameters are required so that we can minimize the value of surface roughness. In this experiment the necessary parameters like discharge current(Amp), pulse on time(µs), gap voltage(volt) and duty cycle(%) are considered.

II. Literature Review

A literature survey was made on the various optimization techniques that have been used in the optimization of EDM process parameters. Some of the surveys have been listed below.

Lee and Li et.al[2] studied the effects of EDM parameters on surface characteristics of a kind of tungsten carbide. They have concluded that MRR and surface roughness of the work piece are directly proportional to the discharge current intensity. Bhattachrya et al. [3] implemented Response Surface Methodology (RSM) to develop a mathematical model for correlating the process parameter with the responses. Kanagarajan et al. [4] applied RSM along with multiple linear regression analysis to obtain second order response equations for MRR and Ra in EDMing WC/30%Co composite. Though the most influential parameters aiming at maximizing MRR and minimizing Ra were identified by carefully examining surface and contour plots of the responses, however, again, their suggested approach suffers from the just aforementioned drawbacks.M.M. Rahman et al. [5] investigated the effect of the peak current and pulse duration on the performance characteristics of the EDM. The conclusions drawn were: the current and pulse on time greatly affected the MRR, TWR and SR, the MRR increases almost linearly with the increasing current, the SR increases linearly with current for different pulse on time, TWR increased with increasing peak current while decreased when the pulse on time was increased.S.L et al.[6]performed Electrical discharge machining of TiNiCr and TiNiZr ternary shape memory alloys and observed that the roughness of EDMed surface increases with the discharge current and pulse duration.I. Puertas et al. [7] carried out results which showed that pulse on time factor and current intensity were the most important in case of surface roughness while the duty cycle factor was not significant at all.

III. Experimental Setup

A. Electric Discharge Machine

The experiments were conducted using an electronica's elecktra puls PS 50 which is die sinking electric discharge machine and four necessary process parameters were taken in this experiments like discharge current, pulse on time, gap voltage and duty cycle. Commercial grade EDM oil (specific gravity = 0.763, freezing point = 94˚C) was used as dielectric fluid. In the below table we have taken a lower and upper limits of these parameters so that we can optimize the best results.

Table 1: Parametric Variables and Their Limits

parameters	Lower limit	Upper limit
Discharge current(Amp)	4	40
Pulse-on-time(µsec)	100	250
Gap voltage(V)	3	6
Duty cycle(%)	1	11

B. Work Piece Material

The work piece material chosen is AISI M2 which is high speed steel mainly used for cutting tool for the conventional machining processes and making dies and moulds. As it belongs to the M grade family so it is molybdenum based high speed steel. It is most widely used type and it can be used for same applications as

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T1 high speed steel which is tungsten based high speed steel. Its higher carbon content and balanced analysis produce properties applicable to all general purpose of high speed uses.

Table 2: AISI-M2 High Speed Steel Composition

Sr.no	Elements	Weight in %
1.	Carbon	0.78-1.05
2.	Chromium	3.75-4.50
3.	Tungsten	5.50-6.75
4.	Molybdenum	4.50-5.50
5.	Vanadium	1.75-2.20
6.	Iron	Balance
7.	silicon	0.20-0.45
8.	Sulphur	0.30 max.
9.	phosphorus	0.30max.
10.	manganese	0.15-0.40

Table 3: Physical Properties of AISI M2

Density(×1000kg/m³)	8.16
Poisson's ratio	0.27-0.30
Elastic modulus	190-220
Thermal expansion(10^{-6}/°C)	10.1-11.5
Thermal conductivity(W/m-k)	19.1
Specific heat (J/kg °C)	500-600

C. Electrode Material

The tools selected for this experiment is Electrolytic Copper, which is a ductile metal with high thermal and electric conductivity. Pure copper is soft and mealiable and copper surface has reddish-orange colour. It is used as conductor of heat and electricity and constituent of various metal alloys.

IV. Experimental Procedure

The experiments have been conducted using response surface method, experimental design which consists of 31 combinations of discharge current, pulse-on-time, gap voltage and duty cycle. The experiments are executed as per the orthogonal matrix generated by response surface method with four factors and two levels while 0 blocking and replicate value of 1. The machining time for one experiment to be done is 5 mins. After the machining on EDM the surface roughness is measured by profilometer device which have a diamond tip for measuring the roughness. The three values of Ra for each work piece has been taken and then calculated mean of values is considered a final value of surface roughness. The value of surface roughness depends on the scale of measurement. The characterization of surface roughness can be done in two principal planes.

Table 4: Execution of Experiment

StdOrder	RunOrder	PtType	Discharge current(Amp)	Pulse on time(µs)	Gap voltage(volt)	Duty cycle(%)	Ra µm
13	1	1	4	100	6	11	2.84
26	2	0	22	175	4.5	6	3.25
16	3	1	40	250	6	11	7.1
15	4	1	4	250	6	11	4.2
18	5	-1	58	175	4.5	6	4.07
5	6	1	4	100	6	1	3.89
10	7	1	40	100	3	11	5.01
19	8	-1	22	25	4.5	6	2.88
25	9	0	22	175	4.5	6	3.43
8	10	1	40	250	6	1	3.17
29	11	0	22	175	4.5	6	7.83
21	12	-1	22	175	1.5	6	9.49
9	13	1	4	100	3	11	3.71
20	14	-1	22	325	4.5	6	6.68
24	15	-1	22	175	4.5	16	2.33
1	16	1	4	100	3	1	3.47
7	17	1	4	250	6	1	2.26
2	18	1	40	100	3	1	2.95
14	19	1	40	100	6	11	2.79
6	20	1	40	100	6	1	1.95
22	21	-1	22	175	7.5	6	4.79
30	22	0	22	175	4.5	6	2.69
31	23	0	22	175	4.5	6	5.37
28	24	0	22	175	4.5	6	3.07

12	25	1	40	250	3	11	4.69
4	26	1	40	250	3	1	8.28
3	27	1	4	250	3	1	3.89
23	28	-1	22	175	4.5	-4	3.04
27	29	0	22	175	4.5	6	3.65
17	30	-1	-14	175	4.5	6	4.51
11	31	1	4	250	3	11	2.17

Using a sinusoidal curve as a simplified model of the surface profile, roughness can be measured at right angles to the surface in terms of the wave amplitude, and parallel to the surface in terms of the surface wavelength. The latter one is also recognized as texture. The technique used to measure roughness in any of these two planes will inevitably have certain limitations. The smallest amplitude and wavelength that the instrument can detect correspond to its vertical and horizontal resolution, respectively. Similarly, the largest amplitude and wavelength that can be measured by the instrument are the vertical and horizontal range. The first amplitude parameter used for roughness measurements was the vertical distance between the highest peak and the lowest valley of the unfiltered profile point. The designation of this parameter was subsequently changed to right when electrical filters were incorporated.

V. Experimental Analysis

As the surface roughness is the response of this experiment and similarly to minimize the surface roughness(Ra), the MINITAB has performed RSM on the selected input variables. The roughness factor have been measured with profilometer for each experimental run. Firstly the surface roughness data has been checked for its normality. In fig. 1, the data points in the first plot of the figure 1 are distributed along the normal line and they have negligible outliers, so data can be concluded as normally distributed. The second plot does not showing any trend while plotting residual versus fitted value of data which implies RSM model chosen is well fitted in given data set. The third plot of figure1 is frequency histogram showing data distribution and the fourth plot is the residual versus observation order which highlights the random data points which signifies non-significance of experimental order as far as response (Ra) is concerned.

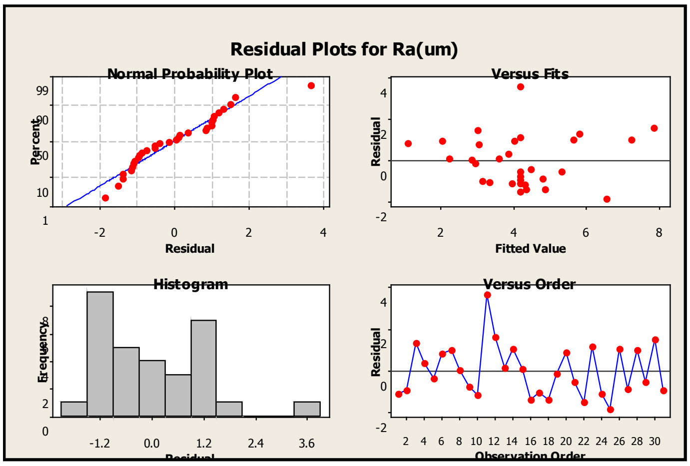

Fig. 1: Data Normality Test

Response surface method for surface roughness has been applied at the 95% confidence, so all the factors and their interactions having p (probability) value less than 0.05 will be statistically significant for Ra and it can be taken further for more details of statistical analysis of RSM for Ra.

Table 5: Estimated Regression Coefficients for Ra

Term	Coef	SECoef	T	P
Constant	4.18429	0.6366	6.573	0.000
Discharge current(Amp)	0.71917	0.6876	1.046	0.011
Pulse on time(µs)	1.39583	0.6876	2.030	0.029
Gap voltage(volt)	-1.2808	0.6876	-1.863	0.008
Duty cycle(%)	0.10250	0.6876	0.149	0.883
Discharge current(Amp) *discharge current(Amp)	-0.4447	1.2599	-0.353	0.039
Pulse on time(µs)* Pulse on time(µs)	0.04530	1.2599	0.036	0.002
Gap voltage(volt)* Gap voltage(volt)	2.40530	1.2599	1.909	0.044
Duty cycle(%)*Duty cycle(%)	-2.0497	1.2599	-1.627	0.023
Discharge current(Amp)*pulse on time	2.98250	1.6843	1.771	0.096
Discharge current(Amp)*gap voltage	-1.4675	1.6843	-0.871	0.006
Discharge current(Amp)*duty cycle	0.95750	1.6843	0.568	0.578
Pulse on time(µs)* Gap voltage(volt)	0.34250	1.6843	0.203	0.041
Pulse on time(µs)* Duty cycle(%)	-0.3825	1.6843	-0.227	0.023
Gap voltage(volt)* Duty cycle(%)	2.16750	1.6843	1.287	0.016
R-Sq = 97.73%	R-Sq(pred) = 90.70%		R-Sq(adj) = 92.75%	

As p values are more than the 0.05 for duty cycle(%), discharge current(Amp)×pulse on time(µs) and discharge current(Amp)×duty cycle(%) and hence they can be ignored during optimization of Ra because of their negligible analytical affect. Coefficients represent the relative impact of each factor and its interactions on Ra that have been analyzed at 97.73 % R-sq value.

Graphical implications of RSM for surface roughness(Ra) response have been also represented. Variation of surface finish with considered input factors, have been drawn in figure 2. As the surface roughness (Ra) increases than its corresponding surface finish decreases and vice versa.

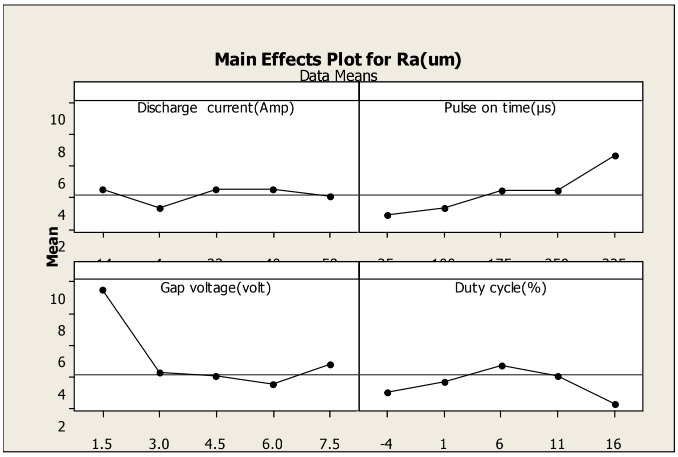

Fig. 2: Main Effect Plot for Surface Roughness

In the first plot of fig. 2 the value of Ra first decreases with increase in discharge current upto 4 Amp and the value of Ra increases when discharge current increases from 4 to 22 Amp and the value of Ra remain constant between 22 to 40Amp and then finally decreases with further increase in discharge current. The second plot of fig. 2 represents the increase in surface roughness with increase in pulse on time. In this plot the value of Ra remains constant in between 175-250µs pulse on time and then increases rapidly with rise in pulse on time. The third plot is drawn for gap voltage, in this with increase in gap voltage the surface roughness decreases but after 6volt of gap voltage the value of surface roughness starts increases. The last plot is made for duty cycle, the surface roughness increases with increase in duty cycle upto 6% but after that further increase in duty cycle the value of surface roughness decreases and become less at 16% of duty cycle.

VI. Conclusion

In this experiment RSM techniques have been used to optimize the process parameters of EDM process. The surface roughness could be effectively predicted by using discharge current, pulse on time, gap voltage and duty cycle as input variables. It has been found that individual parameters like discharge current and duty cycle are more influencing than other parameters like gap voltage and pulse on time. The corresponding predicted value of surface roughness is 2.32µs. The obtained result can be used to select the level of EDM parameters, and hence a remarkable saving of cost and time.

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