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Modeling and Optimization of WEDM Process Parameters on Machining of AISI D2 steel using Response Surface Methodology (RSM)

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Abstract— *The present work demonstrates optimization of Wire Electrical Discharge Machining (WEDM) process parameters of AISI D2 steel with multiple performance characteristics such as Cutting Rate and Gap Current on the Response Surface Methodology (RSM) Method. The process parameters considered in this research work are Pulse On-time, Pulse Off-time and Wire Feed. Taguchi's L9 Orthogonal Array was used to conduct experiments. Optimal levels of process parameters were identified using Response Surface Methodology and the relatively significant parameters were determined by Analysis of Variance (ANOVA). The variation of output responses with process parameters were mathematically modelled by using non-linear regression analysis method and the models were checked for their adequacy. Result of confirmation experiments shows that the established mathematical models can predict the output responses with reasonable accuracy.*

Keywords:*WEDM, ANOVA, RSM, pulse on time, pulse off time, cutting rate, gap current.*

"INTRODUCTION"

The electrical discharge machining (EDM), is a thermo-electric non-traditional manufacturing procedures, which is gaining increased popularity, since it does not require cutting tools and allows machining involving hard, brittle, thin and complex geometry. As there is no direct contact between electrode and the work piece in EDM methodology, the common problems like mechanical stress and vibration problems in machining are eliminated.

In electric discharge machining (EDM), material is removed from the workpiece through localized melting and vaporization of material. Electric sparks are generated between two electrodes when the electrodes are held at a small distance from each other in a dielectric medium and a high potential difference is applied across them. Localized regions of high temperatures are formed due to the sparks occurring between the two electrode surfaces. Workpiece material in this localized zone melts and vaporizes. Most of the molten and vaporized material is carried away from the inter-electrode gap by the dielectric flow in the form of debris particles.

"LITERATURE REVIEW"

WEDM is a complex machining process controlled by a large number of process parameters such as the pulse duration, discharge frequency, wire feed and discharge current density. Any slight variations in the process parameters can affect the machining performance measures such as Gap current and cutting ratio. In this chapter search few selected research paper related to EDM with effect of metal MRR, TWR, surface roughness (SR) work-piece material. Each of these is explained below.

M. Pawade el.al. [6] Give review about die sinking EDM and scope for future.

M.A. Al et al. [5] developed a model to see the effect of Edm Die-sinking Parameters on Material Removal Rate.

Y. Chen el al. [3] developed a theoretical model to estimate the MRR and surface quality of workpiece. Experiments with different values of discharge current, pulse duration time and interval time were conducted to investigate their effects on the surface finish of the workpiece and material removal rates. The theoretical prediction and experimental results are in agreement when compared.

Kansal [2] adopted the response surface optimization scheme to select the parameters in powder mixed EDM process.

Keskin [8] used design of experiments (DOE) for the determination of the best machining parameters in EDM.

M.A. Ali el al. [5] findEffect of Edm Die-sinking Parameters on Material Removal Rate of Beryllium Copper Using Full Factorial Method.
Among the different material removal processes, Die-sinking is considered as an effective and economical tool in machining of modern composite materials.

"RESPONSE SURFACE METHODOLOGY"

Response surface methodology is a collection of statistical and mathematical method that is useful for modeling and analysis of engineering problems. In this technique, the main objective is to optimize the response surface that is influenced by various process parameters. For example, the growth of a plant is affected by a certain amount of water x_1 and sunshine x_2. The plant can grow under any combination of treatment x_1 and x_2. Therefore, water and sunshine can vary continuously. When treatments are form a continuous range of values, then a Response Surface methodology is useful for developing, improving and optimizing the response variable. In this case, the plant growth yis the response variable, and it is function of water and sunshine. It can be expressed as

$$y = f(x_1, x_2) + \varepsilon$$

The variables x_1 and x_2 are independent variables where the response y depends on them. The dependent variable y is a function of x_1, x_2 and the experimental error term denote as ϵ. The error term ϵ represents any measurement error on the response, as well as other type of variations not counted in f .

For the present work, RSM has been applied for developing the mathematical models in the form of multiple regression equations for the quality characteristic of machined parts produced by WEDM process. In applying the response surface methodology, the dependent variable is viewed as a surface to which a mathematical model is fitted. For the development of regression equations related to various quality characteristics of WEDM process, the second order response surface has been assumed as:

$$Y = \beta_o + \sum_{i=1}^{k} \beta_i x_i + \sum_{i=1}^{k} \beta_{ii} x_i^2 + \sum_{i<j} \beta_{ij} x_i x_j \pm \epsilon \quad (1)$$

Where, Y is the desired response and the x_i (1, 2, k) are the independent of k quantitative process variables. $\beta_o$is constant and β_i, β_{ii} and β_{ij} are the coefficient of the linear, quadratic and cross product term. is the experiment error.

"Table 1. Important process parameters and their levels"

Factors	Levels		
	-1	**0**	**1**
T_{on} (μsec)	110	115	120
T_{off} (μsec)	45	50	55
WF (mm/min)	2	4	6

In this work, Central Composite design was used which fit the second order response surface very accurately. Central Composite design provides relatively high quality predictions over the entire design space and do not require using points outside the original factor range. The upper limit of a factor was coded as +1, and the lower limit was coded as -1. The chosen levels of the selected process parameters with their units and notations are presented in Table 1.

"EXPERIMENTAL DETAIL"

"Electrode and Workpiece material"

In the present work brass wire of 0.25mm diameters used as Electrode and the workpiece used in the study was AISI D2 steel. The chemical compositions are shown in the Table 2

"Table 2 Chemical Composition of workpiece"

Element	Composition (%)
C	1.40 – 1.60
Mn	0.60
Si	0.60
Co	1.00
Cr	11.00 – 13.00
Mo	0.70 – 1.20
V	1.10

"Experimental Procedure"

The experimental work was conducted on Wire cut Electro Discharge Machine of type Electronica Ultracut S2. Deionizes water was used as the dielectric fluid. During experiment, the input parameters were pulse on time, pulse off time and wire feed. Square specimens of (5 mm x14 mm x 22mm) size are cut. The Performance Parameters Gap current and cutting rates were measure digitally on the display of machine. Table 3 shows the performance parameters and the design matrix based on the L9 Orthogonal Array.

"Table 3 Design matrix and Performance Parameters"

Run	**PROCESS PARAMETERS**			**PERFORMANCE PARAMETERS**	
	T_{on} (µsec)	**T_{off} (µsec)**	**WF (mm/min)**	**I_G (Amp)**	**CR (mm/min)**
1	1	1	1	1.40	0.76
2	-1	-1	1	1.50	0.98
3	0	-1	0	2.00	1.10
4	-1	0	-1	1.00	0.55
5	0	1	-1	1.30	0.80
6	0	0	1	1.70	1.25
7	1	-1	-1	2.80	1.86
8	1	0	0	2.00	1.22
9	-1	1	0	0.90	0.64

"Development of mathematical model"

Design Expert statistical software package was used for analysis of measured response and determining the mathematical models with best fit. The transformation of response that has been used to find the relation between Gap current and the process parameters is Inverse Square Root. On the other hand Square Root has been used as the transformation of the response to predict the effect of process parameters on Cutting Rate. The final mathematical models thus obtained are show in the equation 2 &3.

$$\frac{1}{\sqrt{Gap\ Current}} = +0.77 - 0.12 * Ton + 0.081 * Toff - 2.122E - 003 * WF - * Ton * Toff + 0.05 * Ton * Toff - 5.105E - 003 * Toff * WF + 0.056 * Ton2 + 0.019 * Toff^2$$

$$\sqrt{Cutting\ Rate} = +0.77 - 0.12 * Ton + 0.081 * Toff - 2.122E - 003 * WF - 0.011 * Ton * Toff + 0.05 * Ton * Toff - 5.105E - 003 * Toff * WF + 0.056 * Ton2 + 0.019 * Toff^2 \quad 3$$

"Checking Adequacy of model"

"Table 4 ANOVA analysis for the Gap Current (I_G)"

Source	**Sum of Squares**	**df**	**Mean Square**	**F Value**	**p-value Prob > F**
Model	0.17	6	0.028	20.29	0.0477
A	0.057	1	0.057	41.53	0.0232
B	0.029	1	0.029	21.43	0.0436
C	1.455E-003	1	1.455E-003	1.07	0.4103
AB	1.175E-003	1	1.175E-003	0.86	0.4515
AC	6.151E-005	1	6.151E-005	0.045	0.8515
BC	3.354E-003	1	3.354E-003	2.46	0.2575
Residual	2.729E-003	2	1.365E-003		
Cor Total	0.17	8			
Std. Dev.	0.037		R-Squared	0.9838	
Mean	0.82		Adj R-Square	0.9353	
C.V. %	4.51		Pred R-Squared	0.0024	
PRESS	0.17		Adeq Precision	13.354	

The adequacy of the models so developed was tested by using the analysis of variance technique (ANOVA). Using this technique, it was found that calculated F- ration were larger than the tabulated value at a 95% confidence level; hence, the models are considered to be adequate. The more criterion that are commonly used to illustrate the adequacy of a fitted regression models are the coefficient of determination (R^2). For the models developed, the calculated R^2 and adjusted R^2 values were above 80% and 70%, respectively. These values indicate that the regression models are quite adequate. The results of ANOVA are given in Table 4 and Table 5.

"Table 5 ANOVA analysis for the Cutting Rate"

Sum of Source	Mean Squares	df	F Square	P-value Value	Prob > F
Model	0.28	6	0.047	7.31	0.1253
A-	0.058	1	0.058	9.09	0.0947
B-	0.026	1	0.026	4.09	0.1804
C-	5.296E-003	1	5.296E-003	0.83	0.4591
AB	0.011	1	0.011	1.70	0.3224
AC	7.273E-003	1	7.273E-003	1.14	0.3982
BC	9.314E-004	1	9.314E-004	0.15	0.7396
Residual	0.013	2	6.404E-003		
Cor Total	0.29	8			
Std. Dev.		0.080	R-Squared	0.9564	
Mean	0.99		Adj R-Squared	0.8255	
C.V. %	8.06		Pred R-Squared	-1.7059	
PRESS	0.79		Adeq Precision	8.840	

"RESULT AND DISCUSSION"

"Effect of Process Parameters on Gap Current"

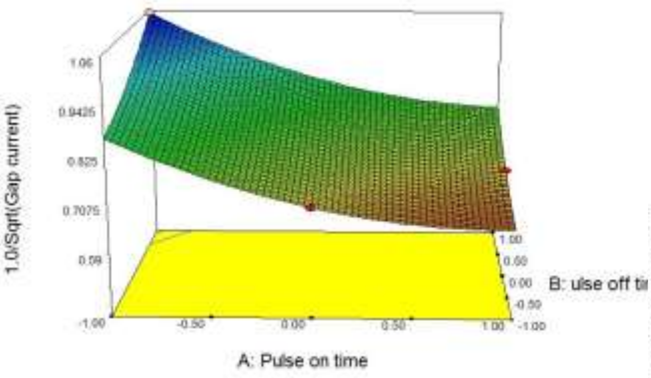

Fig 1 (a)

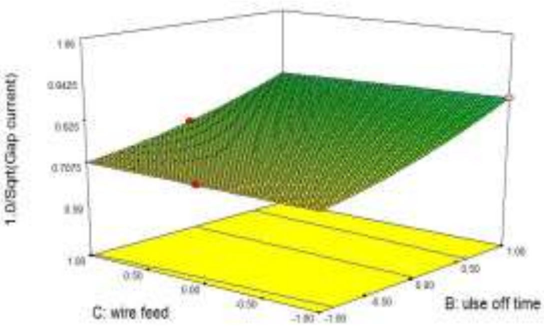

Fig 1 (b)

Fig.1 the response surface plot between Ton, Toff and WF on gap current (a, b)

Figs.1a, 1b (Response Surface plot) show the influence of the three different process parameters pulse on time, pulse off time and wire feed on the performance parameter Gap Current. The figures below demonstrate that with the increase in pulse on time the gap current decreases and with the increase in pulse off time the gap current increase. With the increase of wire feed the gap current first increases.

"Effect of Process Parameters on Cutting Rate"

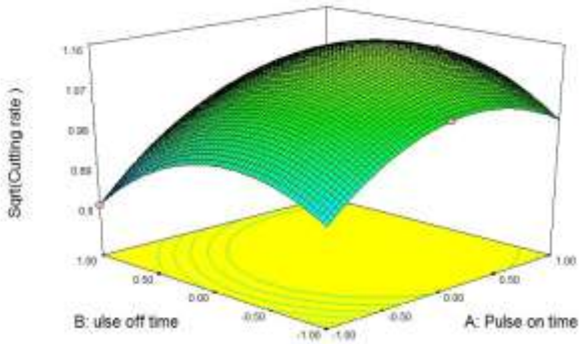

Fig 2 (a)

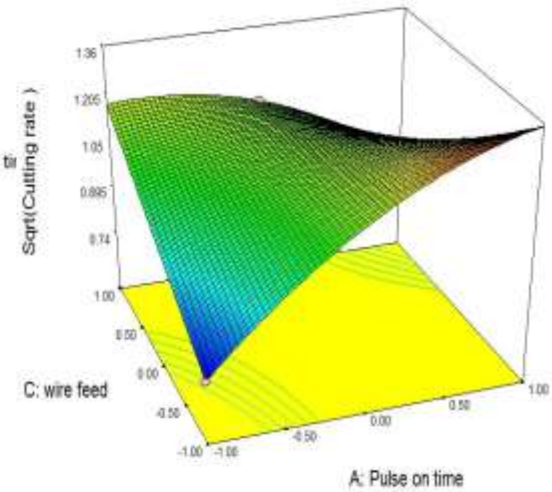

Fig 2 (b)

Fig.3 the response surface plot between Ton, Toff and Wire feed on cutting rate (a, b)

Fig.2a, 2b, (Response Surface plot) show the influence of the three different parameters pulse on time, pulse off time and wire feed. Thefigures below demonstrate that increase in pulse on time and wire feed results in increase of Cutting rate and the increase of pulse off time cutting rate first increase then decrease the cutting rate.

CONCLUSION

In this present work, regression equation of the polynomial type were calculated to predict the Gap current and Cutting rate obtained during Wire Electro Discharge Machining (WEDM). The predication is for a particular value of machining parameters within the range studied. The finding also establishes that the effect of pulse on time on gap current is higher then the effect of other parameters. While in case of Cutting rate the most influential factor was the intensity of pulse off time.

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