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Modeling & Analysis of performance characteristics of Wire EDM of SS304

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Abstract— ***Wire electrical discharge machining (WEDM) allowed success in the production of newer materials, especially for the aerospace and medical industries. Using WEDM technology, complicated cuts can be made through difficult-to-machine electrically conductive components. The high degree of the obtainable accuracy and the fine surface quality make WEDM valuable. WEDM is so complex in nature that the selection of appropriate input parameters is not possible by the trial-and-error method. The selection of machining parameters in any machining process significantly affects production rate, product quality and production cost of a finished component. WEDM process involves a large number of variables that affect its performance. However, based on the literature survey and the pilot experiments, five process variables, viz., pulse-on time, pulse-off time, wire tension, and water pressure are taken into consideration for the research. In the present work Response Surface Methodology (RSM) is used to develop the quantitative relationships between the input and the output responses for the experimental data collected as per the DOE. Also the effects of the input process parameters over the MRR and Ra were plotted and studied. Later the developed models can be utilized for optimization.***

Index Terms— ***WEDM, DOE, RSM, Optimization***.

I. INTRODUCTION

Wire electrical discharge machining (WEDM) has become an important non-traditional machining process, is mainly used to cut intricate shapes and designs into hard metals, which are otherwise difficult to form, mold or manipulate. It is most useful in the electronics and aerospace sectors for prototyping and manufacturing various parts. Most often, steel and titanium are processed with help of wire electrical-discharge machining. It is a thermo-electrical process in which material is removed by generating a series of discrete sparks between electrode and work piece immersed in a liquid dielectric medium. A thin electrically conductive wire is used as the electrode. Normally, the wire is held by a pin guide at the upper and lower parts of the work piece as shown in fig 1. In most cases, the wire will be discarded once used. The major advantage of EDM is that this machining process enables us to obtain components with desired shape and closer Typical materials, used as EDM electrodes, include copper, graphite, tungsten, brass, steel, copper–tungsten, copper– chromium alloy, haste alloy etc. WEDM finds extensive applications in various fields like aerospace, automobile, electronics industries. Electrical discharge machining (EDM) actually is a process of utilizing the removal phenomenon of electrical-discharge in dielectric. Therefore, the electrode plays an important role, which affects the material removal rate and the tool wear rate.

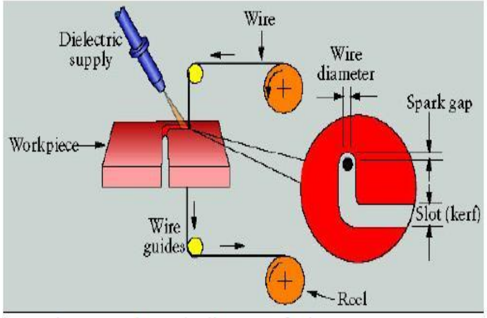

Fig.1. WEDM process

The selection of machining parameters in a machining process significantly affects production rate and quality of machined components. The selection of these parameters in WEDM is primarily dependent on the operator's experience and machining parameter tables provided by the machine-tool manufacturers. However, such criterion does guarantee neither high production rate nor good surface quality. Hence there is a need to develop a methodology to find the optimal process parameters. The present work deals with conducting the experiments as per the design of experiments, then using the experimental data modeling is done by using RSM. By using RSM empirical models were developed. Then the models were tested for its adequacy using ANNOVA. Later these predicted models can be used for subsequent optimization. Also the effects of the output responses with respect to the various process parameters were plotted and studied.

II. EXPERIMENTAL DETAILS

The machining experiments were performed on a five-axis CNC-Wire Electrical Discharge Machine, Ultima1F available with Sri Venkateswara Tools Pvt. Ltd, Hyderabad. WEDM involves several machining parameters such as pulse-on time, pulse-off time, peak current, wire feed rate, servo reference voltage, wire tension, and dielectric flow rate. However based on the trial experiments the variables such as pulse-on time (X1), pulse-off time (X2), wire tension (X3), and dielectric flow rate (X4) were considered as the input (control) parameters.

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The machining conditions at which the experiments were conducted are (i) Wire: brass wire of diameter 0.25 mm, (ii) Work piece material: Stainless Steel 304 160 mm L× 75mm B×16 mm H, (iii) Length of cut: 12.5 mm, (iv) Angle of cut: vertical, (v) Servo reference voltage: 35 V, (vi) Dielectric temperature: 25°C, (vii) Dielectric fluid: distilled water & Wire Feed = 2. The actual and coded values for each control factor are given in Table 1.

Table 1. Control factors and their levels

S. No.	Control Factors	Symbol	Levels					Units
			-2	-1	0	1	2	
1	Pulse-on time (ON)	x_1	113	114	115	116	117	µs
2	Pulse-off time (OFF)	x_2	51	54	57	60	63	µs
3	Wire tension (WT)	x_3	1	3	5	7	9	Gm
4	Water pressure (WP)	x_4	6	8	10	12	14	kg/cm^2

Table 2. Experimental Observations

S.NO	ON	OFF	WT	WP	MRR	R_a
1	114	54	3	8	0.0101636	2.36
2	116	54	3	8	0.0123805	2.66
3	114	60	3	8	0.0081443	1.58
4	116	60	3	8	0.0098336	2.64
5	114	54	7	8	0.0111759	2.5
6	116	54	7	8	0.0117787	2.49
7	114	60	7	8	0.0082276	1.42
8	116	60	7	8	0.0096729	2.66
9	114	54	3	12	0.0104369	2.25
10	116	54	3	12	0.0120506	2.66
11	114	60	3	12	0.0078346	1.68
12	116	60	3	12	0.0091989	2.65
13	114	54	7	12	0.0100977	2.36
14	116	54	7	12	0.0125683	2.98
15	114	60	7	12	0.0078758	2.05
16	116	60	7	12	0.009495	2.54
17	113	57	5	10	0.0083423	1.56
18	117	57	5	10	0.0118547	3
19	115	51	5	10	0.0140657	2.64
20	115	63	5	10	0.0084022	2.27
21	115	57	1	10	0.0102226	2.42
22	115	57	9	10	0.0104722	2.4
23	115	57	5	6	0.0105349	2.54
24	115	57	5	14	0.0099679	2.42
25	115	57	5	10	0.0100163	2.47
26	115	57	5	10	0.0096956	2.36
27	115	57	5	10	0.0097029	2.25
28	115	57	5	10	0.0098416	2.41
29	115	57	5	10	0.009849	2.39
30	115	57	5	10	0.0098729	2.48
31	115	57	5	10	0.0099043	2.42

The selected design is a five-level, four factor central composite rotatable factorial design (CCD) consisting of 31 sets of coded conditions. Metal removal rate (MRR) and surface roughness (Ra) are considered as the output responses. MRR was calculated as the ratio of volume of material removed from work piece to the machining time. Ra was measured in perpendicular to the cutting direction using TALYSURF surface roughness tester. An average of three measurements taken at three different places was recorded as the response value and are shown in Table 2.

III. DEVELOPMENT OF EMPIRICAL MODELS

In the present study, mathematical relationships between the control variables and the output responses were developed using the RSM. The following equations were obtained for Ra and MRR:

$$Ra = 2.37 + 0.66X_1 - 0.32X_2 + 0.040X_3 + 0.052X_4 + 0.61X_1X_2 - 0.1X_1X_3 - 0.025X_1X_4 - 0.07X_2 + 0.07X_2X_3 + 0.095X_2X_4 + 0.22X_3X_4$$

$$MRR = 9.840 * 10^{-3} + 1.671 * 10^{-3}X_1 - 2.641 * 10^{-3}X_2 + 1.123 \times 10^{-4}X_3 - 2.461 * 10^{-4}X_4 - 1.965 * 10^{-4}X_1X_2 - 1.866 * 10^{-4}X_1X_3 + 2.784 * 10^{-4}X_1X_4 - 8.228 * 10^{-4}X_2X_3 - 2.822 * 10^{-4}X_2X_4 + 4.567 * 10^{-5}X_3X_4 - 2.479 * 10^{-5}X_1^2 + 1.111 * 10^{-3}X_2^2 + 2.241 * 10^{-4}X_3^2 + 1.281 * 10^{-4}X_4^2$$

The need in developing the relationships is to relate the machining responses to the cutting parameters thereby facilitating the optimization of the machining process. Design Expert statistical analysis software, is used to compute the regression coefficients of the proposed models. Because of the lower predictability of the first-order model for the present problem, the second-order models are postulated. The analysis of variance (ANOVA) was used to check the adequacy of the developed models. Table 3 shows the ANOVA for the Ra.

Table 3 Analysis of variance for Ra

Sourse	Sum of Squares	df	Mean Square	F value	p-value Prob>F
Model	3.70	10	0.37	15.98	<0.0001
X_1	2.64	1	2.64	113.93	<0.0001
X_2	0.60	1	0.60	25.69	<0.0001
X_3	9.600E-003	1	9.600E-003	0.41	0.5271
X_4	0.016	1	0.016	0.69	0.4156
$X_1 X_2$	0.37	1	0.37	16.06	0.0007
$X_1 X_3$	0.010	1	0.010	0.43	0.5187
$X_1 X_4$	6.250E-004	1	6.250E-004	0.027	0.8712
$X_2 X_3$	4.900E-003	1	4.900E-003	0.21	0.6506
$X_2 X_4$	9.025E-003	1	9.025E-003	0.39	0.5396
$X_3 X_4$	0.046	1	0.046	1.99	0.1732
Residual	0.46	20	0.023		
Lack of Fit	0.43	14	0.031	5.10	0.0275
Pure Error	0.036	6	5.990E-003		
Cor Total	4.17	30			

Std. Dev.	0.15	R-Squared	0.8888
Mean	2.37	Adj R-Squared	0.8332

The P value for the model lower than 0.05 (i.e. at 95% confidence level) indicates that the model is considered to be statistically significant. Similar analysis is carried out for the MRR and is given in Table 4.

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Table 4. Analysis of variance for MRR

Sourse	Sum of Squares	df	Mean Square	F value	p-value Prob>F
Model	6.155E-005	14	4.397E-006	32.65	<0.0001
X_1	1.674E-005	1	1.674E-005	124.35	<0.0001
X_2	4.186E-005	1	4.186E-005	310.87	<0.0001
X_3	7.572E-008	1	7.572E-008	0.56	0.4642
X_4	3.634E-007	1	3.634E-007	2.70	0.1199
$X_1 X_2$	3.860E-008	1	3.860E-008	0.29	0.5997
$X_1 X_3$	3.481E-008	1	3.481E-008	0.26	0.6181
$X_1 X_4$	7.749E-008	1	7.749E-008	0.58	0.4591
$X_2 X_3$	6.769E-009	1	6.769E-009	0.050	0.8250
$X_2 X_4$	7.965E-008	1	7.965E-008	0.59	0.4530
$X_3 X_4$	2.086E-009	1	2.086E-009	0.015	0.9025
X_1^2	1.099E-009	1	1.099E-009	8E-003	0.9292
X_2^2	2.205E-006	1	2.205E-006	16.37	0.0009
X_3^2	8.976E-008	1	8.976E-008	0.67	0.4262
X_4^2	2.933E-008	1	2.933E-008	0.22	0.6470
Residual	2.155E-006	16	1.347E-007		
Lack of Fit	2.079E-006	10	2.079E-007	16.40	0.0014
Pure Error	7.603E-008	6	1.267E-008		
Cor Total	6.371E-005	30			

Std. Dev.	3.670E-004	R-Squared	0.9662
Mean	0.010	Adj R-Squared	0.9366

The normal probability plots of the residuals for the output responses are shown in Figs. 2 and 3. A check on these plots reveals that the residuals are located on a straight line, which means that the errors are distributed normally and the regression models are fairly well fitted with the observed values.

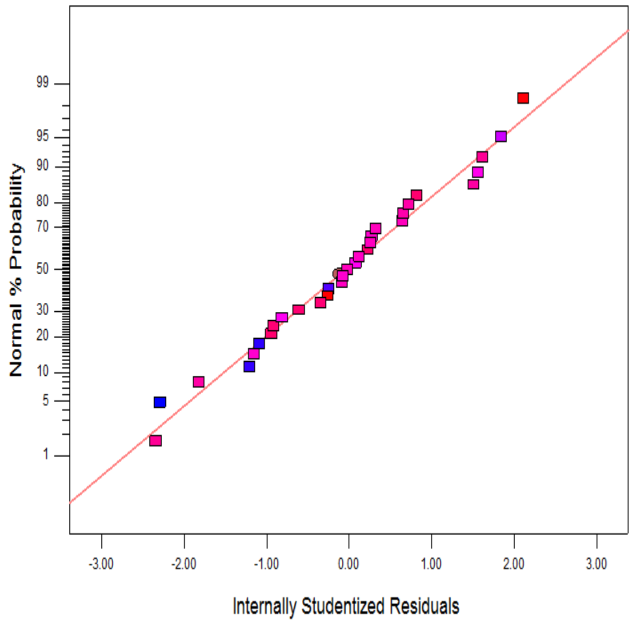

Fig. 2 Normal probability plot of residuals for surface roughness(Ra)

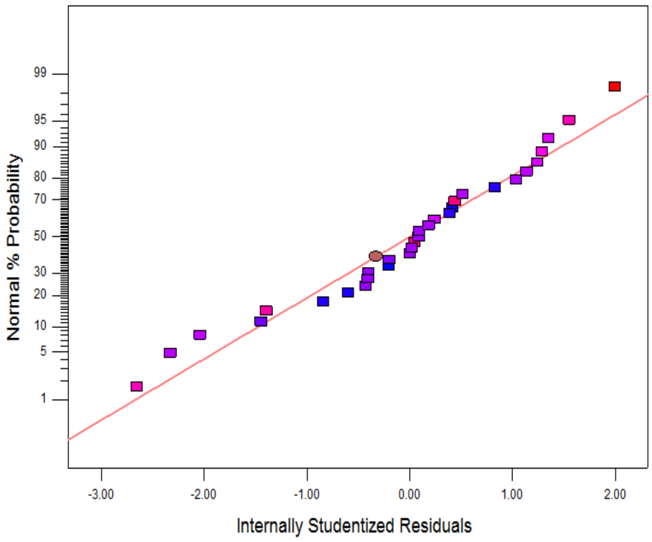

Fig. 3 Normal probability plot of residuals for Material Removal Rate(MRR)

To check whether the fitted models actually describe the experimental data, the multiple regression coefficients (R^2) were computed. The multiple regression coefficients (R^2) for Ra and MRR were found to be 0.888 and 0.966, respectively. This shows that the second-order model can explain the variation in the Ra and the MRR up to the extent of 89% and 97%, respectively. On the basis of the high values of the multiple regression coefficients, it can be said that the second-order models are adequate in representing the process.

IV. CONCLUSION

The selection of right combination of input parameters in WEDM is difficult as the process involves a large number of control variables. The effects of input parameters pulse-on time, pulse-off time, wire tension and water pressure on surface roughness, metal removal rate while machining the stainless steel 304 material were analyzed with the experimental data obtained after conducting the experiments as per the Design of Experiments. Later RSM is used to find the Empirical models. Then the models were tested for its adequacy using ANNOVA. The multiple regression coefficients (R^2) for Ra and MRR were found to be 0.888 and 0.966, respectively. This shows that the second-order model can explain the variation in the Ra and the MRR up to the extent of 89% and 97%, respectively. Later these predicted models can be used for subsequent optimization.

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