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Optimization of Machining Parameters in Rough Cut WEDM Operation of EN 18 Die Tool Steel using Response Surface Methodology

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Abstract: **In the present paper, experimental study has been made to optimize the process parameters during machining of EN 18 die tool steel by wire electrical discharge machining (WEDM).The experiments were designed out using response surface methodology (RSM) on Elektra Sprintcut 734 WEDM machine. The input process parameters of WEDM namely Peak Current (I), Pulse-On time (Ton), Pulse-Off time (Toff) and Servo Voltage (SV) were chosen as variables to study the process performance in terms of Surface Roughness (SR). The analysis of variance (ANOVA) was carried out to study the effect of process parameters on machining performance. The results of the experimentation were analyzed by Designexpert 9 software analytically as well as graphically. Surface characteristic optimization model have been developed using desirability function.**

Keywords: **WEDM, Responsesurfacemethodology, Surface Roughness, Plain brass wire, Zinc Coated wire, Single Response optimization**

1. INTRODUCTION

Wire electrical discharge machining (WEDM) is a widely accepted non-traditional material removal process used to manufacture components with intricate shapes and profiles[1]. It is considered as a unique adaptation of the conventional EDM process, which uses an electrode to initialize the sparking process. However, WEDM in fig.1 utilizes a continuously traveling wire electrode made of thincopper, brass or tungsten of diameter 0.05-0.3 mm [2] which is capable of producing very small corner radii. The wire is kept in tension using a mechanical tensioning device reducing the tendency of producing inaccurate parts. During the WEDM process, the material is eroded ahead of the wire and there is no direct contact between the work piece and the wire, eliminating the mechanical stresses during machining. In addition, the WEDM process is able to machine High strength and temperature resistive (HSTR) materials and eliminate the geometrical changes occurring in the machining of heat-treated steels.

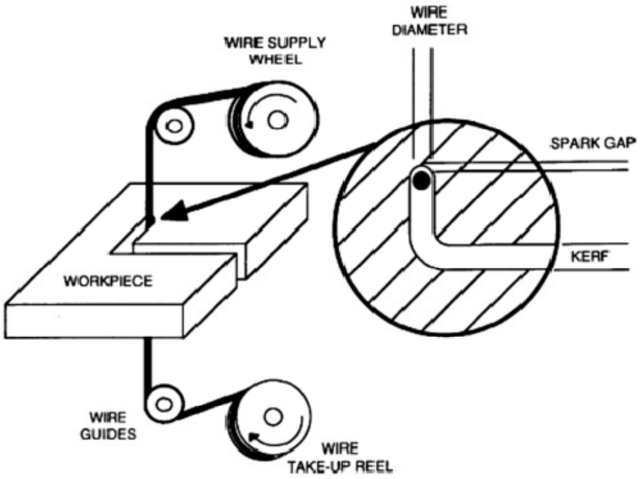

Fig. 1. Wire Electric Discharge Machining

To investigate the literature gap or the problem formulation, it is necessary to go through the various research works.Bhatti and Hashmi [3] machined the internal and externalsurfaces of components on wire cut electric discharge machine.Their research describes briefly the design and interfaceof manipulator to solve the problems during research work.The work of Rajurkar and Wang [4] is concerned on thedetection of thermal load for online control to prevent wirebreakage with the help of WEDM sparking frequency monitor.Mishra, Prashad, and Banerjee [5] found that frequentoccurrence of wire rupture is one of the most serious productionconstraints in electrical discharge machining (EDM) wirecutting as after the wire break, machine tool required a lot oftime for its setting.Saha et al. [6] analyzed the wire electrical dischargemachining of tungsten–carbide–cobalt composite.

Asecond-order multivariable regression model and a feedforwardbackpropagation neural network model have beendeveloped to correlate the input process parameters, such aspulse-on time, pulse-off time, peak current, and capacitancewith the process performance namely cutting speed andsurface roughness. It was observed that neural networkarchitecture provide the best prediction result although theproposed regression model was adequate and accepted. Leeet al. [7] found that WEDM assisted by ultrasonic vibrationof the wire has better results than that of wire cut alone. Forobtaining a higher cutting rate and better surface finishsimultaneously, a high frequency of wire electrode has beenestablished. The simulation of the dynamic characteristics ofthe wire electrode under the action of continuous dischargeforces show that ultrasonic vibration facilitates the shift ofthe discharge points and improves their distribution.

A set ofstatistical experiments has been designed to analyze theutilization of the pulse. It is investigated that with ultrasonicvibration, there is a greater utilization of energy, which is acritical factor in securing an increase in the cutting rate. Lokand Lee [8] worked on two advanced ceramics viz. sailonand Al203–Tic using wire-cut EDM which is evolving asone of the promising methods for processing advancedceramics.In WEDM, material is eroded from the work piece by a series of discrete sparks occurring between the work piece and the wire separated by a stream of dielectric fluid, which is continuously fed to the machining zone. The present application of WEDM process includes automotive, aerospace, moulds, tool and die making industries. WEDM applications can also be found in the medical, optical, dental, jewelry industries, and in the automotive and aerospace R & D areas..

2. EXPERIMENTATION

In this research work, Surface roughness is the response characteristic that has been investigated. The response characteristic, investigated under the varying conditions of input process parameters namely Ton, Toff, servo gap voltage (SV) and peak current (IP). The experiments were performed on Electronica make ELEKTRA Sprintcut 734 CNC Wire cut machine. Plain brass wire of 0.25 mm diameter was used as the tool material. The surface roughness of machined surface was measured in micrometer (µm). The measurements were taken three times using the Mitutoyo's SURFTEST (SJ-301). The average of the measurements was taken for the analysis of results. Deionized water used as the dielectric, which flush away the metal particle from the workpiece. The workpiece shape is 5×5×23 mm of EN 18 Die tool steel. The composition of EN 18 Die tool steel is shown in Table 1.

2.1Experimental planning

RSM is a compilation of mathematical and statistical techniques useful for the modeling and analysis of problems in which output factors are influenced by several input parameters and the main aim is to optimize this output parameters [9]. The procedure for RSM is as follows:

1. Preliminary experiments are performed.
2. Design the input parameters according to preliminary experiments and output quality characteristics according to requirement.
3. Then, select the experimental design.
4. Regression analysis is to be carried out.
5. Analysis of variance is to be found out.
6. If the model is significant
7. Optimal settings are to be found.

Experimentation for the best is an old-age practice. Perform the experiment; repeat it for five to ten times for better results. But in non-conventional machining, a lot of parameters are there. So the number of experiments becomes so large, that it is difficult to interpret. There is a need of design of experiment, so that the total number of experiments becomes less. Polynomial response surface in RSM has great advantages; it has a few disadvantages also. One such disadvantage is that the polynomials are untrustworthy when extrapolated beyond the experimental region.Another important disadvantage of using second-order polynomial in RSM is that the size of experiments becomes too large and analysis becomes too complicated with more than three X variables or with more than three levels. However, a well designed experimental plan can substantially reduce the total number of experiments.

TABLE 1: Composition of EN 18 Die tool steel

Constituent	C	Si	Mn	Cr	Mo	Ni	Cu	Al	S	P	Fe
% COMPOSITION	0.428	0.227	0.734	1.07	0.022	0.112	0.446	0.032	0.0198	0.027	96.86

Central composite designs are one of those means. Proceeding a step ahead, central composite rotatable designs of second order have been found to be the most efficient tool in RSM to establish the mathematical relation of the response surface using the smallest possible number of experiments without losing its accuracy [10]. The output response (y) can be modeled as follows.

$$y = \beta_0 + \sum_{i=1}^{k} \beta_i x_i + \sum_{i=1}^{k} \beta_{ii} x_i^2 + \sum_{i<j} \beta_{ij} x_i x_j + \varepsilon$$

Where

x_i, x_j, and x_k are input or independent process parameters.

β_o, β_{ii}, and β_{ij} are unknown parameters or regression coefficients.

Ɛ is random error

Table 2 Different levels of Process parameters with coded form and units

Process parameters	Coded factors	Units	Range
Pulse on time (T_{on})	Aμs	115 -	125
Pulse off time (T_{off})	B	μs	30 - 60
Peak current (IP)	C	A	120 - 220
Spark gap voltage (SV)	D V	20 - 60	

The main limitation of WEDM is the loss in productivity due to wire breakage. If the preliminary experiments before the actual experimentation are done carefully, then a range of process parameters obtained, where breakage of wire did not take place. In the present research work, the following four process parameters, i.e., Ton, Toff, SV and IP are chosen as input variables (x_i). There are other process parameters which effect less significantly on the measures of response quality characteristics; these are kept constant and called WEDM machining conditions. Table 2 shows the different process parameters, their coded symbols, and their range. Table 3 shows WEDM machining conditions. According to central composite rotatable design, with four process parameters, a total of 30 experiments need to be performed as illustrated in Table 4. Each time the experiment was performed, a particular set of process parameter was chosen.

Table 3 WEDM machining conditions

Work piece material	EN 18 Die tool steel
Tool material	Brass wireϕ 0.25 mm
Shape and size of work piece	Square, 5 mm× 5 mm×23 mm
Dielectric conductivity	15–20 mho
Servo feed	2, 050 machine units
Dielectric pressure	7 Kg/cm^2
Dielectric temperature	24 °C
Wire feed	8 machine units

3. RESULTS AND DISCUSSION

There are 30 experiments in total carried out according to the design of experiments. The average values of SR is shown in Table 4. For analysis of data, checking the goodness of fit of model is required. The model adequacy checking includes test for significance of regression model, test for significance on model coefficients, and lack of fit test [11]. For this purpose, ANOVA is performed.

3.1 Analysis of surface roughness.

According to the fit summary obtained from analysis, it is found that 2F1 model is statistically significant for SR. The results of the 2F1 model for SR in the form of ANOVA are presented in Table 5. If the F value is more corresponding, p value must be less corresponding resulting in a more significant corresponding coefficient. Nonsignificant terms are removed by backward elimination for the fitting of SR in the model. Alpha out value is taken at 0.05(i.e., 95 % confidence level). A model is said to be hierarchical if the presence of higher-order terms (such as interaction and second-order terms) requires the inclusion of all lower-order terms contained within those of higher order.

TABLE 4: Design of experiments and results

			Process	**Parameters**		**Response**
Standard no.	**Run no.**	**A:Ton**	**B:Toff**	**C:Current**	**D:SV**	**SR**
25	1	120	45	170	40	3.00
11	2	117	52	140	50	2.189
27	3	120	45	220	40	3.35
13	4	117	37	190	50	3.651
5	5	117	37	190	30	3.355

16	6	122	52	190	50	2.385
24	7	120	45	170	60	2.48
9	8	117	37	140	50	2.845
17	9	115	45	170	40	2.368
15	10	117	52	190	50	2.258
6	11	122	37	190	30	4.354
12	12	112	52	140	50	2.104
10	13	122	37	140	50	3.392
28	14	120	45	170	40	3.044
26	15	120	45	170	60	2.48
14	16	122	37	190	50	3.482
8	17	122	52	190	30	2.837
21	18	120	45	120	40	2.836
29	19	120	45	170	40	3.064
4	20	122	52	140	30	2.581
7	21	117	52	190	30	2.372
22	22	120	45	220	40	3.388
18	23	125	45	170	40	3.586
3	24	117	52	140	30	2.254
19	25	120	40	170	40	3.684
2	26	122	42	140	30	4.134
30	27	120	45	170	60	3.005
20	28	120	60	170	40	1.922
1	29	117	37	140	30	3.216
23	30	120	45	170	20	3.362

It is found from Table 5.The Model F-value of 27.85 implies the model is significant. There is only a 0.01% chance that an F-value this large could occur due to noise. Values of"Prob > F" less than 0.0500 indicate model terms are significant. In this case A, B, C, D, AB, AD are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve the model. The "Lack of Fit F-value" of 0.99 implies the Lack of Fit is not significant relative to the pure error [12]. There is a 55.47% chance that a "Lack of Fit F-value" this large could occur due to noise. Non-significant lack of fit is good -- we want the model to fit.From Table 5, The "Pred R-Squared" of 0.7908 is in reasonable agreement with the "Adj R-Squared" of 0.9025; i.e. the difference is less than 0.2. "Adeq Precision" measures the signal to noise ratio. A ratio greater than 4 is desirable. The ratio of 22.674 indicates an adequate signal. This model can be used to navigate the design space.

TABLE 5: ANOVA for Response Surface 2FI model Plain brass wire

Analysis of variance table [Partial sum of squares]						
	Sum of		Mean	F	p-value	
Source	Squares	df	Square	Value	Prob > F	
Model	10.28	10	1.03	27.85	< 0.0001	significant

A-Ton	1.5	1	1.5	40.53	< 0.0001	significant
B-Toff	6.41	1	6.41	173.51	< 0.0001	significant
C-Current	0.29	1	0.29	7.92	0.0111	significant
D-SV	1.18	1	1.18	32.01	< 0.0001	significant
AB	0.19	1	0.19	5.26	0.0334	significant
AC	0.025	1	0.025	0.66	0.4249	
AD	0.54	1	0.54	14.7	0.0011	significant
BC	1.94E-03	1	1.94E-03	0.052	0.8212	
BD	0.051	1	0.051	1.38	0.2547	
CD	0.055	1	0.055	1.48	0.2387	
Residual	0.7	19	0.037			
Lack of Fit	0.51	14	0.037	0.99	0.5547	not significant
Pure Error	0.19	5	0.037			
Cor Total	10.98	29				

Figure 2 shows the normal probability plot of residuals for SR. Most of the residuals are found around the straight line, which means that errors are normally distributed. By applying multiple regression analysis on the experimental data, the empirical relation in terms of actual factors is obtained as follows:

Final equation for SR in terms of actual factors:

$$\text{SR} = +78.9002 + 0.737307 * \text{Ton} + 0.600055 * \text{Toff} + 0.0666159 * \text{Current} + 0.729248 * \text{SV} - 0.00587343 * \text{Ton} * \text{Toff} - 0.000579134 * \text{Ton} * \text{Current} - 0.00691615 * \text{Ton} * \text{SV} - 0.0000663593 * \text{Toff} * \text{Current} + 0.000817252 * \text{Toff} * \text{SV} + 0.000255964 * \text{Current} * \text{SV} \quad (1)$$

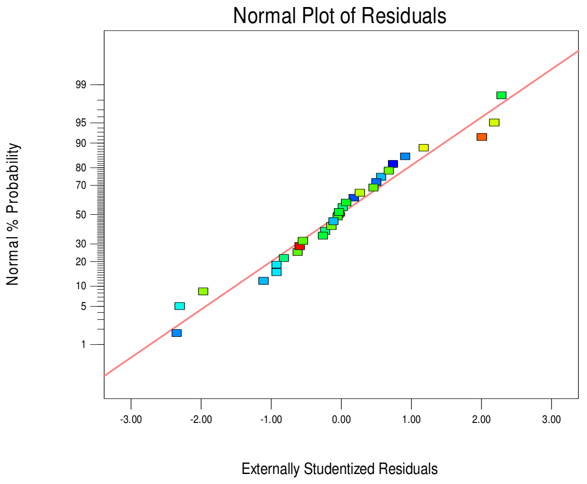

Fig. 2. Normal probability plot of residuals for SR (plain brass)

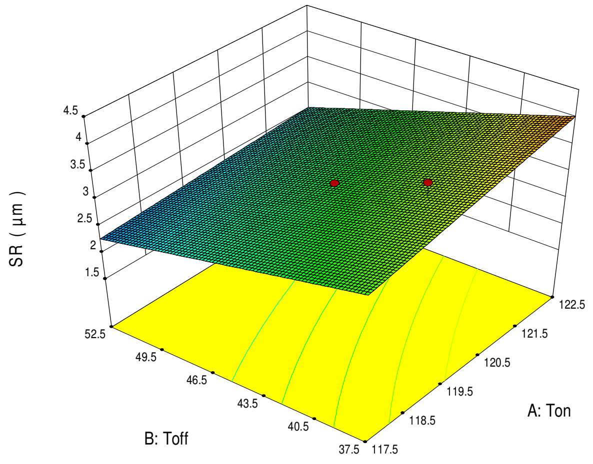

Fig. 3. Interaction effect of T_{on} andT_{off}

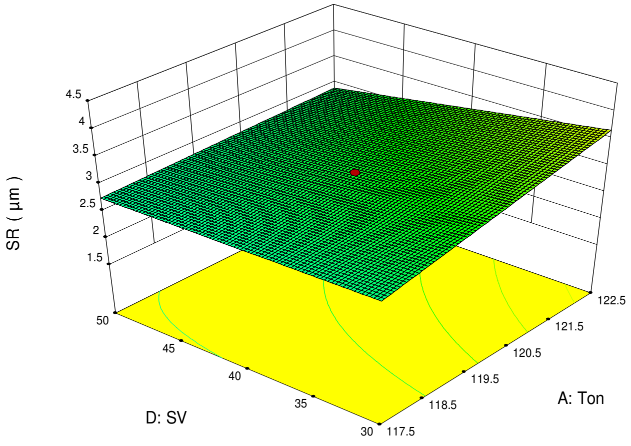

Fig. 4. Interaction effect of T_{on} and SV