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Parametric Optimization of Surface Roughness in Wire Electric Discharge Machining (WEDM) using Taguchi Method

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Abstract: Wire electrical discharge machining (WEDM) is widely used in machining of conductive materials when precision is of primary significance. Wire-cut electric discharge machining of AISI D3 tool steel has been considered in the present work. Experimentation has been completed by using Taguchi's L9orthogonal array with different levels of input parameters. Optimal combination of parameters was obtained by this technique. The Taguchi technique was used for design of experiment so that with minimum number of experiments, the complete problem can be solved as compared to full factorial design. Experimental results make obvious that the machining model is proper and the Taguchi's method satisfies the practical requirements. The results obtained are analyzed for the selection of an optimal combination of WEDM parameters for proper machining of AISI D3 tool steel to achieve better surface finish. Different analysis was made on the data obtained from the experiments.

Keywords: ANOVA, D3 tool steel, Design of experiments, Surface roughness, Taguchi method, Wire electrical discharge machining (WEDM).

1. INTRODUCTION

WEDM process is one of the most widely used non-traditional machining processes in current manufacturing (Fig.1). It involves the removal of metal by discharging an electrical current from a pulsating DC power supply across a thin inter-electrode gap between the tool and the work piece. It is most commonly used for machining hard and difficult to machine materials with very close tolerances. Generally, WEDM is perceived to be an extremely actuate process and there are various reasons for this perception. Firstly, in WEDM, no direct contact takes place between the cutting tool (electrode) and the work piece; as a result, the adverse effects such as mechanical stresses, chatter, and vibration normally present in traditional machining are eliminated. Secondly, the wire used as a cutting tool has high mechanical properties and small diameter 0.076 to 0.30 mm that produces very fine, precise, clean cuts. Finally, in WEDM, the movements of the work piece during cutting are controlled by a highly accurate CNC system (with positioning accuracy up to ±0.5 μm)[1] as a result, the effects of positioning errors present in conventional machining are significantly diminished.

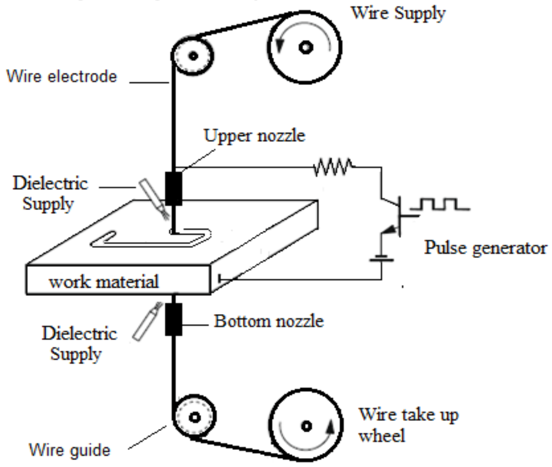

Fig 1: Schematic representation of WEDM process

II. WEDM PARAMETER OPTIMIZATION

Over the years researchers have used various approaches to improve the performance characteristics of wire electric discharge machining (WEDM) process. Lee and Li [2] presented a study on the surface integrity of tungsten carbide composite machined on sinking EDM. They reported that, the surface roughness is a function of two main parameters namely peak current and pulse duration. Tosun[3]studied cutting performance like pulse time, open circuit voltage, wire speed and dielectric fluid pressure in WEDM process. Brass wire with 0.25 mm diameter and AISI 4140 steel were used as tool and work materials in the experiments. The cutting performances considered in this study were surface roughness and cutting speed also the variation of cutting speed and surface roughness with cutting parameters is modeled by using a regression analysis method. Chiang and Chang [4] employed grey relational analysis to optimize the WEDM parameters for Al_2O_3 particle reinforced material with two performance characteristics namely material removal rate and surface roughness. Kanlayasiri and Boonmung

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[5]investigated machining of DC53 die steel by varying the process parameters to investigate their effects on surface roughness. Esme et.al [6] Presented factorial design and neural network (NN) techniques for modeling and predicting the surface roughness of AISI 4340 steel. Mathematical relation between the surface roughness and WEDM cutting parameters were established by regression analysis method. Kumar et. Al [7] demonstrated optimization of WEDM process parameters of Incoloy800 super alloy with multiple performance characteristics such as Material Removal Rate (MRR), surface roughness and Kerf based on the Grey-Taguchi Method. Pasam [8]experimentally studied WEDM of titanium alloy (Ti6Al4V).The behavior of input parameters on surface finish was studied using Taguchi parameter design. A mathematical model is developed by means of linear regression analysis to establish relationship between control parameters and surface finish as process response. Rao [9] Considered WEDM of Aluminum-24345 for their study. Experimentation has been done by using Taguchi's L18 orthogonal array under different conditions of parameters. The response of surface roughness is considered for improving the machining efficiency. Optimal combinations of parameters were obtained by this method also multiple linear regression model have been developed relating the process parameters and machining performance. Kumar et.al [10] reported an investigation on WEDM of pure titanium (grade-2). An attempt has been made to model the response variable i.e. surface roughness in WEDM process using response surface methodology. Kumar and Singh [11] studied WEDM of Skd 61alloy for present work. Experimentation has been completed by using Taguchi's L18 orthogonal array under different conditions of parameters. The results obtained are analyzed for the selection of an optimal combination of WEDM parameters for proper machining of Skd 61 alloy to achieve better surface finish. Dharmender et.al [12]studied the effect of different process parameters on the response variable-Surface roughness using Brass wire electrode (0.25 mm diameter) while machining of En31Tool Steel. Taguchi design methodology has been chosen for design of experiment and L 9 orthogonal array has been selected for present study. Rajyalakshmi and Ramaiah[13] carried out an experimental investigation on the influence of cutting parameters of WEDM during the machining of Inconel825. The response of surface roughness is considered for improving the machining efficiency. Yadav et.al [14] studied the effect of WEDM parameters on machining characteristics of AISI D3 steel. By referring experimental results they reported that there is decrease in surface roughness with increase in wire feed rate because of formation of small crater over machined surface and for a fixed value of pulse on time, gap voltage should be higher for better surface finish. Singh et.al [15] Performed experiments using two different wires, namely-cryogenically treated zinc coated diffused brass wire and plain brass wire as cutting tool. In this study AISI D3 die steel has been taken work piece and pulse width, time between two pulses, wire mechanical tension and wire feed rate as an input parameters.

III. EXPERIMENTAL WORK

In this study, Taguchi method is used for single characteristics optimization has been used to establish correlation between the independent variables therefore; the experiments were performed according to a Taguchi design of experiments.

3.1 Work material & cutting tool (Electrode)

The work material selected in this investigation was AISI D3 tool steel. The chemical composition of the D3 tool steel includes:

C	Si	Mn	Cr	Ni	W	V	Cu	P, S
2.25	0.60	0.60	12	0.30	1	1	0.25	0.03

A Commercially available D3 plate with 30 mm thickness was used to prepare 20× 20 mm square shaped specimens for performing WEDM experiments. A commercially available Molybdenum wire of diameter 0.18 is used as electrodes material.

3.2 Design of experiments

Experiments were designed using Taguchi method which uses an OA to study the entire parametric space with a limited number of experiments. In present research four process parameter (factors) chosen such as Pulse on Time, Pulse off Time, Peak Current and Wire Speed. All of them were set at three different levels. (See Table 1)

Table 1: Level values of input parameters

Sr. No.	Parameters	Unit	Level 1	Level 2	Level 3
1	Pulse on time (T_{on})	µs	3	6	9
2	Pulse off time (T_{off})	µs	2	4	6
3	Peak current (I_P)	Amp	1	2	3
4	Wire speed (Ws)	m/min	3	5	7

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Selection of a particular OA is based on the number of levels of various factors. Here, 4 parameters each at 3 levels, therefore Degree of Freedom (DOF) [16] can be calculated by using Eq.1 as

$$DOF = P \times (L - 1) \qquad (1)$$

Where, P = number of factors, L = number of level

$$DOF = 4 \times (3 - 1) = 8$$

Total DOF of OA should be greater than or equal to the total DOF required for the experiment. [17], here 9 > 8 hence *L9* (3^4) OA is selected (See Table 2). Each machining parameter is assigned to a column of OA and 9 machining parameter combinations are designed. The response variables chosen for the present investigation was Surface roughness (Ra). The “Smaller -is -better” quality characteristic has been used for calculating the signal to noise (S/N) ratio of surface roughness, See Eq. 2[18].

$$MSD_{LB} = \frac{1}{R}\sum_{J=1}^{R}\left(Y_J^2\right) \qquad (2)$$

Where y_j is the response value for i_{th} experiment

Table 2: L9 Design matrix

Expt. No	Parameter 1	Parameter 2	Parameter 3	Parameter 4
E 1	3	2	1	3
E 2	3	4	2	5
E 3	3	6	3	7
E 4	6	2	2	7
E 5	6	4	3	3
E 6	6	6	1	5
E 7	9	2	3	5
E 8	9	4	1	7
E 9	9	6	2	3

IV. EXPERIMENTATION

Experiments were conducted using an ELCTRONICA EL-CUT CNC WEDM as per *L9* OA combinations & each experiment were repeated three times for getting reliable database i.e.9×3 total 27 experiments conducted. Figure 2 shows the experimental setup for present study.

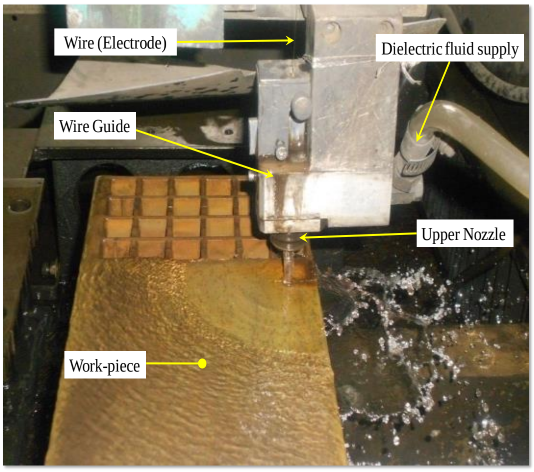

Fig.2: Experimental set-up

4.1 Experimental results and discussion

In order to see the effect of process parameters on the surface roughness (Ra) Value, experiments were conducted using *L9* OA (Table2).Performance characteristics chosen for present investigation was Surface roughness which value for all 27 specimens was measured using MITUTOYO made surf tester SJ-210(See Fig.3) and corresponding data is displayed in Table 3.The average values of surface roughness (Ra) for each parameter at levels 1, 2 and 3 for raw data and S/N data are displayed in Table 4 and same values plotted in Fig.4.

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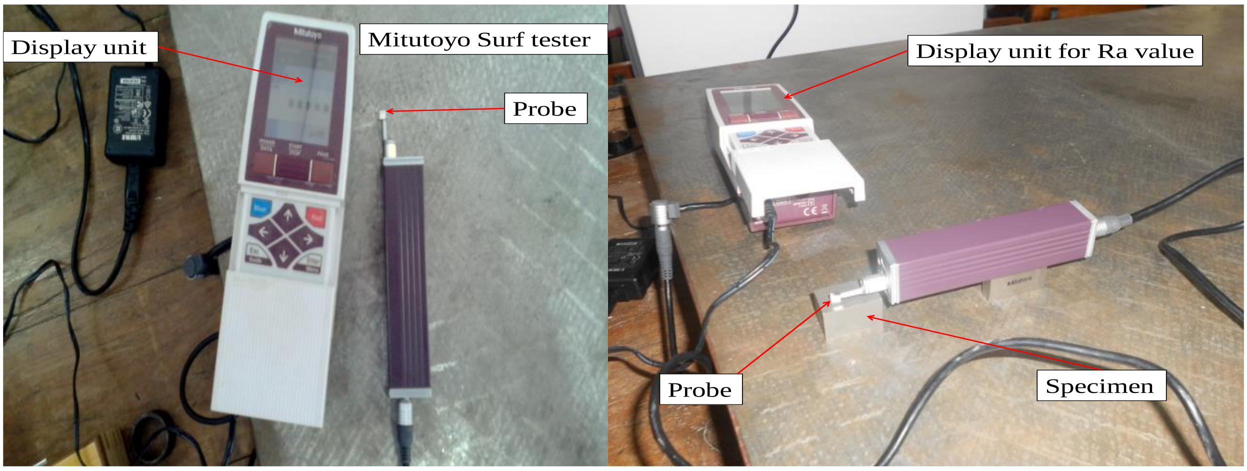

Fig 3: MITUTOYO roughness tester and measurement set-up

Table 3: Surface roughness (Ra) Value& S/N ratio against trial numbers

Expt. No.	Trial no's (Values of Surface roughness-Ra)			Average Ra	S/N Ratio (Smaller is better)
	1	2	3		
1	1.794	1.751	1.833	1.793	-5.06999
2	1.301	1.299	1.308	1.303	-2.29667
3	1.418	1.409	1.427	1.418	-3.03352
4	1.639	1.589	1.662	1.630	-4.24375
5	2.011	1.997	2.028	2.012	-6.07256
6	1.578	1.591	1.576	1.582	-3.9823
7	1.556	1.577	1.578	1.570	-3.91984
8	1.787	1.798	1.794	1.793	-5.07161
9	1.738	1.742	1.741	1.740	-4.81265

4.2 Effect of process parameters on surface roughness

Table 4: Response Table for Surface roughness

Level	Response for Mean Data				Response for S/N Data			
	Pulse on Time T_{on}	Pulse off Time T_{off}	peak current I_p	wire speed Ws	Pulse on Time T_{on}	Pulse off Time T_{off}	peak current I_p	wire speed Ws
1	1.504	1.664	1.722	1.848	-3.467	-4.411	-4.708	-5.318
2	1.741	1.703	1.558	1.485	-4.766	-4.480	-3.784	-3.400
3	1.701	1.580	1.667	1.614	-4.601	-3.943	-4.342	-4.116
Delta	0.237	0.123	1.165	0.363	1.299	0.537	0.924	1.919
Rank	2	4	3	1	2	4	3	1

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Fig. 4 shows that the Ra value increases with the increase of pulse on time from level 1 to level 2 and then it decreases, whereas it decreases with increment in pulse off time. Second levels of current and wire speed gives best Ra values.

4.3 Selection of optimal levels for MRR

In order to study the significance of the process variables towards Surface roughness value, analysis of variance (ANOVA) was performed. From Tables 5, it is clear that pulse on time, pulse off time, peak current and wire speed significantly affect both the Surface roughness. The response Table 4 show the average of each response characteristic (S/N data, means) for each level of each parameter. The ranks and the delta values show that wire speed have the greatest effect on Surface roughness and is followed by peak current, pulse on time and pulse off time in that order. As Surface roughness is the "Smaller is better" type quality characteristic, it can be seen from Fig.4that the first level of pulse on time (A1), second level of pulse off time (B2),second level of peak current(C2) and second level of wire speed (D2) provide minimum value of Surface roughness. The S/N data analysis also suggests the same levels of the variables (A1, B2, C2 and D2) as the best levels for minimize Surface roughness in WEDM process

Table 5: ANOVA for Ra value

Parameter	DOF	Seq. sum of square	Adj.sum of square	Adj. Mean square	% Contri (P)
Pulse on time	2	3.0032	3.0032	1.5016	28.72
Pulse off time	2	0.5130	0.5130	0.2565	4.90
peak current	2	1.2979	1.2979	0.6490	12.41
wire speed	2	5.6405	5.6405	2.8202	53.95
Total	8	10.4546			

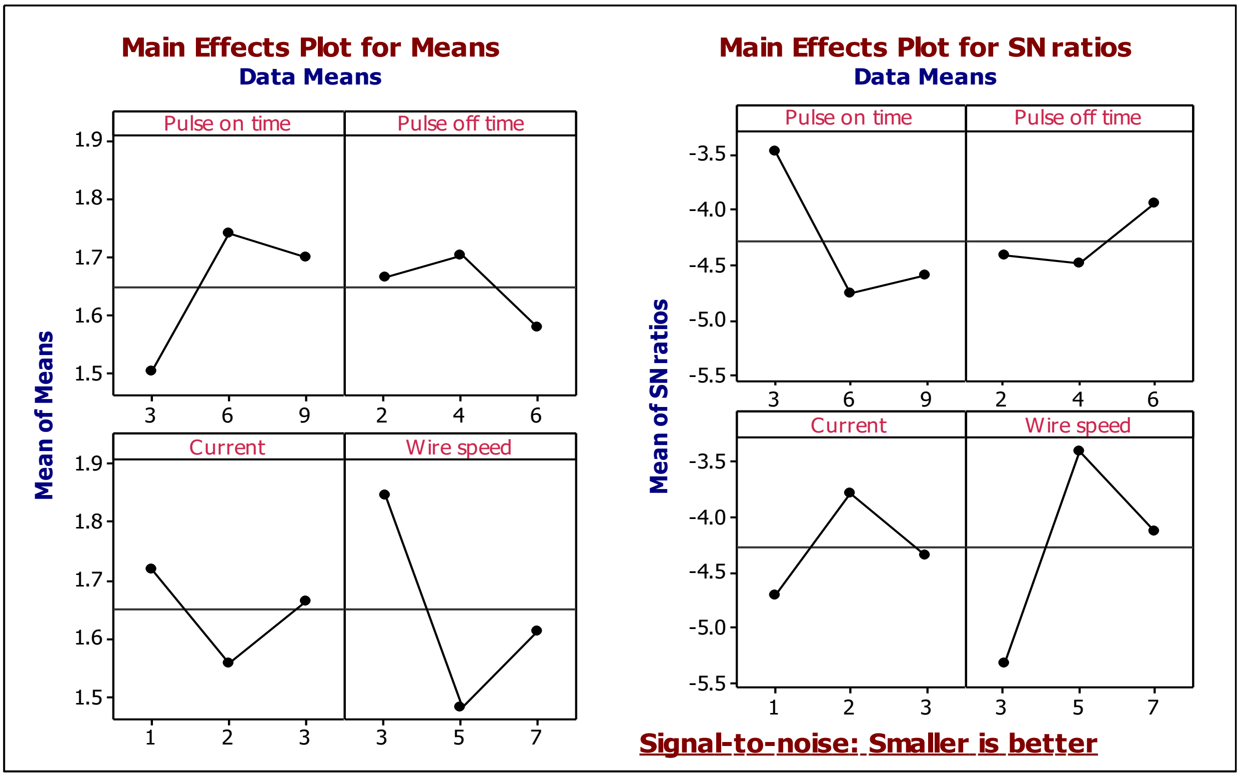

Fig.4: Effects of Process parameters on raw data and Ra (S/N Data)

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4.4 Empirical Modeling

With the help of data obtained through experimentation, regression analysis was carried out and following correlations was obtained for surface Roughness:

Ra = 1.88552 + 0.0327963 Pulse on time - 0.0210833 Pulse off time - 0.0278333 Current - 0.0586667 Wire speed.

V.CONCLUSIONS

Taguchi Design of experiments method was proposed to study the optimization of WEDM process parameters. Surface roughness (Ra) of the machined components was selected as quality targets. Twenty-seven experimental runs based on orthogonal arrays were performed. The conclusions based on the Taguchi method are summarized as follows:

- The recommended levels of WEDM parameters for surface roughness are pulse on time (A1) 3 µs, pulse off time (B2) 4 µs, peak current (C2) 2 A and wire speed (D2) is 5 m/min.
- Among the tested parameters, the Wire speed and pulse on time shows strongest correlation to surface roughness as compared to current and pulse on time.

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