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Investigations and Optimization on WEDM of O_2 Steel

K.N Arun Kumar and A.S.Rajan, R. Bharathikannan
Assistant Professor, Department of Automobile Engineering,
Nehru Institute of Technology, Coimbatore
Correspondent e-mail: athisayas@gmail.com

Abstract— Wire Electrical discharge Machining plays an important role in the field of strong conductive metal machining. It offers accuracy, precision, ability to achieve intricate profiles, complex shaped components of any hardness, unmanned machining, less noise and residual stress on work. WEDM is stochastic process and hence difficult to determine parameters for the improvement of cutting performance and optimization. The material and the machining hours are expensive, hence instead of rule of thumb or manufacturer's catalogue, DOE using Taguchi's robust design L16 orthogonal array with four important parameter at four levels each was applied on O_2 Tool steel. The optimum machining parameter combination was obtained by using the signal-to-noise ratio and the level of importance of the machining parameters on the material removal rate and surface roughness were determined from analysis of variance. Confirmation experiment was carried out. The results indicates high spark duration, low wire-electrode speed and gap voltage characteristics improves material removal by 29.5%,whereas, lower pulse duration, gap voltage and high wire-electrode speed, reduces the surface roughness by 11%. This result could be used for multi-pass rough cuts or fine finish cut.

Keywords— WEDM; ANOVA; MRR; S/Nratio; Surface roughness;O2 steel

I. Introduction

Guitrau [1] observed, as newer and more exotic materials are developed and more complex shapes are presented, conventional machining operations will continue to reach their limitations and the increased use of the WEDM in manufacturing will continue to grow, at an accelerated rate. Wire EDM provides the best alternative, or sometimes the only alternative, for machining conductive, exotic and HSTR (high strength and temperature resistive) materials. Past few decades, the average cutting, speed, relative machining costs, accuracy and surface finish have been improved many times. Engineers rely on machining operator, who follows the rule of thumb or the manufacturer's catalogue, without trying optimization techniques available to maximize their gains. The purpose of this research is to provide optimization solution for material removal rate and surface finish, to meet the increasing demand of precision and accuracy by the WEDM manufacturing industry. To improve MRR and roughness Chiang et al [2] used grey relational analysis for their study on aluminum oxide particle reinforced material with multiple performance characteristics. Ho et al [3] reviewed the WEDM research involving the optimization of the process parameters surveying the influence of the various factors affecting the machining performance and productivity. Liao et al [4] carried out study on the machining parameters optimization of WEDM in SKD 11 alloy steel. Mahapatra et al. [5] optimized the WEDM process parameters using Taguchi method. Ozdemir et al. [6] performed investigation on machinability of nodular cast iron by WEDM. Variation of the surface roughness and cutting rate with machining parameters were mathematically modeled by using the regression analysis method. Muthuraman et al. [7, 8, 9] applied desirability approach, regression analysis and ANN modeling for studying multi characteristics of WEDM ed WC-Co composites. From the above literature survey, it is revealed, the selection of optimum machining parameter combinations for obtaining higher material removal rate and lower surface roughness is a challenging task in WEDM due to the presence of a large number of process variables and complicated stochastic process mechanisms.

II. Material and Methods

The experimental studies were performed on an Electronica sprint-cut machine tool, which has ceramic parts and linear motors to reduce friction and backlash enabling high speed machining.O_2

steel, Oil hardened and cold worked with 75 mm x 75 mm x 12.43mm size was applied as work material. The composition is presented in Table I.Different settings of input parameters, pulse on time, pulse off time, wire speed and gap voltage that were used in the experiments are provided in Table II. A 0.25mm diameter copper-zinc wire, selected as the tool electrode. During the experiments 12mm length with 12.5 mm width was made to cut. The cutting speed is evaluated from the length of cut to time taken for the cut. During machining process the wire diameter and width of cut is kept constant. The output response,surface roughness was measured by Talysurf surtronic 3+ at 0.8 mm cut-off value. The material removal rate is evaluated from Eq.1.The composition of work material is provided in Table 1.

$$MRR = ktv \quad mm^3/min \quad (1)$$

Where,

t = thickness of work piece mm = 12.43 mm

k = Kerf width= (d+2 Δg) = 0. 35 mm

d = diameter of wire = 0.25 mm

Δg=wire-work spark gap = 0.05 mm

v = Cut Length/Machining time mm/min

TABLE I. CHEMICAL COMPOSITION OF O_2 STEEL

Elements	C	Si	Mn	Cr	V	Ni	Mo
% of	0.80	0.5	1.3	0.4	0.2	0.3	0.3

The motive is to study the effect of selected input parameters on the output response, material removal rate and surface finish and to identify parameters through ANOVA that would improve the machining performance. Table II displays the input parameters, ranges that are selected. Four levels were selected to avoid linearity effects.

TABLE II. EXPERIMENTAL PLAN FOR L_{16}

Control Factors	Symbol	Level			
		1	2	3	4
Pulse on	A	122	125	128	131
Off-time	B	44	47	50	53
Wire	C	1	2	3	4
Voltage	E	10	13	16	19

The process parameters and corresponding output response MRR and Ra obtained are presented in Table III with coded units.

TABLE III TAGUCHI L_{16} WITH CODED UNITS AND THE EXPERIMENTAL RESULTS.

Sl	Input Parameters				Output	
	A	B	C	D	MRR	Ra
1	1	1	1	1	0.728	3.76
2	1	2	2	2	0.522	3.73
3	1	3	3	3	0.393	2.97
4	1	4	4	4	0.365	3.09
5	2	1	2	3	0.599	2.46
6	2	2	1	4	0.486	3.55
7	2	3	4	1	0.481	2.24
8	2	4	3	2	0.433	3.34
9	3	1	3	4	0.586	3.56
1	3	2	4	3	0.460	3.48

contd.,

Sl	Input Parameters				Output	
	A	B	C	D	MRR	Ra
1	3	3	1	2	0.515	3.65
1	3	4	2	1	0.478	3.53
1	4	1	4	2	0.607	3.77
1	4	2	3	1	0.509	3.34
1	4	3	2	4	0.427	3.23
1	4	4	1	3	0.513	3.40

Taguchi method for parameter design was used to reduce the number of experiments that need to be carried out and to determine optimal machining parameters. The analysis of variance (ANOVA) establishes statistically significant machining parameters and the percent contribution of parameters on the surface roughness and the MRR. In Taguchi method, a loss function is calculated, which is the deviation between the experimental value and the desired value. This loss function is

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converted into a signal-to-noise (S/N) ratio. Regardless of the category of the performance characteristics, greater S/N values implies a better performance. In WEDM, the lower surface roughness and higher MRR are indication of better performance.

For the higher is better (HB) and lower the better (LB), the loss function (L) for machining performance of n repeated trials are,

$$L_{HB}=1/n\sum_{i=1}^{n}1/Y^{2} \quad (2)$$

$$L_{LB}=1/n\sum_{i=1}^{n}Y^{2} \quad (3)$$

Where, Y is the response and n denotes the number of experiments. The S/N ratio can be calculated as a logarithmic transformation of the loss function as shown below:

$$S/N \text{ ratio of MRR} = -10 \log_{10} (L_{HB}) \quad (4)$$

$$S/N \text{ ratio of SF} = -10 \log_{10} (L_{LB}) \quad (5)$$

By applying these Equations from (2) to (5), the S/N ratio values for each experiment of $L_{16,}$ was estimated (Table IV,V).

TABLE.IV MRR RESPONSE FOR S/N RATIOS

Larger is better: MRR versus A, B, C,				
Level	A	B	C	D
1	-	-4.05	-5.145	-5.347
2	-	-6.14	-5.974	-5.755
3	-	-6.92	-6.474	-6.273
4	-	-7.06	-6.552	-6.770
Delta	0.469	3.012	1.407	1.423
Rank	4	1	3	2

TABLE.V Ra RESPONSE FOR S/N RATIOS

Smaller is Better:Ra versus A, B, C, D				
Level	A	B	C	D
1	-10.5	-	-	-9.985
2	-9.09	-	-	-11.17
3	-11.0	-	-	-9.684
4	-10.7	-	-	-10.50
Delta	1.94	1.464	1.305	1.487
Rank	1	3	4	2

III. Results and Discussion

Among the variables studied Table IV of MRR ranks, off-time as critical parameter, voltage as second in rank, wire speed as third and on-time as fourth,. For the surface roughness from Table V,the rank order are, on-time ranks first, voltage is second, off-time is third and wire speed is fourth in ranking.

The higher ranking parameters should not be attempted to optimize as they will change results rapidly. Less significant parameters can be tuned for improvement.

Based on the analysis of S/N ratio, the optimal machining performance for the MRR was obtained at pulse on time (Level 4) 131µsec., pulse off time (Level 1) 43 µsec., wire feed rate (Level 1) 1 m/min. and gap voltage(Level 1) 10 volts. Settings. i.e.; for MRR A4B1C1D1.Higher on-time allows more exposure time to the WEDM sparks to remove material. Smaller off-time reduces the non-sparking time so that the actual machining time increases. Lower wire speed allows efficient machining, debris removal from spark zone for given dielectric flow rate, and reduces cost on wire. The machining speed increases with decreased spark gap voltage, as the spark gap distance increases with higher gap voltage, lessening the impact of sparking.

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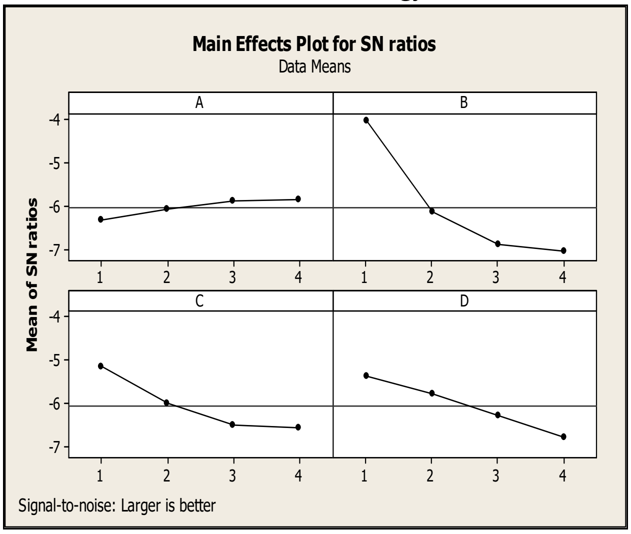

FIG.1 MEAN OF S/N RATIO FOR MRR

As per ANOVA the optimum machining parameter level that would yield lower surface finish was obtained as pulse-on time (Level 2) 125 µsec., pulse- off time (Level 3) 25 µsec., wire feed rate (Level 4) 4 m/min and supply voltage(Level 3) 16 volts. i.e. A2B3C4D3.Increased pulse on-time and low off-time creates heating effect, more melting than spark removal mechanism, the recast sticks to the surface, reduces finish. Hence reduced pulse on -time to level 2 with increase in pulse off-time to level 3 would charge the capacitor with intensity that would yield good finish.

High wire speed for finish cut is desirable as a worn out wire, out of round shaped due to spark erosion may give out un-even spark at hills and valleys. Wire -speed increase to level 4 ensures fresh wire is available to yield best finish. Gap voltage at level 3 ensures thermal damage by sparking wire due to proximity to machining zone is reduced.

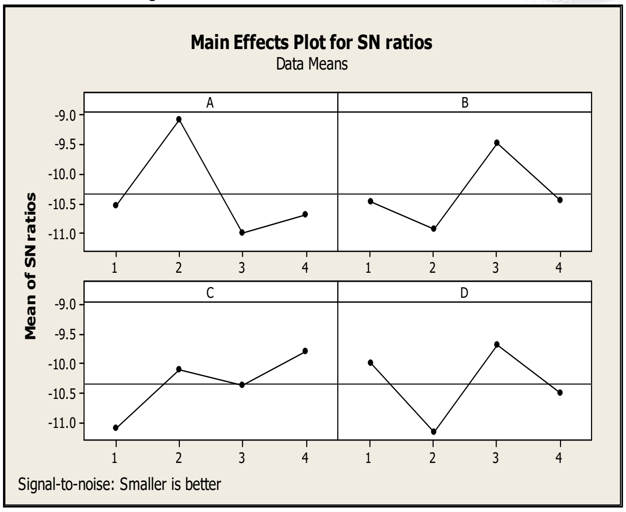

FIG.II MEAN OF S/N RATIO FOR RA

The results of ANOVA for the machining outputs are presented in Table VI and Table VII respectively..

TABLE VI . ANOVA FOR MEANS OF MRR

Para-meter	df	Sum of Square	Mean Square	F Test	%
A	3	0.0053	0.0018	0.18	0.43
B	3	0.0867	0.0289	30.03	72.14
C	3	0.0176	0.0059	6.10	14.65
D	3	0.0154	0.0051	5.32	12.78
Error	3	0.0029	0.0011		
Total	15	0.1231			100

Statistically, F-test provides at 95% confidence level the significance. Larger F-value indicates that the variation of the process parameter influence significantly the performance characteristics.

Percent contribution indicates the relative power of a factor to reduce variation. High percent contribution indicates even a small variation will have a great influence on the performance. Accordingly, among the input parameters selected, statistically effective parameter with respect to

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MRR (Table6) is pulse off time (72.14%) followed by wire speed (14.65%). The Supply voltage (12.78%) and pulse on- time (0.43%) were less and least significant respectively.

TABLEVII ANOVA FOR MEANS OF RA

Para-meter	df	Sum of Square	Mean Square	F Test	%
A	3	1.0060	0.3353	3.24	38.16
B	3	0.5419	0.1806	1.74	20.49
C	3	0.4425	0.1475	1.42	16.73
D	3	0.6489	0.2163	2.09	24.62
Error	3	0.3106	0.1035		
Total	15	2.9500			100

From Table VII of ANOVA for the surface finish, pulse on time was found to be the major factor affecting the surface finishes (38.16%) whereas supply voltage is significant second ranking factor (24.62%), followed by pulse off time (20.49%).The Wire speed is the least significant (16.72%). The confirmation experiment validates the selection of optimal parameters. Under this condition, a new experiment was conducted, prediction and verification of improvement using the optimal levels of the machining parameters can be calculated as:

$$\eta_{opt} = \eta_m + \sum_{i=1}^{p}(\eta_i - \eta_m) \quad (6)$$

Where,

ηm is total mean of S/N ratio, ηi is the mean of S/N ratio at the optimal level, and p is the number of main machining parameters that significantly affect the performance. Table 8, shows the comparison of the predicted MRR with the actual MRR using optimal machining parameters. The MRR is increased by 26.39%..MRR is improved by using this approach.

TABLE VIII RESULTS OF MRR CONFIRMATION TEST

Responses	Levels	Values	Improvement
MRR average (mm^3/min)	A4B2C3D1	0.519	26.39%
MRR optimal (mm^3/min)	A4B1C1D1	0.656	
Ra average (μm)	A2B4C3D2	3.34	11%
Ra optimal (mm^3/min)	A2B3C4D3	2.97	

Table VIII shows the comparison of the predicted surface finish with the actual by use of the optimal machining parameters. The surface roughness is decreased by 33.71%.The experimental results confirmed the validity of the used Taguchi method for enhancing the machining performance and optimizing the machining parameters (MRR and surface finish).

IV. CONCLUSION

This paper has presented an investigation on the optimization and the effect of machining parameters on the MRR and the surface finish in WEDM operations. The effect of various machining parameter such as pulse on time, pulse off time, wire speed, and supply voltage has been studied through the machining of O2 steel. The level of importance of the machining parameters on the MRR and surface finish was determined by using ANOVA Method, optimum parameters for maximum MRR and minimum surface roughness were obtained. The confirmation tests indicated that it is possible to increase MRR and decrease surface roughness significantly by using the statistical technique. The experimental results confirmed the validity of the used Taguchi method for enhancing the machining performance and optimizing the machining parameters in WEDM operations.

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