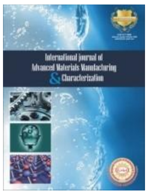

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Optimization of Machining Parameters in Wire Cut EDM of Stainless Steel 304 Using Taguchi Techniques

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ABSTRACT

This paper presents the optimization of Wire Electrical Discharge Machining (WEDM) process parameters such as pulse on-time (T_{on}), pulse off-time (T_{off}) and wire feed rate (WF) to obtain the greatest material removal rate (MRR) and less surface roughness (Ra) of stainless steel 304. The machining experiments were conducted according to the Taguchi parametric design (L_9 orthogonal array) using 0.25 mm diameter brass wire as a cutting tool. Signal to noise ratio (S/N) and Analysis of variance (ANOVA) were used to find the consequence of each parameter. Optimum cutting parameters have been verified through experiments. The results indicate that pulse on-time is the most significant factor influencing the MRR and Ra followed by pulse off-time and wire feed rate.

Key Words: WEDM, Stainless steel 304, Taguchi, ANOVA

1.0 Introduction

WEDM generate sparks, discharges between a small wire electrode and a workpiece with de-ionized water as the dielectric medium. Which erodes the workpiece and to produce complex shapes by numerically controlled (NC) path. The main goals of WEDM are to achieve a better stability, higher productivity with a desired accuracy and surface finish in manufacturers and users. However, due to a large number of variables even a highly skilled operator with a state of the art WEDM is rarely able to achieve the optimal performance. An effective way to solve this problem is to determine the relationship between the performance measures of the process and its controllable input parameters [1]. Investigations into the influences of machining input parameters on the performance of WEDM have been reported widely. Several attempts have been made to develop a mathematical model of the process. In this study, the MRR and Ra of the machined workpiece were taken into account as measures of the process performance. Hence, investigations were carried out to study the effect of spark on-time, spark off-time and wire feed rate on the Ra characteristics and MRR. In setting the machining parameters, the main goals of the maximization of MRR with minimization of Ra were considered. A suitable selection of machining parameters for the WEDM process is mostly relying on the operator's experience and manufacturer guidelines. Machining parameter table provided by the manufacturer is more generic in nature and does not address recent materials. Hence the need to optimize the parameters for newer / advanced materials rises. Various research works have been carried out in WEDM of advanced materials. The following paragraph summarizes the outcome of those researchers.

A study made by S.T.Newman, et al., [1] reveals various research areas like optimizing process variables monitoring and controlling the process wire EDM developments. A theoretical and experimental study is done by Jerzy, et al., [2] employed silver coating technique to minimize the change in resistance afforded by workpiece material. The study on the machining parameters optimization WEDM by Y.S.Liao [3] reveals that Taguchi quality design method and analysis of variance can be used to find out significant parameters which affect machining performance of WEDM. An experimental study on effect cutting parameters on surface roughness by Mustafa Than Gokler [4] selected suitable cutting and offset parameter communication. In order to get good surface finish by creating table charts. An experiment carried out by S.S Mahapatra and A.Panaik [5] was thought design genetic algorithm to measure various parameters and to optimize the machining process. A non-linear regression analyses and mathematic modeling are used for performance measurement.

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The present work describes the effect of cutting parameters in WEDM of stainless steel 304. Hence this research attempts to the study the optimum cutting parameters for machining of stainless Steel 304 in WEDM by using Taguchi design methodologies.

1.1 Taguchi Method

A statistical technique of Taguchi method used for analyzing and optimizing the process parameters. The Taguchi analysis uses orthogonal arrays from the design of experiments, theory to study the power of a large number of variables on responses with a small number of experiments. In this method, the experimental results are changed into a signal-to-noise (S/N) ratio. It uses the S/N ratio as a measure of quality characteristics deviating from or nearing the desired values [6]. Taguchi classified the quality characteristics into three categories such as Lower the better, Higher the better and Normal the better. These formulas used for calculating S/N ratio is as follows.
The characteristics that lower value represents better machining performance, such as surface roughness is called "lower is better (LB)" and that higher values represent better machining performance, such as the material removal rate is called "higher is better (HB)" in quality engineering. The S/N ratio (signal to noise) could be an effective representation to find the significant parameter by evaluating the minimum variance. The equations for calculating the S/N ratio are,

"Lower is better" (LB) S/N ratio = $- 10 \log (1/r (y_1^2 + y_2^2 + y_3^2 + \dots\dots\dots + y_n^2))$ (1)
"Higher is Better" (HB) S/N ratio = $- 10 \log (1/r (1/y_1^2 + 1/y_2^2 + 1/y_3^2 + \dots\dots\dots + 1/y_n^2))$ (2)
Where,
$y_1, y_2, \dots y_n$ = observed response values and n= number of replications.

By applying the equation 1, the S/N values of the obtained Ra values are computed. By applying the equation 2, the S/N values of machining performance of the obtained MRR values are computed. In order to obtain the effects of machining parameters for each level, the S/N values of each fixed parameter and level in each machining performance were summed up.

1.2 Process Parameters Selection

In this analysis, WEDM parameters such as T_{on}, T_{off} and WF were considered. According to Taguchi's design of experiments, for three parameters and three levels L_9 Taguchi orthogonal array [L_9 OA] was selected. The number of factors and their corresponding levels are shown in the Table 1 and the basic Taguchi L_9 (3^3) orthogonal array used for this work is shown in Table 2.

Table.1 Levels of factors used in the experiment

Sl.No.	Symbol	Cutting Parameters	Levels			Units
			1	2	3	
1	A	Pulse on-time (T_{on})	1	5	8	µ Sec
2	B	Pulse off-time (T_{off})	10	5	2	µSec
3	C	Wire feed rate (WF)	1	2	3	m/min

Table.2 Standard L_9 Orthogonal array

Experiment No.	Levels		
	Pulse on-time(T_{on})	Pulse off-time(T_{off})	Wire Feed Rate (WF)
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

1.3 Experimental Set up

Table.3 Chemical composition of grade 304 stainless steel

Grade Wt.%	C	Mn	Si	P	S	Cr	Mo	Ni	N
304	0.08	2	0.75	0.04	0.03	20	-	10	0.1

Fig.1 Experimental setup

The experiments were conducted on a CNC WEDM. The trials conducted based on the settings shown in the L_9 orthogonal array. Stainless steel (grade 304) materials were used as the workpiece. The surface roughnesses are measured on the machined surface using surf test 211 machine. The surface roughness-measuring device is slid on the workpiece and readings are taken in the middle of each test specimen. The material removal rate is calculated by loss of weight / time taken for each trial. The work material, electrode and other machining settings are as follows

Work piece (anode) : stain less steel. (Grade 304)
Electrode (cathode) : 0.25 mm diameter brass wire.
Work piece thickness : 10 mm.
Voltage : 80 V.

1.4 Calculation of Material Removal Rate (MRR) and Surface Roughness

To optimize the machining process parameters, the most important outcomes of WEDM such as Material Removal Rate (MRR) and Surface Roughness (Ra) were considered in this investigation. The Material Removal rate was calculated as
MRR : (Length of cut x Spark gap x thickness)/ Time taken

Thickness of job : 10 mm
Spark gap : 0.4 mm
After machining the workpiece, the surface roughness values were measured using a Surf test 211.

1.5 Results and Discussion

1.5.1 Process Parameters Influence on Metal Removal Rate

Statistical analysis software MINITAB 18 was used for analysis, the design of experiments to perform the analysis of Taguchi and ANOVA to create regression equations. In Taguchi method, the optimization of process parameters provides the effect of individual independent parameters on the identified quality characteristics. The statistical analysis of variance was conducted. The role of each parameter in influencing the variation in quality characteristic was calculated based on the ANOVA. The ANOVA also suggest the process parameters which are statistically significant. The table 4 of results for MRR and Ra was revealed with the input parameters.

Table.4 Response table.

T_{on}	T_{off}	WF	MRR	Ra
1	10	1	1.02	1.23
1	5	2	1.08	1.34
1	2	3	1.42	1.22
5	10	2	1.36	1.21
5	5	3	2.12	1.94
5	2	1	2.37	2.35
8	10	3	2.25	1.46
8	5	1	3.01	2.23
8	2	2	3.12	2.34

Table.5 Response table for Means of MRR.

Level	T_{on}	T_{off}	WF
1	1.173	1.543	2.133
2	1.950	2.070	1.853
3	2.793	2.303	1.930
Delta	1.620	0.760	0.280
Rank	1	2	3

MRR was analyzed to determine the effects of WEDM process parameters. The experimental results were changed into S/N ratio using MINITAB 18 and calculated the main effects at all levels of chosen parameters listed in table 5. The main effect for mean and S/N ratio is plotted in figure 2 and 3 respectively. In figure 2 and 3 the MRR is greatest at the level 3 of T_{on}, at the level 3 of T_{off} and at the level 1 of WF. It is clear that the highest ratio of S/N is the optimal level of each process parameter, therefore both the mean effect and S/N ratio values point out that the MRR is at the maximum when T_{on} at 8, T_{off} at 2 and WF at 1.

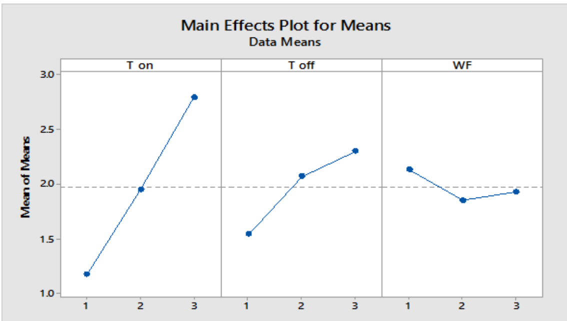

Fig.2 Main effects plots for mean of MRR.

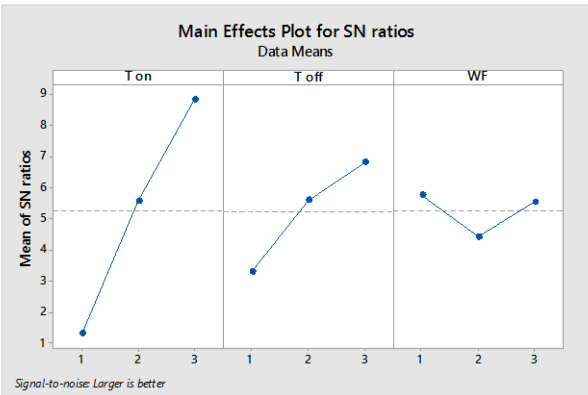

Fig.3 Main effects plots for S/N ratio of MRR.

The factors of ANOVA are shown in Table 6 which shows clearly that the contributions of T_{on} (78.24%) is the most influencing factor for MRR followed b y T_{off} (18.06%) and WF (2.49%).

Table.6 Analysis of Variance for S/N ratios for MRR.

Source	DF	SS	Percentage of Contribution
T_{on}	2	3.93882	78.24
T_{off}	2	0.90942	18.06
WF	2	0.12562	2.49
Error	2	0.06029	1.19
Total	8	5.03416	100

1.5.2 Influence of Process Parameters on Surface Roughness

The S/N ratio was chosen according to the criterion, the "smaller-the-better" in order to minimize surface roughness. The S/N ratio for the "smaller -the-better" target for all the responses was calculated using the equation (1).

Table.7 Response table for Means of Ra.

Level	T_{on}	T_{off}	WF
1	1.263	1.300	1.937
2	1.833	1.837	1.630
3	2.010	1.970	1.540
Delta	0.747	0.670	0.397
Rank	1	2	3

Ra was analyzed to determine the effects of WEDM process parameters. The experimental results were changed into S/N ratio using MINITAB 18 and calculated the main effects at all levels of chosen parameters listed in table 7. The main effect for mean and S/N ratio is plotted in figure 4 and 5 respectively. In figure 4 and 5 the Ra is lowest at the level 3 of T_{on}, at the level 3 of T_{off} and at the level 1 of WF. It is clear that the highest ratio of S/N is the optimal level of each process parameter, therefore both the mean effect and S/N ratio values point out that the Ra is at the minimum when T_{on} at 8, T_{off} at 2 and WF at 1.

Fig.4 Main effects plots for mean of Ra.

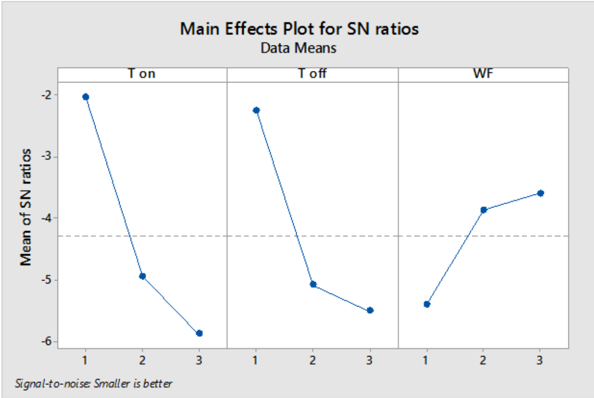

Fig.5 Main effects plots for S/N ratio of Ra.

The factors of ANOVA is shown in Table 8 which shows clearly that the contributions of T_{on} (44.58%) is the most influencing factor for Ra followed by T_{off} (36.82%) and WF (12.66%).

Table 8. Analysis of Variance for S/N ratios for Ra.

Source	DF	SS	Percentage of Contribution
T_{on}	2	0.9136	44.58
T_{off}	2	0.7547	36.82
WF	2	0.2595	12.66
Error	2	0.1214	5.92
Total	8	2.0492	100

1.5.3 Regression Equations

A statistical technique Regression analysis was used to determine the relationships between process parameters and outcomes for predicting the results at intermediate values within the range of the level. During this investigation, the regression equations were established between the process parameters and responses. Nonlinear regression models were developed based on the experimental values to predict MRR and Ra. It is found that a second order polynomial curve fits the experimental results.
The equations obtained are as follows

$$MRR = 2.291 + 0.1196\ T_{on} - 0.054\ T_{off} - 0.815\ WF + 0.0124\ T_{on}^2 - 0.00344\ T_{off}^2 + 0.178\ WF^2$$

$$R^2 = 98.80\% \quad (3)$$

$$Ra = 2.097 + 0.214\ T_{on} + 0.011\ T_{off} - 0.632\ WF - 0.0119\ T_{on}^2 - 0.0079\ T_{off}^2 + 0.108\ WF^2$$

$$R^2 = 94.08\% \quad (4)$$

1.6 Conclusions

On the basis of experimental results, calculated S/N ratio, analysis of variance (ANOVA) and 'F' test values, the following conclusions are drawn machining of stainless steel grade 304 of WEDM. The pulse on-time is the most significant machining parameter for surface roughness (SR) and material removal rate (MRR) while machining of stainless steel. For better surface finish and higher material removal rate, the recommended parametric combination is pulse on-time at level 3, pulse off-time at level 3 and wire feed rate at level 1 for machining of stainless steel grade 304 Based on the minimum number of trials conducted to arrive at the optimum cutting parameters, Taguchi method seems to an efficient methodology to find the optimum cutting parameters.

1.7 References

1. **K.H .HO,S.T Newman, S Rahimifard ,R.D.Allen.**, "State of the art in wire electrical discharge machining" Journal of machine tool and manufacturing .Vol 44(2004) 1247-1259.

2. **Jerzy Kozak, Kamlakar P. Rajurkar, Niraj Chandarana,** "Machining of low electrical conductive materials by wire Electrical discharge machining (WEDM)", Journal of Materials Processing Technology Vol 149 (2004) 266–271.

3. **Y.S Liao, J.T.Huang, H.C.Su,**"A Study on the machining parameters optimization of WEDM', Journal of materials processing technology, vol.71, pp.487-493.

4. **Gokler, M.I., Ozanozgu, A.M.,** "Experimental investigation of effects of cutting parameters on surface roughness in the WEDM process", International Journal of Machine Tools and Manufacture, Volume 40, Number 13, October 2000 , pp. 1831-1848(18).

5. **S.S Mahapatra,A Panaik ,** "determination of optimal parameters setting in wire electric discharge machining (WEDM) process using Taguchi method.

6. **G. Venkateswarlu, P. Devaraj** "Optimization of Machining Parameters in Wire EDM of Copper Using Taguchi Analysis" International Journal of Advanced Materials Research, Vol. 1, No. 4, 2015, pp. 126-131,4November 2015.

7. **J. T. Huang, and Y. S. Liao,** Optimization of machining parameters of Wire-EDM based on Grey relational and statistical analyses, International Journal of Production Research, vol. 41, pp.1707–1720 (2013).

8. **N. Tosun, C. Cogun and H. Pihtili,** The effect of cutting parameters on wire crater sizes in wire EDM, International Journal of Advanced Manufacturing Technology, vol. 21, pp. 857–865, (2003).

9. **S. S. Mahapatra and Amar Patnaik,** Optimization of wire electrical discharge machining (WEDM) process parameters using Taguchi method, The International Journal of Advanced Manufacturing Technology, vol. 34, pp. 911-925, (2007).

10. **S. Datta and S.S Mahapatra,** Modeling, simulation and parametric optimization of wire EDM process using response surface methodology coupled with grey-Taguchi technique, International Journal of Engineering, Science and Technology, vol. 2, pp. 162-183,(2010).

11. **H. Singh and A. Singh,** Effect of Pulse On/Pulse Off Time On Machining Of AISI D3 Die Steel Using Copper And Brass Electrode In EDM, International Journal of Engineering and Science, vol. 1, pp. 19-22, (2012).

12. **M. Durairaj , D. Sudharsunb, N. Swamynathan,** Analysis of Process Parameters in Wire EDM with Stainless Steel using Single Objective Taguchi Method and Multi Objective Grey Relational Grade Procedia Engineering, Vol. 64, pp. 868–877, (2013).

13. **S. Y. Martowibowo, A. Wahyudi**, Taguchi Method Implementation in Taper Motion Wire EDM Process Optimization, Journal of The Institution of Engineers (India): Series C, Vol 93,(4), pp. 357-364, (2012).