Investigation of WEDM Process Parameter for Surface Roughness and MRR of ASTM A633 Grade E

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ABSTRACT

With the expanding demands of high surface finish and machining of complex shape geometries, regular machining process are currently being supplanted by non-traditional machining processes. Wire EDM is one of the versatile non-conventional machining process. In this research paper, focuses study on the pulse on time , pulse off time , wire feed & tension as input parameters by keeping other parameters constant like spark voltage, water pressure etc. whereas surface roughness and material removal rate are considered as output parameters.
Taguchi's L9 orthogonal array is used for the design of experiments. For analysis ANOVA is used for achieving the objectives of this project are to maximize the material removal rate and to minimize the surface roughness value (Ra). Material used is ASTM A633 Grade E alloy steel.

Keyword : Wire EDM , wire feed, material removal rate, ANOVA, ASTM A633 grade E, Taguchi's L9 orthogonal array.

1. INTRODUCTION

In Wire Electrical Discharge Machining (WEDM), or Wire-Cut EDM, a thin single metal wire is held into upper and lower strands passed through the work piece, which is submerged in tank of dielectric liquid or de-ionized water. This liquid cools the procedure and flush away the eroded material. The Wire EDM process works spark erosion principal and high electric current to cut conductive materials leaving a smooth surface that requires no further finishing. This procedure is utilized to make punches, devices, and kicks the bucket from any conductive material, including hard metals that are excessively troublesome, making it impossible to machine with different techniques, for example, graphite, carbide and hard metals. The wire is held amongst upper and lower precious stone aides. By using WEDM can cut intricate and complex shapes , angular with difficult profiles at top and bottom surface also.

A. Muniappan, J. Vijayarangam et. al. [1] studied effect of different wire electrodes used in wire electrical discharge machining (WEDM) on the machining characteristics of Al/SiC/Graphite. In this they have used three types of wires Brass wire, zinc coated wire and diffused coated wires. Six process parameters, namely pulse on time, pulse off time, peak current, gap set voltage, wire feed and Wire tension have been considered. Cutting speed, kerf width, surface roughness is calculated for each experiment.

Zahid A. Khana [2] et al studied the multi response optimization in WEDM using Taguchi (L-16) orthogonal array. They considered three responses namely material removal rate, surface roughness, and wire wear ratio. This paper presents a study that investigates the effect of the WEDM process parameters on the surface roughness average and the kerf width of the stainless steel (SS 304). Nine experimental runs based on an orthogonal array of Taguchi method are performed and grey relational analysis method is subsequently applied to determine an optimal WEDM parameter setting. Surface roughness and kerf width are selected as the quality targets. An optimal parameter combination of the WEDM process is obtained using Grey relational analysis. By analyzing the Grey relational grade matrix, the degree of influence for each controllable process factor onto individual quality targets can be found. The pulse ON time is found to be the most influential factor for both the surface roughness and the kerf width. Further, the results of the analysis of variance (ANOVA) reveals that the pulse ON time is the most significant controlled factor for affecting the multiple responses in the WEDM according to the weighted sum grade of the surface roughness and the kerf width.

R V Rao, V D Kalyankar [3] invented detailed algorithm is explained in this paper. The important advanced machining processes identified for the process parameter optimization in this work are electrochemical machining (ECM) process and electrochemical discharge machining (ECDM) process. Two different multi objective problems of these processes are considered in this work which was attempted previously by various researchers using recent optimization technique such as artificial bee colony algorithm (ABC). However, comparison between the results gives the superiority of the new algorithm in terms of population size, number of generations and computational time.

Liao and Huang [5] studied on the machining-parameters optimization of WEDM. Luis and Puertas gave the methodology for making technological tables used in EDM (Electric Discharge Machining) processes of conductive ceramics. In EDM machining, Selection of process parameter is very important.LIN and LIN use the orthogonal array with grey relational analysis to optimize the electrical discharge machining process with multiple performance characteristics.

A. Patel, K. Patel et al. [6] studied the effect of WEDM input parameters like pulse on time, pulse off time, and voltage on the performance measures like cutting rate & gap current. Taguchi method will be employed for the experimental work. The research work is expected to assist in finding out the optimum output parameters that will lead to maximum cutting rate and minimum gap current. Genetic Algorithm will use for optimize the output parameters.

Noor Zaman Khan, Zahid A. Khan [9] studied Surface roughness (Ra) and micro-hardness (μh) are two important output parameters by taking input parameters the pulse on period, pulse off-period, current of the High Strength Low Alloy steel (ASTM A572-grade 50) used multi optimization technique, found that pulse off time is plays important role for surface integrity.

From above literature survey almost no work is carried out on the material steel alloy A633 grade E commonly used in industry for different application such as power plant, refineries, industrial shades, cold storage, metro station, aircraft hangers, commercial buildings etc. This material has good machinabilty and weld ability.

This study having Taguchi's DOE approach is used to analyze the effect of WEDM process parameters pulse-on-time, pulse-off-time and wire feed on the material removal rate and surface roughness by using coated wire having zinc coating on the material A633 grade E and optimal setting of these parameters is found that may result in maximizing material removal rate and improvisation of surface roughness. . Geometry of cut is decided inclined 20˚ to vertical which is almost maximum inclination of wire while cutting, this is almost very difficult to machine as wire inclined and due to inclination water cannot easily enter in sparking zone. This may lead to decrease both surface finish and MRR.

Table 1: Chemical Composition of Work Material ASTM A633 Grade E

Elements	(C)	(Mn)	(P)	(S)	(Si)	(Nb)
Weight Max. %	0.14	1.15-150	0.035	0.04	0.15-1.50	0.01-0.05

2. METHODOLOGY

Single Response Optimization:

For design of experiments Taguchi approach is used for evaluating the mean performance characteristics and determination of confidence intervals for the predicted mean has been applied. Orthogonal array, L9 is used for experimentation setup for four variables as cutting parameter having three levels (shown in Table 2) and two output responses. The Taguchi method is a commonly adopted approach for optimizing design parameters. The method was originally proposed as a means of improving the quality of products through the application of statistical and engineering concepts. ANOM is used to evaluate the optimal levels after experimentation and ANOVA is used to evaluate the contribution of each factor and for F-test. For the analysis of Taguchi Minitab17 software is used.

There are Taguchi's standard ratios are used to calculate S/N ratio. For maximization of material removal rate following equation(1) is considered.

Larger is better:

$$S/N = -10 \log_{10} \frac{1}{n} \times \sum 1/y2 \quad (1)$$

Where,

n = no. of total experiments and y = observed material removal data

For measurement of surface roughness "SJ210 by Mitutiyo" company made equipment is used which is having cutoff length 5mm. For the material removal rate calculation following equation (2) is used, which has been used by Surinder Kumar et al.[12]

$$MRR = F \times Dw \times H \quad (2)$$

Where, F is machine feed rate in mm/min; Dw is wire diameter used as electrode; H is thickness of work piece. F is given by machine while cutting.

For minimizing the surface roughness (Ra), following equation (3) is used.

Smaller the better:

$$S/N = -10 \log_{10} \frac{1}{n} \times \sum 1/y2 \quad (3)$$

Where, n = no. of total experiments and y = observed surface roughness data.

Before machining, work pieces is machined to clean out surface debris by milling process.

Figure 1: Experimental setup of Wire cut electro-discharge machining

Figure 2: Work piece before machining and Coated wire used for cutting

Figure 3: Work piece after machining and cut profiles

Figure 4: Measurement of Surface roughness of cut profiles

Figure 5: Surface Roughness graph

3. EXPERIMENTATION:

Experiments are performed on Electronica CNC wire electro–discharge machine which is manufactured by ELECTADURACUT India Tools, Pune, as shown in fig. 1. Work piece plate material is A633 grade E having specimen size is 19mm thickness, width of 80mm and length is 200mm. Nine experiments are carried out with different settings of parameter given by orthogonal array. Geometry of cut is decided inclined 20˚ to vertical which is almost maximum inclination of wire while cutting. A coated wire of core brass having zinc coating having diameter 0.25mm is used to erode work piece and electrolytic water was used as the dielectric fluid. Work piece before machining with wire and after machining with the cut profiles is shown in fig. 2 and fig. 3 respectively. By referring the experimental set-up given by orthogonal array; experiments are carried out after which recorded and calculated results of output parameters with input parameters settings shown in Table 2. The surface roughness measurements taken by using the "Mitutiyo" surface roughness testing equipment and measurement profile and Ra reading is shown in Figure 4 and Figure 5 respectively.

Process Parameters:

There are process parameters varied in three ranges called levels other parameters like voltage, current, water pressure are kept constant.

- Pulse On period:

This is measured in micro seconds, this is spark on time, dissiptates energy on workpiece in form of spark. Due to high temp. of spark material is eroded. This factor is responsible to remove material.

- Pulse off period:

Pulse interval, also called as Pulse off period, is also expressed in micro seconds. It's the time between discharges. Off Time has no effect on discharge energy. This time allows the debris to solidify and be removed material away by the dielectric prior to the next discharge. If using very low values of T off, may result wire breakage which in turn reduces the cutting efficiency.

- Wire Feed:

Wire feed measured in m/min. As it increases, cutting speed increase and consumption of wire also increases; whether as low feed rate of wire brakes down at high speeds. It should ne optimum to achieve high cutting speeds with no breakage of wire.

- Wire tension:

Wire tension should be enough as it affect surface finish and accuracy of cut. At low tension, may lead to lower cutting speed but to increase surface finish, hence it should be maintain at optimal level to achieve high cutting speed and good surface finish.

Table 2 : Levels of Cutting Parameters

Cutting Parameters	**T ON**	**T OFF**	**Wire Feed**	**Wire Tension**
Level 1	108	52	4	6
Level 2	110	54	5	7
Level 3	112	56	6	8

Table 3: Test data summary for Ra & MRR

Experiment no.	**T ON** μ_s	**T OFF** μ_s	**Wire Feed** m/min	**Wire Tension** units	**S.R.(Ra)** μ_m	**MRR** mm^3/min
1	108	52	4	6	2.3377	6.4790
2	108	54	5	7	3.1283	6.2166
3	108	56	6	8	2.5987	5.8484
4	110	52	5	8	3.6760	6.6880
5	110	54	6	6	3.1517	4.7975

6	110	56	4	7	3.0433	4.1539
7	112	52	6	7	3.1173	7.8418
8	112	54	4	8	2.3160	7.3150
9	112	56	5	6	3.0513	6.8733

4. RESULT AND DISCUSSION:

Minitab 17 software is used for response tables, S/N ratio calculation & optimal means calculation. From Table 3; it has been observed that maximum MRR of 6.873mm3/min which is achieved in trail no. 9 having T on 112µs, T off 56 µs, Wire feed 5m/min and Wire tension is 6. This seems highest MRR achieved at highest pulse on time, highest pulse off time and moderate wire feed and lowest wire tension. For Surface roughness primarily it is observed that less Ra is found out at trail no.8 having T on 112µs, T off 54 $\mu_{s,}$ Wire feed 4m/min and wire tension is 8; which resulted least surface roughness 2.3166$\mu_{m.}$

Table 4 shows response S/N ratio for surface roughness and ANOVA calculation for contribution shown in Table5. From responses table, we found the optimal level combination for the four input parameters for minimum surface roughness value is A_1 B_2 C_2 D_3. Wire Feed contributed more for the surface roughness also pulse on time having 37% contribution in surface roughness whether wire tension having negligible effect on Ra from ANOVA result in Table 5. Figure 6 shows main effect plot for the S/N ratio for surface roughness for smaller is better.
Response Table for the material removal rate and ANOVA calculation is shown in Table 6 & 7 respectively. For maximization of MRR, response table gave optimal level of for parameters that is A_3 B_1 C_2 D_3. In table 7 of ANOVA result, it is concluded that pulse on time having highest contribution 59.5% , pulse off period having 26% and other parameters are having very less effect on increase in MRR. Figure 7 shows main effect plot of S/N ratio for material removal rate.
Prdicted values are calculated by using Taguchi's standard formulae for both of output responces that is predicated Ra for optimal setting A_1 B_2 C_2 D_3 is 2.2062µm and for MRR fort optimal setting is 9.5968 mm^3/min which is shown in Table 8.

Table 4: Response Table & ANOM for Surface roughness

Symbol	Cutting Parameter	Mean S/N Ratio			Max - Min(Delta)	Optimal level	Optimized Level of Parameters
		Level 1	Level 2	Level 3			
A	T ON	-8.526	-10.315	-8.953	1.789	-8.526	1,A_1
B	TOFF	-9.52	-9.057	-9.217	0.463	-9.057	2,B_2
C	WF	-8.112	-10.301	-9.38	2.189	-8.112	1C_2
D	WT	-9.012	-9.816	-8.966	0.85	-8.966	3,D_3

Table 5: Analysis of variance for Surface roughness

Symbol	Cutting parameter	DoF	SS	MS	F	Contribution %
A	T ON	2	5.24	2.62	0.18	36.93
B	T OFF	2	0.33	0.17	0.01	2.33
C	W.F.	2	7.25	3.62	0.26	51.07

D	W.T.	2	1.37	0.69	0.05	9.67
Total		8	14.19			100.00
P. Error		2	0.33	0.165		

Table 6: Response Table & ANOM for material removal rate

Symbol	Cutting Parameter	Mean S/N Ratio			Max - Min(Delta)	Optimal level	Optimized Level of Parameters
		Level 1	Level 2	Level 3			
A	T ON	15.81	14.17	17.31	3.14	17.31	3,A_3
B	TOFF	16.87	15.6	14.82	2.05	16.87	1,B_1
C	W.F.	15.29	16.37	15.62	1.08	16.37	2,C_2
D	W.T.	15.53	15.38	16.38	1	16.38	3,D_3

Table 7: Analysis of variance for material removal rate

Symbol	Cutting parameter	DoF	SS	MS	Contribution %
A	T ON	2	14.80	7.40	59.54
B	T OFF	2	6.48	3.24	26.05
C	W.F.	2	1.84	0.92	7.40
D	W.T.	2	1.74	0.87	7.00
Total		8	24.86		100.00

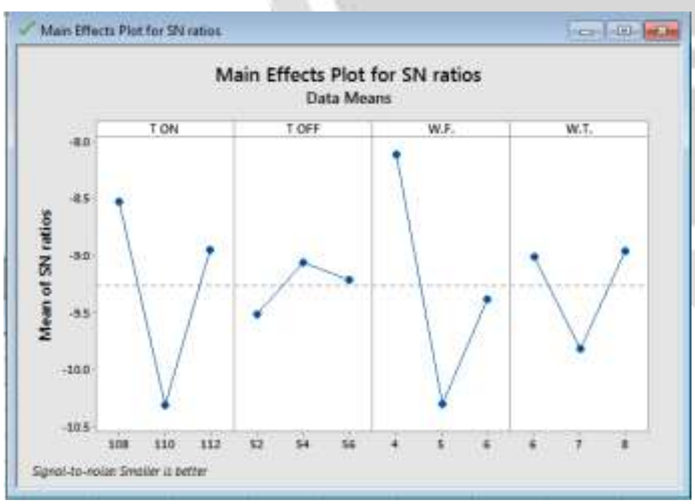

Figure 6: Main effect plot for S/N ratio for surface roughness

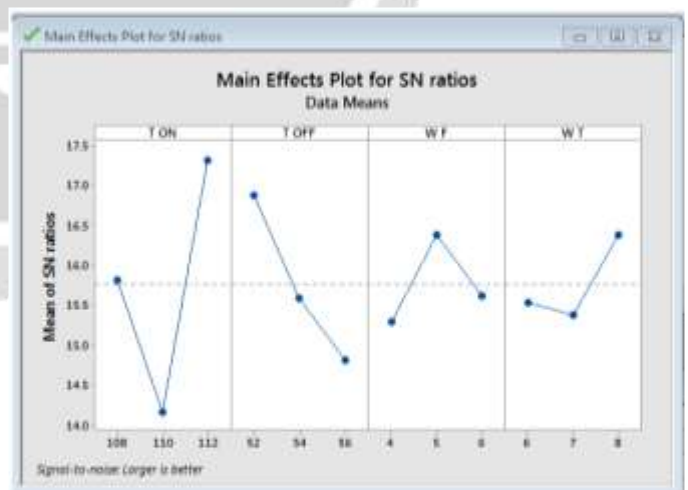

Figure 7: Main effect plot for S/N ratio for material removal rate

Table 8: Single Response Optimization Results

Method	Characteristics	Optimal condition	Optimal Predicted Value
Single Response Optimization	Surface roughness	$A_1 B_2 C_2 D_3$	2.2062µm
	Material Removal rate	$A_3 B_1 C_2 D_3$	9.5968 mm^3/min

Table 9: Confirmatory Experimental Result

Response	Predicted value	Optimal Experimental Value
Surface roughness	2.3961µm	2.9047 µm
MRR (mm^3/min)	9.5968 mm^3/min	7.6927 mm^3/min

5. CONCLUSION

There is the following conclusions are made after analysis of data obtained from confirmatory or validation experiments.

Two confirmation experiments are performed; one for Ra and one for MRR at the optimal settings of the WEDM process parameters recommended by the investigation. Therefore, the predicated optimum surface finish Ra=2.396 µm and experimental value obtained is 2.9µm which is more than predicated. Hence it is concluded that for less surface roughness; less pulse on time and less wire fees is required.

The predicted MRR is 9.59 mm^3/min and practically obtained at optimal level is 7.69 mm^3/min, it is concluded For maximization of MRR, the highest level of Pulse on time, less Pulse off time, moderate level Wire feed and higher wire tension is required.

From ANOVA calculation it is concluded that for surface roughness it is found that wire feed is most significant factor and wire tension is less contributing factor. For material removal rate it is found that pulse on time is more significant factor than other parameters, while wire tension is less significant factor.

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