Process Parameters Optimization of Wire EDM on AISI 304 Using the Taguchi Method

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1 Introduction

Wire electrical discharge machining (WEDM) has widely used for machining of high strength and conductive materials for generating an intricate profile that would be very difficult to produce using any conventional machining. The machining process is used in the automobile, aerospace and tool manufacturing industries where close tolerance and dimensional accuracy are required. WEDM is a non-traditional machining process in which material is being removed from the workpiece by a series of sparks between workpiece and wire separated by a dielectric fluid without any contact. The dielectric fluid in machining not only washes detritus produced between them, but it restricts them to become an obstacle for the next spark. It also acts as a cooling agent for the cutting zone. When a potential difference has established between wire and workpiece, then the emission of electron starts. These electrons collide with the dielectric fluid that breaks it into ions and an electron that forms a plasma. A high amount of heat is generated that melts the material nearby sparking zone and evaporated [1]. The current intensity is a more dominant factor on surface roughness, and also an excellent surface finish has been obtained at a low value of current intensity as well as pulse-on time [2–4]. Varun et al. [5] used grey relational analysis (GRA) coupled with genetic algorithm (GA) to study the effect of input parameters on the out responses (MRR) on EN353 alloy steel. Mathew et al. [6] optimized the parameters of WEDM on AISI 304 steel against the MRR and SR, and it was found that MRR and SR increased with an increase in servo voltage up to a specific range.

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Durairaj et al. [7] study the analysis of WEDM on stainless steel to optimize the parameters against the performance characteristic such as kerf width and surface finish. Rebolo et al. [8] investigated the effect of EDM process parameters on the material removal rate and surface quality on high strength copper-beryllium alloys. They have developed the mathematical model using response surface methodology for MRR and SR to determine the relationship between process parameters and machining performance. An abrasive particle mixed with dielectric fluid shows better machining rates at the desired surface quality [9, 10]. However, the machining parameters have selected for experimental work on AISI 304 steel, and their effect on the output characteristics was studied.

2 Experimental Method

The experiments have executed on three-axis CNC controlled WEDM (ELECTRONICA ULTRA CUT 51), as shown in Fig. 1. A brass wire having a diameter of 0.25 mm is used as an electrode. De-ionized water has used as the dielectric medium for the experiment. The work material is AISI 304 steel of size 150 × 50 × 5 mm plate, and their constituents are shown in Table 1.

The working range of WEDM parameters was selected based on a trial experiment, and their levels are shown in Tables 2, 3 and 4. The machine variables have validated

Fig. 1 Photograph of WEDM

Table 1 Chemical composition of AISI 304

Element	Cr	Ni	Mn	M	Si	P	C	Fe
%	19.04	7.93	1.74	1.24	0.368	0.018	0.019	Remaining

Table 2 WEDM parameters and their levels

Parameters	Level 1	Level 2	Level 3
T_{on} (μs)	100	105	110
T_{off} (μs)	55	59	63
Servo voltage (V)	20	30	40

Table 3 L9 orthogonal array

S. No.	Process parameters coded value		
	T_{on} (μs)	T_{off} (μs)	Servo voltage (V)
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

Table 4 Experimental results

S. No.	Process parameters			Responses	
	T_{on} (μs)	T_{off} (μs)	Servo voltage (V)	MRR (mm^3/min)	Ra (μm)
1	100	55	20	0.7471	1.619
2	100	59	30	0.6849	1.683
3	100	63	40	0.8343	1.443
4	105	55	30	3.4860	1.993
5	105	59	40	1.5396	1.809
6	105	63	20	0.6953	1.947
7	110	55	40	2.8640	2.639
8	110	59	20	2.6982	2.952
9	110	63	30	1.4375	2.869

by performing confirmation experiment.

In the present research work, Taguchi L9 orthogonal array has used for the design of experiment (DOE) and three levels of each process parameters have selected.

The output response has been recorded in the form of MRR and SR. Machining time has been kept constant for each experiment. Surface roughness is measured using an apparatus called as Talysurf.

3 Results and Discussion

After experimentation, MRR and SR were calculated and arranged in a tabular form corresponding to each parameter combination. According to Taguchi technique, S/N ratio is the relation of signal to noise where the signal is desirable value and noise is undesirable value. As MRR value should be high for machining, and surface roughness value should be less for sound application. Since MRR should be maximum, then higher the better characteristic is used for the calculation of S/N ratio. The surface roughness should be minimum for machined parts, thus, lower the better characteristic is used for the calculation of S/N ratio, as shown in Table 5. The experimental results were analysed by ANOVA to find the significance of each process parameter on the material removal rate and surface roughness.

3.1 Material Removal Rate

The results obtained by Taguchi analysis indicate that MRR increases with an increase in pulse-on time as the duration of sparks increases, the discharge energy increases with T_{on}. Similarly, it has observed that with an increase in pule-off time, the MRR decreases. There is no current supply to the electrode as time duration between two sparks is increased. Figure 2 shows the plot for the effect of the S/N ratio on MRR. Table 6 shows the S/N ratio of each parameter and its relation with MRR. From the responses, S/N ratio for MRR is calculated for larger the better by Taguchi analysis;

Table 5 S/N ratio value for MRR and SR

Ex. No.	S/N ratio of MRR	S/N ratio of SR
1	−2.5324	−4.18494
2	−3.2875	−4.52168
3	−1.5736	−3.18533
4	10.8465	−5.99015
5	3.7482	−5.14877
6	−3.1566	−5.78732
7	9.1395	−8.42879
8	8.6215	−9.40233
9	3.1522	−9.15461

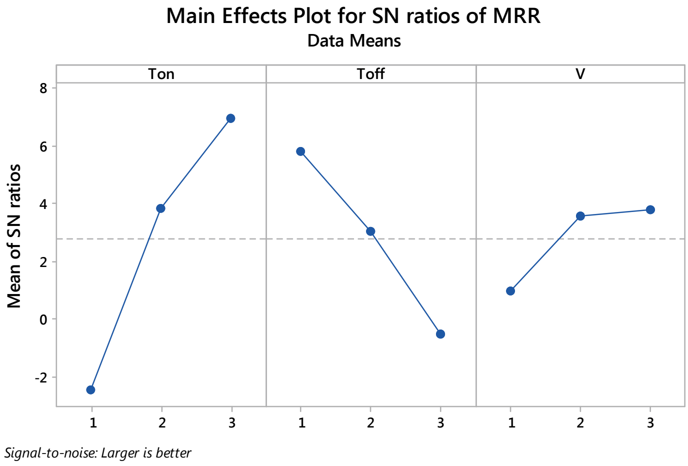

Fig. 2 Effect of parameters on MRR

Table 6 Response for S/N ratios for MRR

Level	T_{on}	T_{off}	V
1	−2.4645	5.8179	0.9775
2	3.8127	3.0274	3.5704
3	6.9710	0.5260	3.7714
Delta	9.4355	6.3438	2.7939
Rank	1	2	3

the ranks are (1) pulse-on time (T_{on}), (2) pulse-off time (T_{off}) and (3) servo voltage (V).

3.2 Analysis of Variance

Influence of process parameters on MRR and SR has calculated, and the contribution of each parameter on response has presented in Table 7. From Table 7, ANOVA shows the importance of selected input parameters on MRR. It has concluded that the MRR is influenced by T_{on} of 56.72%, T_{off} contributes of 19.60% and servo voltage (V) contributes of 6.89%.

Table 7 ANOVA results for MRR

Source	DF	Seq SS	Contribution (%)	Adj SS	Adj MS	F-value	p-value
T_{on}	2	0.34852	56.72	0.34852	0.17426	3.38	0.228
T_{off}	2	0.12044	19.60	0.12044	0.06022	1.17	0.461
V	2	0.04236	6.89	0.04236	0.02118	0.41	0.709
Error	2	0.10314	16.79	0.10314	0.05157		
Total	8	0.61446	100.00				

3.3 Surface Roughness (Ra)

The results obtained from Taguchi analysis for surface roughness (Ra) indicate that with an increase in pulse-on time, the surface roughness decreases. Similarly, an increase in pulse-off time, the Ra shows slight variation. Figure 3 shows the plot of S/N ratio effect on surface roughness. Table 8 shows the S/N ratio of each parameter and its relation with surface roughness. S/N ratio for Ra has calculated for smaller

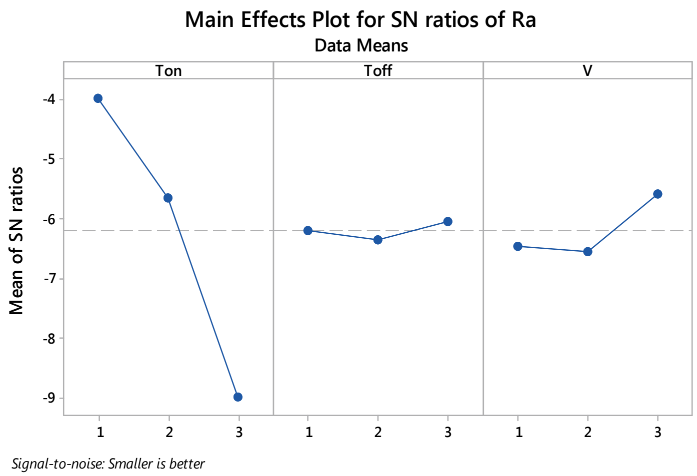

Fig. 3 Variation of S/N ratio with selected parameters for Ra

Table 8 Response for S/N ratios for Ra

Level	T_{on}	T_{off}	V
1	−3.964	−6.201	−6.458
2	−5.642	−6.358	−6.555
3	−8.995	−6.042	−5.588
Delta	5.031	0.315	0.968
Rank	1	3	2

Table 9 ANOVA result for surface roughness

Source	DF	Seq SS	Contribution (%)	Adj SS	Adj MS	F-value	p-value
T_{on}	2	0.050328	95.71	0.050328	0.025164	6688.24	0.000
T_{off}	2	0.000169	0.32	0.000169	0.000084	22.42	0.043
V	2	0.002081	3.96	0.002081	0.001040	276.52	0.004
Error	2	0.000008	0.01	0.000008	0.000004		
Total	8	0.052585	100.00				

the better by Taguchi analysis; the ranks are (1) T_{on}, (2) T_{off} and (3) servo voltage (V).

The ANOVA constructed from the experimental data for surface roughness (Ra) shows that the percentage contribution of each control factor on Ra. From Table 9, it can conclude that surface roughness (Ra) is profoundly affected by T_{on} which is contributed by 95.71%, servo voltage contributes of 3.96% and T_{off} contributes of 0.32% with an error of 0.01%.

3.4 Grey Relational Analysis

The most popular optimization techniques used for multiple responses in engineering problems is grey relational analysis. In GRA, multiple quality responses have been converted into a single grade. GRA used as the performance measurement characteristic where multiple parameters against the multiple responses have to be optimized.

Based on grey relational normalized and grey relation coefficient value, the grey relational grade has been calculated corresponding to each response value. From the grey relation grade (GRG), the value which nearer to one corresponding to that GRG process parameters is the optimum parameters for maximum MRR and minimum surface roughness value for the operation on AISI 304, which is depicted in Table 10.

It has concluded that the experiment number 4 has the highest grey relation grade value, i.e., nearer to one, thus, a perfect combination of process parameters for MRR and SR.

4 Conclusions

The experiments were conducted based on the L9 orthogonal array on AISI 304 steel using WEDM. The following conclusion has drawn from the present study:

(a) The optimized input parameters for maximum MRR are pulse-on time of 110 μs, pulse-off time of 55 μs and servo voltage of 40 V.

Table 10 Optimized grey relational grade

Ex. No.	GR normalized value		GR coefficient value		Grey relational grade
	MRR	SR (Ra)	MRR	SR (Ra)	
1	0.022206	0.883366	0.338342	0.810854	0.574598
2	0	0.840954	0.333333	0.758673	0.546003
3	0.053336	1	0.345623	1	0.672811
4	1	0.63552	1	0.578383	0.789191
5	0.30513	0.757455	0.418456	0.67336	0.545908
6	0.003713	0.666004	0.33416	0.599523	0.466842
7	0.777944	0.207422	0.692467	0.386824	0.539646
8	0.718753	0	0.640003	0.333333	0.486668
9	0.26868	0.055003	0.406068	0.346022	0.376045

(b) From the analysis of variance for MRR, pulse-on time and pulse-off time is the significant factor.

(c) From grey relational grade, it has observed that the optimum process parameters combinations are the pulse-on time of 105 μs, pulse-off time of 55 μs and servo voltage of 30 V for better MRR and Ra.

References

1. Müller F, Monaghan J (2000) Non-conventional machining of particle reinforced metal matrix composite. Int J Mach Tools Manuf 40(9):1351–1366
2. Peuratos I (2004) Analysis of the influence of EDM parameters on the surface quality, MRR and EW of WC-Co. J Mater Process Technol 153:1026–1032
3. Vijaya Babu T, Soni JS (2018) Investigation of process parameters optimization in die-sinking and wire-cut EDM to improve process performance using Taguchi technique. Mater Today Proc 5(13):27088–27093
4. Varun A, Venkaiah N (2015) Simultaneous optimization of WEDM responses using grey relational analysis coupled with genetic algorithm while machining EN 35. Int J Adv Manuf Technol 76(1–4):675–690
5. Mathew B, Benkim, Babu J (2014) Multiple process parameters optimization of WEDM on AISI 304 using Taguchi grey relational analysis. Int Conf Adv Manuf Mater Eng 5:1613–1622
6. Nayak BB, Mahapatra SS (2016) Optimization of WEDM process parameters using deep cryo-treated Inconel 718 as work material. Eng Sci Technol Int J 19(1):161–170
7. Durairaj M, Sudharsun D, Swamynathan N (2013) Analysis of Process parameters in wire EDM with stainless steel using single objective Taguchi method and multi-objective grey relational grade. Procedia Eng 1(64):868–877
8. Rebolo JC, Morao Dias A, Mesquita R (2000) An experimental study on electro-discharge machining and polishing of high strength copper-beryllium alloys. J Mat Process Technol 103(3):389–397
9. Rabindranath B, Madhu V, Gogia AK (2015) Multi response optimization of wire-EDM process parameters of ballistic grade aluminium alloy. Eng Sci Technol Int J 18(4):720–726

10. Kumar A, Maheswari S, Sharma C, Beri N (2010) A study of multiobjective parametric optimization of silicon abrasive mixed electrical discharge machining of tool steel. Mater Manuf Process 25(10):1041–1047