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Research Article

PROCESS PARAMETER OPTIMIZATION OF WIRECUT ELECTRIC DISCHARGE MACHINE ON TOOL STEEL A2 USING TAGUCHI METHOD

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ABSTRACT

This paper presents the effect of process parameters on material removal rate (MRR) and surface roughness (SR) of wire electric discharge machine (WEDM). Experimental work has been performed on Electronica Ecocut ELPULS-15 wirecut CNC machine, zinc coated brass wire having diameter 0.25 mm is used as a tool electrode and cold work tool steel A2 is used as a workpiece material. By using Taguchi design approach, L_9 orthogonal array has been chosen for the optimization and ANOVA for the analysis of experimental results in MINITAB-18. After analysis, it is concluded that wire tension (W_T), pulse on time (T_{ON}) are the most significant and spark gap set voltage (S_V), pulse off time (T_{OFF}) are the less significant parameters on MRR. S_V and W_T are the most significant and T_{ON}, T_{OFF} are the less significant parameters on SR.

INTRODUCTION

WEDM is the best choice of the non-conventional EDM principle which consists of a worktable, wire drive & controller mechanism. WEDM is a machining process, producing complex geometry shapes (2-D or 3-D shapes) using a simple wire eroding the material from an electrically conducting material. WEDM has a movable worktable which is used for bounding the workpiece and provide motion along X-axis and Y-axis. In WEDM, the wire is wound on wire spool that has continuous rotating during machining along the Z-axis and used wire is stored in wire box by wire take-up wheels. It is preferable to use thin electrode wire (as a tool) which is made from brass, copper, molybdenum and tungsten material to their physical significance and wire moves through the workpiece. The working principle of WEDM is based on the removal of metal from the workpiece by using vaporization and material melting by an electric spark. In WEDM process, electrical energy is converted into thermal energy by spark erosion, electrical energy is produced due to the cathode-anode operation and spark is produced between wire (anode) and workpiece (cathode) in the presence of dielectric fluid. A pulse generator is used to generate the continuous pulse which is applied between workpiece and moving wire. In very less span of time, sparks are generated by which amount of heat increase sharply. The heat generates due to conversion of kinetic energy of electrons into heat.

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This high energy is required to erode the material from the workpiece by using thermal vaporization process. One important thing about WEDM that it doesn't involve any cutting force due to absence of contact between workpiece and charged wire. Those parts that require level of accuracy and complexities that conventional machining can't approach but can easily be produced via WEDM. Due to its electro-thermal process, WEDM has found extreme potential in the field of conductive material machining. For highest degree of surface finishing and dimensional accuracy on small-scale industrial production, WEDM is the best alternative [1-4].

LITERATURE REVIEW

Kumar A. *et al.* studied the effect of process parameter like T_{ON}, T_{OFF}, peak current (I_P), and S_V on MRR and SR. For experimentation, they used Monal K-500 as a workpiece on Ultima-IF Wire-cut-EDM. By using Taguchi Design approach, L_{27} orthogonal array is selected for the experimentation and Gray relational analysis (GRA) for optimization and analysis the experimental results and they got T_{ON}, T_{OFF}, I_P, and S_V effects on MRR and SR, for optimal multi-characteristic setting optimization had setup some confirmation on WEDM as T_{ON} -123μs, T_{OFF} -50μs, I_P -13A, S_V -30V [5].

Aggarwal V. *et al.* described the effect of process parameters as T_{ON}, T_{OFF}, I_P, S_V, wire feed (W_F) and wire tension (W_T) on MRR and SR. For experimentation, they used zinc coated brass wire 0.25 mm diameter and Inconel 718 as a workpiece material on Electra sprintcut CNC WEDM. Response surface methodology (RSM) is chosen for experiments design, and ANOVA for analysis the experimental results and after analyzing the results, it is found that T_{ON} was the highly affected parameter on MRR, T_{ON} and S_V are highly affected parameters on SR [6].

Singh J. *et al*. determined the effect of process parameters as T_{OFF}, I_P, W_T,W_F,T_{ON}, S_V on MRR, SR. For experimentation, they used brass wire 0.25 mm diameter as a tool electrode and P20 tool steel as a workpiece material on sprintcut 734 CNC WEDM. By using Taguchi design approach, L_9 orthogonal array chosen for design of experiments. After analysis the results, they got as the increase in the level of I_P, T_{ON} the value of MRR increased but on the other hand decreases in the levels of S_V, T_{OFF} MRR decreased. SR increased with ncrease in the levels of T_{ON}, I_P and W_F and decreased with decrease in the levels of T_{OFF}, S_V, W_T [7].

Singh J. *et al*. described the effect of process parameters as T_{ON}, T_{OFF}, I_P, S_V, W_T, W_F on MRR and SR. For experimentation, they used brass wire 0.25mm diameter as a tool electrode and H-13 Hot work tool steel as a workpiece on Electra sprintcut 734 CNC WEDM. By using Taguchi design approach, L_{18} orthogonal array chosen for the design of experiments. After analysis, it was found that the MRR increased with increase the levels of T_{ON} and I_P and MRR decreased with decreases the levels of T_{OFF} and S_V. SR increased with increase the levels of T_{ON}, I_P and W_F and SR decreased with decreases in the levels of T_{OFF}, S_V, W_T [8].

Prajapati S. *et al*. investigated the effect of process parameters as T_{ON}, T_{OFF}, S_V, W_T, W_F on MRR, kerf width and SR. For experimentation, they used AISI A2 tool steel as a workpiece material on Electra sprintcut 734 CNC WEDM. By using Taguchi design approach, L_{27} orthogonal array chosen for experimentation. After analysis the results, it is found that the T_{ON} and T_{OFF} are the most effective process parameter for MRR and SR. SV is effective for kerf width [9].

Shah C. *et al*. described the effect of process parameters as T_{ON}, I_P T_{OFF}, W_F on MRR. For experimentation, they used molybdenum wire 0.18 mm diameter and Inconel 600 as a workpiece material on Concord DK7720C CNC WEDM. By using Taguchi design approach, L_{18} orthogonal array chosen for experimentation and ANOVA for analysis the experimental results. After analysis the experimental results, they got increase in the levels of I_P, T_{ON} MRR increased and decreases in the level of T_{OFF} MRR decreased [10].

Patel *et al*.investigated the effect of process parameters as T_{ON}, T_{OFF}, I_P and W_T on MRR and SR. For experimentation, they used brass wire 0.25 mm diameter and Stainless-Steel grade-304 as a workpiece material on 4-axis Electronica sprintcut CNC WEDM. By using Taguchi design approach, L_9 orthogonal array chosen for experimentation and ANOVA for analysis. After analysis the experimental results, it is found that the increase in levels of I_P, T_{ON} MRR increased. SR decreased with increase in levels of I_P, T_{OFF}[11].

Reddy B. *et al*.determined the effect of process parameters (T_{OFF}, I_P,T_{ON}, bed speed) on SR, MRR. For experimentation, they used molybdenum wire 0.18 mm diameter and P20 die tool steel as a workpiece material on Concord DK7720C CNC WEDM. By using Taguchi design approach, L_{16} orthogonal array chosen for experimentation. After analysis the experimental results, they found that the MRR increased with increase in process parameters are T_{ON} and I_P, and surface quality is better at low level of T_{OFF} and I_P[12].

Jangra K. *et al*. investigated the effect of process parameters as T_{ON}, I_P, W_T, water pressure (W_P) and taper angle on MRR, SR. For experimentation, they used 0.25 mm diameter zinc coated brass wire as a tool electrode and Tungsten carbide-cobalt (WC-Co) composite material as a workpiece on 5-axis Electronica Sprintcut ELPULS 40 CNC WEDM. By using Taguchi design approach, L_{18} orthogonal array chosen for experimentation and GRA for analysis the experimental results. After analyzing the results, they got the process parameters T_{ON}, T_{OFF} and taper angle are highly significant on MRR and SR [13].

Kumar M. *et al*. described the effect of process parameters such as T_{ON}, T_{OFF}, S_V and W_F on MRR, SR and kerf width. For experimentation, they used 0.25 mm diameter brass wire as a tool electrode and Inconel 800 superalloy as a workpiece on 4-axis Electronica Ecocut CNC WEDM. By using Taguchi design approach, L_9 orthogonal array chosen for experimentation and GRA for analysis the experiment results. After analyzing the results, they got the optimum values of input parameters are T_{ON} -10µs, T_{OFF} - 6µs, S_V - 50V, W_F - 8mm/min for the better performance of output parameters on WEDM [14].

Singh H. *et al*. investigated the effect of process parameters as T_{ON}, S_V, I_P, W_T and W_F on MRR. For experimentation, they used CUZN37 coated brass wire having 0.25 mm diameter and hot die tool steel H-11 as a workpiece on Electronica Sprintcut CNC WEDM. After optimization and analysis of experimental results, they got the increase in the levels of I_P, T_{ON} MRR increased. On the other hand, increases in the level of S_V, T_{ON} MRR decreased. W_F and W_T have negligible effect on MRR [15].

Kanlyasiri *et al*.determined the effect of process parameters (I_P, T_{ON}, W_T, T_{OFF}) on SR. For experimentation, they used zinc coated brass wire 0.25 mm diameter and DC53 die steel as a workpiece material on Sodick model A280 CNC WEDM. After analysis of experimental results by AVOVA, it was found that the process parameters like as T_{ON}, I_P are highly affected on SR, and SR increased while increasing the level of T_{ON} and I_P [16].

Cold work tool steel A2 is having wide application in manufacturing industry. In this research work optimization of process parameters of cold work tool steel A2 on WEDM have been performed. The experimental work is further analyzed using Taguchi and ANOVA optimization techniques in MINITAB 18.

Experimental Setup

Machine tool- The experiments have been performed on Electronica Ecocut ELPULS-15 wire cut CNC machine of Electronica India Limited, Pune. It is a traveling CNC machine installed at RAS AUTO industry, Barhi industrial area, Sonipat (Haryana). Zinc coated soft brass wire having diameter 0.25 mm used as a tool electrode and distilled water as a dielectric fluid for experimentation. Experimental setup of Electronica Ecocut ELPULS-15 CNC WEDM is shown in figure-1.

Figure 1 Experimental setup of the WEDM

Workpiece material

In this research work, Cold work tool steel A2 is used as a work piece for the experimentation. It is an air hardening chromium-molybdenum-vanadium alloy tool steel having good toughness with appropriate wear resistance and is relatively easy to machine, so it is widely used in many applications in manufacturing industries etc. Tool steel A2 is less expensive as compared to the high chromium type of tool steel, due to despite lower percentage of chromium content (0.30%) without affecting its non-deformation property. The amount of carbon (0.5% to 2%), is used for negligible deformation and minimum cracking by air quenching. Dimensions of the workpiece are 150 mm x 100 mm x 10 mm.Chemical composition of tool steel A2 is shown in table-1.

Table 1 Chemical composition of tool steel A2

Carbon	Manganese	Silicon	Chromium	Molybdenum	Vanadium	Nickel	Iron
1.00%	0.75%	0.30%	0.30%	1.00%	0.25%	0.30%	Remaining

Selection of orthogonal array

Taguchi developed a method, the important property of this technique was to minimize the robust of the design during the machining process. Taguchi design approach is adopted as engineering strategies rather to focus on advancement in technology for optimization of parameters and for generating products with high productivity at low cost. Taguchi method selected forthe experimental work. Selection of orthogonal array depends on the total degree of freedom. Four process parameters with three levels are considered for the experimental work. The total degree of freedom according to parameters and levels is equal to 8, therefore L_9 orthogonal array has been selected for performing the experiments. Four Process parameters like as T_{ON}, T_{OFF}, W_T, S_V have been selected for the experimental work and studied of these process parameters on MRR and SR. Process parameters and their level are shown in table-2.

Table 2 Level of process parameters

Sr. No.	Process parameter	Level 1	Level 2	Level 3
1	TON(μs)	120	125	130
2	TOFF(μs)	38	43	48
3	WT(N)	10	12	14
4	SV(V)	15	20	25

EXPERIMENTAL RESULTS

The experiments were performed in random order on WEDM. Experimental and analytical results are shown in table-3. MRR was measured in mm^3/min and SR measured in μm in term of Ra by using digital Mitutoyo Surftest SJ-201 surface roughness tester.

Mathematical formula used for calculating the values of MRR [16]

MRR= Cs x **B** x **H** (1)

Where MRR- Material removal rate (mm^3/min)

Cs- Cutting speed (mm/min)

B- Breadth of workpiece (mm) and H- Height of workpiece (mm)

Table 3 Experimental and analytical results

Exp. No.	T_{ON} (μs)	T_{OFF} (μs)	W_T (N)	S_V (V)	MRR (mm^3/min)	S/Nratio of MRR	SR (Ra)	S/N ratio of SR
1	120	38	10	15	10.257	20.2204	2.049	-6.23084
2	120	43	12	20	11.243	21.0176	2.313	-7.28351
3	120	48	14	25	8.587	18.6768	2.170	-6.72919
4	125	38	12	25	12.483	21.9264	2.313	-7.28351
5	125	43	14	15	10.285	20.2441	1.786	-5.03763
6	125	48	10	20	12.437	21.8943	2.225	-6.94660
7	130	38	14	20	9.900	19.9127	2.258	-7.07448
8	130	43	10	25	10.210	20.1805	2.313	-7.28351
9	130	48	12	15	11.709	21.3704	2.170	-6.72919

For calculating the value of S/N ratio of MRR and SR, as follows

$$\text{S/N ratio for MRR} = -10 \log_{10}(\text{sum}(1/y^2)/N) \quad (2)$$

$$\text{S/N ratio for SR} = -10 \log_{10}(\text{sum}(y^2)/N) \quad (3)$$

Where y= mean value and

N= total no. of experiments

RESULTS AND DISCUSSION

The S/N ratio and Means for MRR and SR obtained on basis of different process parameters were designed and plotted of results by Taguchi design methodology in the MINITAB-18 statistical analysis software.

Response table and graph for MRR

The analytical value of S/N data is shown in table-4 and data plotted in figure-2. According to table-4 and table-5, the values of Delta and Rank defines the W_T and T_{ON} which are the most significant and S_V, T_{OFF} are the less significant parameters on MRR. According to figure-2, the MRR will increase sharply by increasing T_{ON}, W_T, S_V. On the other hand, at the different level of the same parameters, the value of MRR decreases. The value of MRR decreases with increase in T_{OFF} on the other hand at the different level MRR increases. Maximum residual value is at order number 4, so it's an appropriate order for machining of tool steel A2 on WEDM and gets the maximum value of MRR as shown in figure-3.

Response table and graph for SR

The analytical value of S/N data is shown in table-6 and data is plotted in figure-4. According to table-6 and table-7, the values of Delta and Rank defines S_V, W_T which are the most significant and T_{ON}, T_{OFF} are the less significant parameters on SR. According to figure-4, the value of SR will have been decreased sharply by increasing S_V. The value of SR decreases with increase in W_T, on the other hand at the different level SR increases. The value of SR increases with increase in the level of T_{ON} and T_{OFF} levels, on the other hand, at the different level SR decreases.

Mathematical model for MRR and SR

Regression equation is established between process parameters and responses. The following equations 4 and 5 are used to calculate the predicted values of MRR and SR respectively.

Regression equation for MRR

$$MRR = 8.2 + 0.058\, T_{ON} + 0.003\, T_{OFF} - 0.344\, W_T - 0.032\, S_V \qquad (4)$$

Regression equation for SR

$$SR = 1.23 + 0.0070\, T_{ON} - 0.0018\, T_{OFF} - 0.0311\, W_T + 0.0264\, S_V \qquad (5)$$

The comparison of predicted value to the experimental values of MRR and SR in tabular form is shown in table-8, 9 respectively.

Table 4 Response table of S/N ratio for MRR (Larger is better)

Level	T_{ON}	T_{OFF}	W_T	S_V
1	19.97	20.69	20.77	20.61
2	21.35	20.48	21.44	20.94
3	20.49	20.65	19.61	20.26
Delta	1.38	0.21	1.83	0.68
Rank	2	4	1	3

Table 5 Results of ANOVA on MRR

Source	DF	Adj SS	Adj MS	F-Value	P-Value
T_{ON}	1	0.5000	0.49997	0.21	0.672
T_{OFF}	1	0.0014	0.00144	0.00	0.982
W_T	1	2.8456	2.84557	1.18	0.338
S_V	1	0.1571	0.15714	0.07	0.811
Error	4	9.6453	2.41133		
Total	8	13.1495			

Table 6 Response table of S/N ratio for SR (Smaller is better)

Level	T_{ON}	T_{OFF}	W_T	S_V
1	-6.748	-6.863	-6.820	-5.999
2	-6.423	-6.535	-7.099	-7.102
3	-7.029	-6.802	-6.280	-7.099
Delta	0.606	0.328	0.818	1.102
Rank	3	4	2	1

Table 7 Results of ANOVA on SR

Source	DF	Adj SS	Adj MS	F-Value	P-Value
T_{ON}	1	0.007280	0.007280	0.30	0.615
T_{OFF}	1	0.000504	0.000504	0.02	0.893
W_T	1	0.023188	0.023188	0.94	0.387
S_V	1	0.104280	0.104280	4.24	0.109
Error	4	0.098462	0.024615		
Total	8	0.233714			

Table 8 Predicted and experimentally values of RR(mm^3/min)

Exp. No.	1	2	3	4	5	6	7	8	9
Predicted	11.334	10.521	10.324	10.666	10.283	11.523	10.398	11.63	11.276
Experimentally	10.257	11.243	8.587	12.483	10.285	12.437	9.9	10.21	11.709

Table 9 Predicted and experimentally values of SR(Ra)

Exp. No.	1	2	3	4	5	6	7	8	9
Predicted	1.471	2.147	2.208	2.323	1.988	2.236	2.164	2.412	2.076
Experimentally	2.049	2.313	2.170	2.313	1.786	2.250	2.258	2.313	2.170

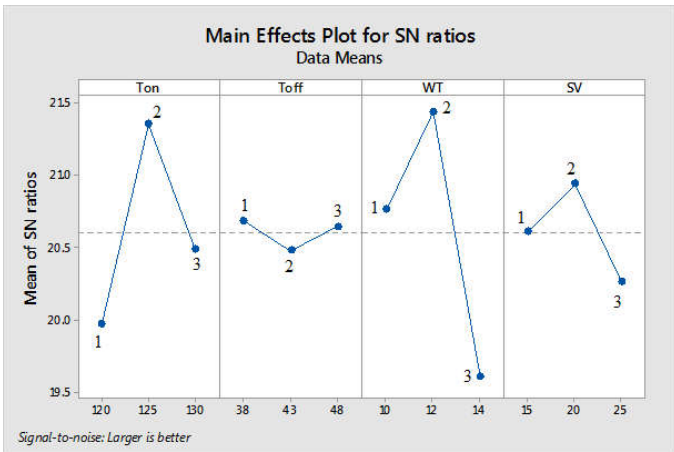

Figure 2 Effect on process parameters on MRR (S/N ratio)

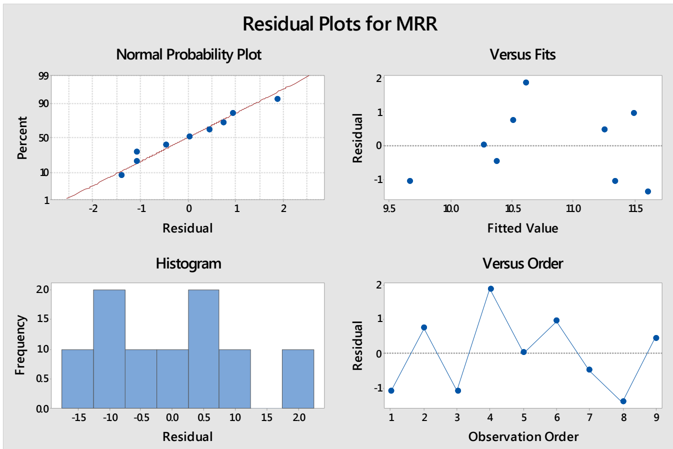

Figure 3 Residual plots for MRR

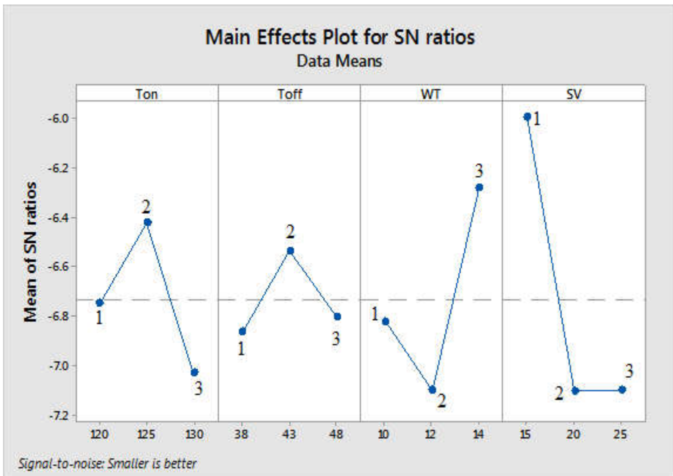

Figure 4 Effect on process parameters on SR (S/N ratio)

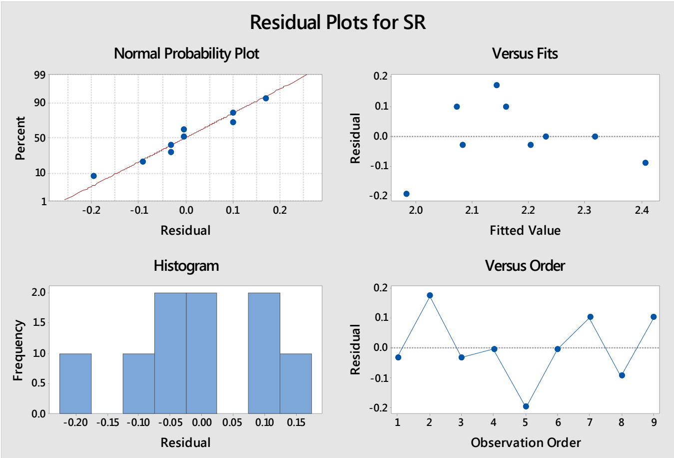

Figure 5 Residual plots for SR

CONCLUSIONS

Conclusions for MRR

1. Process parameters, W_T and T_{ON} are the most significant and T_{OFF} and S_V are less significant parameters on MRR.
2. The value of MRR will increase sharply by increasing T_{ON}, W_T, S_V but on the other hand at the different level of the same parameters, the value of MRR decreases. The value of MRR decreases with increase in T_{OFF} but on the other hand at the different level, value of MRR increases.
3. For getting the maximum value of MRR, optimum setting of process parameters as T_{ON} -125 µs, T_{OFF} -48 µs, W_T - 12 N, S_V -25 V, during machining on WEDM of tool steel A2.
4. Predicted optimum value for MRR is 13.27 mm³/min at $T_{ON}2$, $T_{OFF}3$, W_T2, and S_V2. The 95 % confidence interval (CI_{CE}) for MRR is $7.90 \leq \mu_{MRR} \leq 18.64$ mm^3/min.

Conclusions for SR

1. Process parameters, S_v and W_T are the most significant but T_{ON} and T_{OFF} are less significant parameters on SR.
2. The value of SR decreases with increase in W_T but on the other hand, at the different level, SR increases. The value of SR increases with increase in the level of T_{ON} and T_{OFF} levels, on the other hand at the different level SR decreases.
3. Optimum setting of parameters as T_{ON}-125 µs, T_{OFF}-43 µs, W_T-14 N, S_V-15 V, machining on WEDM of tool steel A2 for getting the optimal value of SR.
4. Predicted optimum value for SR is 1.787 µm at $T_{ON}2$, $T_{OFF}2$, W_T3, S_V1. The 95 % confidence interval (CI_{CE}) for SR is $1.245 \leq \mu_{SR} \leq 2.329$ µm.

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