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Performance Analysis of Wire Electric Discharge Machining (W-EDM)

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Abstract

In this present study variation of cutting performance with pulse on time, pulse off time, open voltage, feed rate override, wire feed, servo voltage, wire tension and flushing pressure were experimentally investigated in wire electric discharge machining (WEDM) process. Brass wire with 0.25mm diameter and Skd 61 alloy steel with 10mm thickness were used as tool and work materials in the experiments. The cutting performance outputs considered in this study were material removal rate (MRR) and surface roughness. Experimentation has been completed by using Taguchi's L_{18} (2^1x3^7) orthogonal array under different conditions of parameters. Optimal combinations of parameters were obtained by this technique. The study shows that with the minimum number of experiments the complete problem can be solved when compared to full factorial design. The results obtained are analyzed for the selection of an optimal combination of WEDM parameters for proper machining of Skd 61 alloy to achieve better surface finish. In addition the importance of the cutting parameters on the cutting performance outputs is determined by using analysis of variance (ANOVA).

***Key words**: Wire EDM, MRR, Surface roughness, Taguchi method, ANOVA.*

1 Introduction:

Additional the growth of mechanical industry, the demands for alloy materials having high hardness, toughness and impact resistance are increasing. However, such materials are difficult to be machined by traditional machining methods. Hence, non-traditional machining methods including electrochemical machining, ultrasonic machining, electrical discharging machine (EDM) etc. are applied to machine such complicated to machine materials. WEDM process with a thin wire as an electrode transforms electrical energy to thermal energy for cutting materials. With this process, alloy steel, conductive ceramics and aerospace materials can be machined irrespective to their hardness and toughness. Furthermore, WEDM is capable of producing a fine, precise, corrosion and wear resistant surface.

WEDM is considered as a unique adoption of the conventional EDM process, which uses an electrode to initialize the sparking process(1). However, WEDM utilizes a continuously travelling wire electrode made of thin copper, brass or tungsten of diameter 0.05-0.30 mm, which is capable of achieving very small corner radii. The wire is kept in tension using a mechanical tensioning device reducing the tendency of producing inaccurate parts. During the WEDM process, the material is eroded ahead of the wire and there is no direct contact between the work piece and the wire, eliminating the mechanical stresses during machining.

2 Literature review:

WEDM is an essential operation in several manufacturing processes in some industries, which gives importance to variety, precision and accuracy. Several researchers have attempted to improve the performance characteristics namely the surface roughness, cutting speed**,** dimensional accuracy and material removal rate. Kanlayasiri and Boonmung (2007) investigated influences of wire-EDM machining variables on surface roughness of newly developed DC 53 die steel of width, length, and thickness 27, 65 and

13 mm, respectively(1). The machining variables included pulse-on time, pulse-off time, pulse-peak current, and wire tension. The variables affecting the surface roughness were identified using ANOVA technique. Results showed that pulse-on time and pulse-peak current were significant variables to the surface roughness of wire-EDM DC53 die steel. The maximum prediction error of the model was less than 7% and the average percentage error of prediction was less than 3%. Ramakrishnan and Karunamoorthy (2008) developed artificial neural network (ANN) models and multi response optimization technique to predict and select the best cutting parameters of wire electro-discharge machining (WEDM) process(2). Inconel 718 was selected as work material to conduct experiments and brass wire of 0.25mm diameter was used as tool electrode. Experiments were planned as per Taguchi L-9 orthogonal array. Experiments were performed under different cutting conditions of pulse on time, delay time, wire feed speed and ignition current. It was found that the pulse on time, delay time and ignition current had more influence than wire feed speed on the performance characteristics considered in the study. An MRR was improved with increase in pulse on time and ignition current. But the surface quality of the work specimen was affected adversely with increased value of pulse on time and ignition current. Gauri and Chakraborty (2008) suggested a modified approach of the principal component analysis (PCA) based procedure for multi-response optimization. Analysis was done data on experimental data on WEDM processes obtained by the past researchers i.e. on γ-titanium aluminized alloy with the settings of six controllable factors(3). Quality characteristics were material removal rate (MRR) (larger the better type), surface roughness (SR) (smaller the better type) and wire wear ratio (WWR) (smaller the better type). Rao and Sarcar (2009) analyzed the effects of process parameters on machining characteristics for CNC WEDM for brass work pieces of varying thickness. Mathematical relations were obtained for cutting speed, spark gap and MRR (4). Pradhan et. al. (2009). Optimized micro-EDM process parameters for machining Ti-6Al-4V super alloy. The influence of machining process parameters such as peak current, pulse-on-time, dielectric flushing pressure and duty ratio on performance criteria like MRR, TWR, over cut and taper have been examined(5). Manna and Kumar (2009) investigated the effects of various cutting parameters of WEDM on wire crater depth, electrode wear rate and surface roughness using Taguchi methods based on L-18 mixed orthogonal array(6).

3 Methodology

3.1 Taguchi Method

The quality engineering method proposed by Taguchi is commonly known as the Taguchi method or Taguchi approach. This approach provides a new experimental strategy in which a modified and standardized form of design of experiment (DOE) is used. In other words, the Taguchi approach is a form of DOE with special application (8). The concept of the Taguchi method is that the parameter design is performed to reduce the sources of variation on the quality characteristics of product, and reach a target of process robustness Taguchi designs experiments using specially constructed tables known as "orthogonal array" (OA). It utilizes the orthogonal arrays from experimental design theory to study a large number of variables with a small number of experiments (9). This technique helps to study effect of many factors (variables) on the desired quality characteristic most reasonably. By studying the effect of individual factors on the results, the best factor combination can be determined. The standardized Taguchi-based experimental design used in this study is an L_{18} orthogonal array.

3.2 Signal-to-Noise ratios (S/N ratio)

In the Taguchi method, the term 'signal' represents the desirable value (mean) for the output characteristic and the term 'noise' represents the undesirable value (S.D) for the output characteristic. Therefore, the S/N ratio is the ratio of the mean to the S.D. S/N ratio is used to measure the quality characteristic deviating from the desired value (8-9). The S/N ratio η is defined as

1. Larger the Better:
$S/N = -10 \log (1/n) \sum_{i=1}^{n} 1/y^2$--------------------------(1)

2. Smaller the Better:
$S/N = -10 \log (1/n) \sum_{i=1}^{n} y^2$----------------------------(2)

Where n = no of repetition

4 Experimental Setup

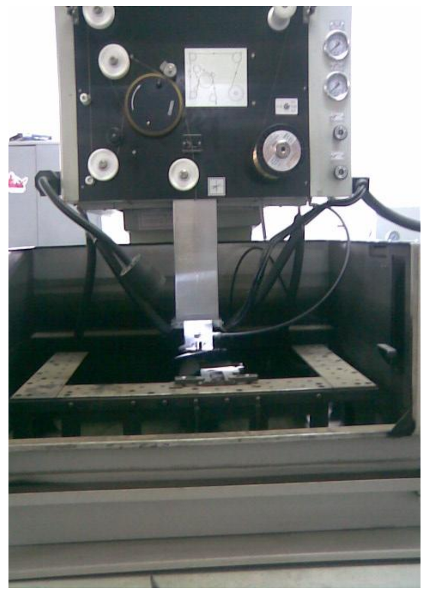
Experiments have been performed on five axes CNC Wire cut EDM (CHMER- CW64GS) at Process and Product Development Centre (PPDC) Agra U.P. (India). The photographic view of CNC Wire cut EDM and experimental set-up are shown in Figure 1. A 0.25 mm diameter brass wire used in this experiment as a cutting tool and Skd 61 alloy steel plate of 100mm x

80mm x 10mm size is mounted on the CHMER-CW64GS WEDM machine tool and specimens of 12mmx10mmx10mm size are cut according to Taguchi L_{18} design. Chemical composition of material is given in Table1

Table 1 Chemical composition of Skd 61 alloy steel

Material	**C**	**Si**	Mn	P	**S**	**Cr**	**Mo**	**Cu**	**V**
Skd 61	0.38	0.9	0.28	0.03	0.02	4.9	1.2	0.26	0.95

(a)



(b)

Figure 1 CNC Wire cut EDM (a) and experimental set-up(b)

4.1 Material Removal Rate (MRR)

The mean cutting speed data (Cs) was observed directly from the computer monitor, which was attached to the machine tool. Generally, during this process the wire diameter is kept constant.
Therefore, the width of cut (W) remains constant. Therefore, the MRR for the WEDM operation is calculated using Eq. 3 which is shown below:

MRR = ***Cs*** **X** *L* -- (3)

Where Cs = cutting speed in mm/mint. L = thickness of the material in mm.

4.2 Surface Roughness measurement

It was measured on Subtronic-10 surface tester giving Ra value in microns. Ra is measured along four different lines on the surface and the average value is considered for further analysis.

5 Selection of cutting parameters

Eight machining parameters were selected as control factors, one parameter have two levels and seven parameters have three levels, denoted by 1, 2, and 3. The experimental design was based on L_{18} orthogonal array based on Taguchi method. Minitab 15 software was used for graphical analysis of the obtained data (10).

Table 2 Wire EDM parameters and their levels

S. No	Parameters	Symbol	Level 1	Level 2	Level 3	Units
1	Pulse On time	T ON	5	10	-	μsec
2	Pulse Off time	TOFF	22	37	52	μsec
3	Open voltage	OV	5	10	15	volt
4	Feed Rate override	FR	10	20	30	mm/min
5	Wire feed	WF	5	10	15	mm/sec
6	Servo voltage	SV	35	55	75	volt
7	Wire tension	WT	5	10	15	N
8	Flushing pressure	WP	3	5	7	Kg/cm^2

Table 3 Experimental design using L18 orthogonal array

S.NO	TON	TOFF	OV	FR	WF	SV	WT	WP
1	5	22	5	10	5	35	5	3
2	5	22	10	20	10	55	10	5
3	5	22	15	30	15	75	15	7
4	5	37	5	10	10	55	15	7
5	5	37	10	20	15	75	5	3
6	5	37	15	30	5	35	10	5
7	5	52	5	20	5	75	10	7
8	5	52	10	30	10	35	15	3
9	5	52	15	10	15	55	5	5
10	10	22	5	30	15	55	10	3
11	10	22	10	10	5	75	15	5
12	10	22	15	20	10	35	5	7
13	10	37	5	20	15	35	15	5
14	10	37	10	30	5	55	5	7
15	10	37	15	10	10	75	10	3
16	10	52	5	30	10	75	5	5
17	10	52	10	10	15	35	10	7
18	10	52	15	20	5	55	15	3

6 Results and Discussion

6.1.1 Effect of process parameters on MRR

In order to see the effect of process parameters on the MRR, experiments were conducted using L18 OA (Table 3). The experimental data is given in Table 4. Figure 2 show that the MRR increases with the increase in pulse on time and decreases with increase in pulse off time and open voltage. The effects of feed rate override, wire feed, servo voltage, wire tension and flushing pressure on MRR are not very significant.

6.1.2 Selection of optimal levels

Analysis of Variance (ANOVA) table 5 shows that the significance of the process variables towards MRR. The response table 6 shows the average of each response characteristic for each level of each factor. The tables include ranks based on delta statistics, which compare the relative magnitude of effects. The delta statistic is the highest minus the lowest average for each factor. Minitab assigns ranks based on delta values; rank 1 to the highest delta value, rank 2 to the second highest, and so on. The ranks indicate the relative importance of each factor to the response. The ranks and the delta values show that pulse off time have the greatest effect on MRR and is followed by pulse on time, feed rate override and open voltage in that order. As MRR is the "higher the better"

Table 4 Experimental results for MRR and Surface Roughness.

S. NO.	MRR mm^2/min	S/N Ratio	Surface Roughness µm	S/N Ratio
1	48.10	33.6429	1.82	-5.221
2	51.20	34.1854	2.03	-6.168
3	42.80	32.6289	2.50	-7.961
4	41.60	32.3819	2.54	-8.119
5	41.10	32.2768	1.89	-5.549
6	38.60	31.7317	2.60	-8.289
7	39.80	31.9977	1.59	-4.063
8	31.20	29.8831	2.74	-8.744
9	31.40	29.9386	2.93	-9.338
10	58.60	35.3580	2.07	-6.332
11	57.50	35.1934	2.90	-9.258
12	51.10	34.1684	3.24	-10.229
13	57.20	35.1479	3.65	-11.249
14	43.20	32.7097	3.13	-9.902
15	48.00	33.6248	2.88	-9.188
16	41.70	32.4027	1.91	-5.606
17	45.90	33.2363	2.73	-8.743
18	45.00	33.0643	3.09	-9.819

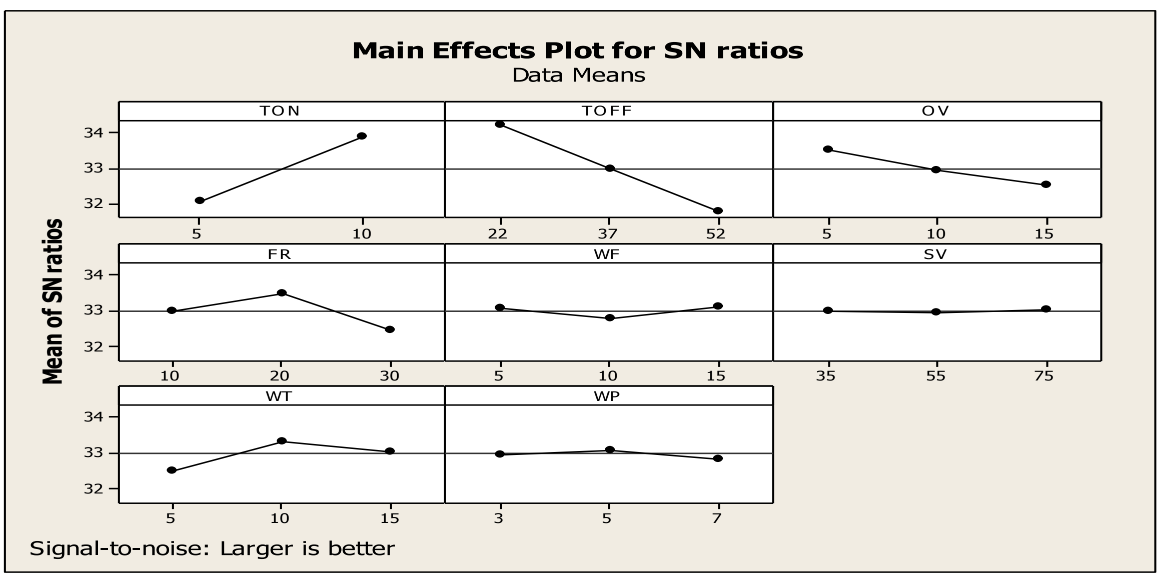


Figure 2 Effect of control parameters on MRR

type quality characteristic, it can be seen from Figure 2 that the second level of pulse on time (A2), first level of pulse off time(B1), first level of open voltage(C1), second level of feed rate override(D2), third level of wire feed(E3), third level of servo voltage(F3), second level of wire tension(G2) and second level of flushing pressure(H2) provide maximum value of MRR

Table 5 Analysis of Variance for MRR

Source	DF	Seq SS	Adj SS	Adj MS	F	P
TON	1	377.209	377.209	377.209	342.74	0.003
TOFF	2	460.708	460.708	230.354	209.31	0.005
OV	2	75.881	75.881	37.941	34.47	0.028
FR	2	71.881	71.881	35.941	32.66	0.030
WF	2	12.591	12.591	6.296	5.72	0.149
SV	2	0.148	0.148	0.074	0.07	0.937
WT	2	58.121	58.121	29.061	26.41	0.036
WP	2	14.631	14.631	7.316	6.65	0.131
Error	2	2.201	2.201	1.101		
Total	17	1073.371				

Table 6 Response Table for MRR Signal to Noise Ratios Larger is better

Level	TON	TOFF	OV	FR	WF	SV	WT	WP
1	32.07	34.20	33.49	33.00	33.06	32.97	32.52	32.97
2	33.88	32.98	32.91	33.47	32.77	32.94	33.36	33.10
3	-	31.75	32.53	32.45	33.10	33.02	33.05	32.85
Delta	1.80	2.44	0.96	1.02	0.32	0.08	0.83	0.25
Rank	2	1	4	3	6	8	5	7

6.2.1 Effect of process parameters on Surface Roughness

In order to see the effects of process parameters on the surface roughness, experiments were conducted using L18 OA (Table 3). The experimental data are given in Table 4. It is seen from the Figure 3 that surface roughness decrease with the increase of pulse on time, open voltage and wire feed and increases with increase in feed rate override and servo voltage. Surface roughness first decrease then increase with pulse off time. Surface roughness first increase then decrease with wire tension. The effect of other parameter is not significant.

6.2.2 Selection of Optimal Levels

Analysis of Variance (ANOVA) table 7 shows that the significance of the process variables towards surface roughness. The response table 8 shows the average of each response characteristic for each level of each factor. The Table include ranks based on delta statistics, which compare the relative magnitude of effects. The delta statistic is the highest minus the lowest average for each factor. Minitab assigns ranks based on delta values; rank 1 to the highest delta value, rank 2 to the second highest, and so on. The ranks indicate the relative importance of each factor to the response. The ranks and the delta values for various parameters show that open voltage has the greatest effect on surface roughness and is followed by wire tension, pulse on time, servo voltage, pulse off time, fluid pressure, feed rate over ride and wire feed in that order. As surface roughness is the “lower the better” type quality characteristic, from Figure 3 it can be seen that the first level of pulse on time(A1), first level of pulse off time(B1), first level of open voltage(C1), third level of feed rate over ride(D3), first level of wire feed(E1), third level of servo voltage(F3), second level of wire tension(G2) and first level of flushing pressure(H1) result in minimum value of surface roughness.

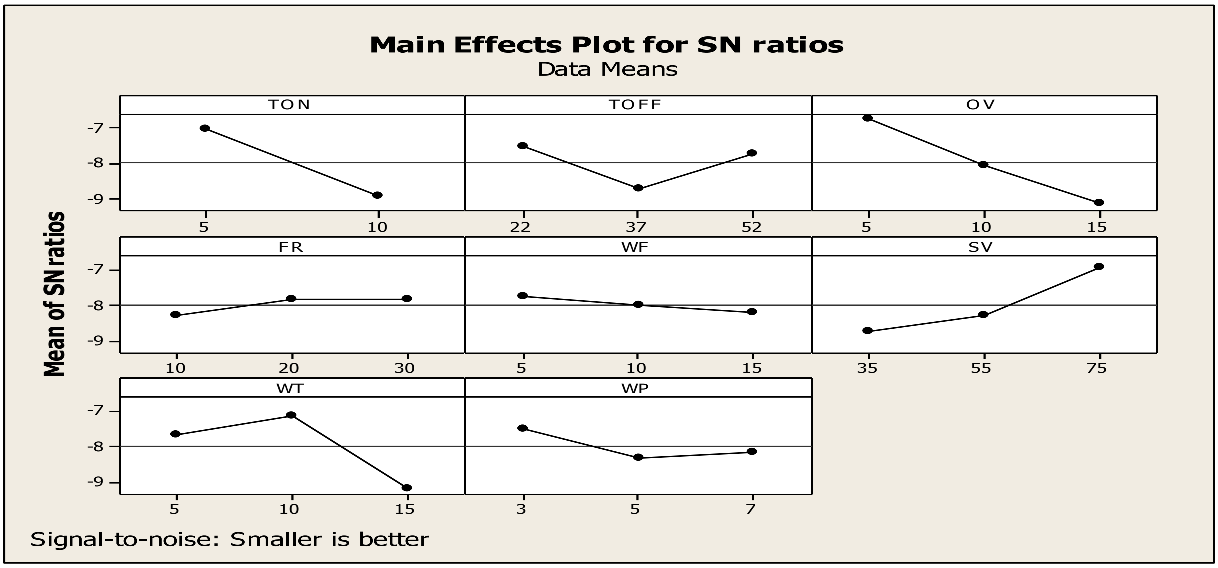


Figure 3 Effect of control parameters on surface roughness

Table 7 Analysis of Variance for Surface Roughness

Source	DF	Seq SS	Adj SS	Adj MS	F	P
TON	1	1.3668	1.3668	1.3668	6.84	0.120
TOFF	2	0.4229	0.4229	0.2114	1.06	0.486
OV	2	1.1163	1.1163	0.5582	2.79	0.264
FR	2	0.0617	0.0617	0.0308	0.15	0.866
WF	2	0.0355	0.0355	0.0177	0.09	0.918
SV	2	0.8415	0.8415	0.4207	2.11	0.322
WT	2	1.0934	1.0934	0.5467	2.74	0.268
WP	2	0.2201	0.2201	0.1101	0.55	0.645
Error	2	0.3995	0.3995	0.1997		
Total	17	5.5576				

Table 8 Response Table for Signal to Noise Ratios for surface roughness Smaller is better

Level	TON	TOFF	OV	FR	WF	SV	WT	WP
1	-7.040	-7.515	-6.752	-8.299	-7.748	-8.739	-7.635	-7.465
2	-9.918	-8.712	-8.053	-7.827	-8.004	-8.269	-7.118	-8.317
3	-	-7.711	-9.132	-7.811	-8.186	-6.929	-9.184	-8.155
Delta	1.879	1.197	2.380	0.488	0.438	1.811	2.066	0.852
Rank	3	5	1	7	8	4	2	6

7 Confirmation experiment

The confirmation experiment is the final step in any design of experiment process. Table 9 and Table 10 show the comparison of the predicted value with the new experimental value for the selected combinations of the machining parameters. As shown in these tables, the experimental values agree reasonably well with predictions because an error of 3.23 % for the S/N ratio of MRR and 9.76 % for the S/N ratio of surface roughness is observed when predicted results are compared with experimental values. Hence, the experimental result confirms the optimization of the machining parameters using Taguchi method for enhancing the machining performance. However, the error in MRR and surface roughness can be further expected to reduce if the number of measurements is increased.

Table 9 result of the confirmation experiment for MRR

	Predicted value	Experimental value	% error
Optimal level	A2B1C1D2E2F3G2H2	A2B1C1D2E2F3G2H2	
MRR	64.79	60.13	
S/N ratio for MRR	36.7768	35.5861	3.23

Table 10 result of the confirmation experiment for surface roughness

	Predicted value	Experimental value	% error
Optimal level	A1B1C1D3E1F3G2H1	A1B1C1D3E1F3G2H1	
Surface roughness	1.27944	1.42	
S/N ratio for surface roughness	-3.37546	-3.04576	9.76

8 Conclusions

In this work, it is intended to study factors pulse on time, pulse off time, open voltage, feed rate override, wire feed, servo voltage, wire tension and flushing pressure for maximizations of MRR and minimization of surface roughness in WEDM process using Taguchi Method. Analysis of the results leads to conclude that factors at level A2B1C1D2E2F3G2 and H2 can be set for maximization of MRR. Similarly, it is recommended to use the factors at levels such as A1B1C1D3E1F3G2 and H1 for minimization of surface roughness. The effects of pulse on time, pulse off time, open voltage, feed rate override, wire feed, servo voltage, wire tension and flushing pressure on MRR and surface roughness was experimentally investigated in machining of Skd 61 alloy using CNC Wire-cut EDM process. The results of confirmation experiment agree well the predicted optimal settings as an error of 3.23 % is found with MRR. Similarly, an error of 9.76 % was observed for surface roughness.

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