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Application of Taguchi Method for Determining Optimum Surface Roughness in Wire Electric Discharge Machining of P/M Cold Worked Tool Steel (Vanadis-4E)

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Abstract

This paper introduced on advancing the wire electrical discharge machine (WEDM) process parameters for the normal surface roughness (Ra) acquired in machining of VANADIS 4e (Powder metallurgical cold worked Tool steel). The Machining analyses were performed at WEDM machine utilizing 0.25 mm wire as electrode material on p/m cold worked tool steel. Taguchi L_{27} orthogonal array (OA) was utilized to outline of trial. Ideal methodology parameters were resolved utilizing the signal- to- noice (S/N) proportion which was computed for R_a as per "the- smaller- the-better" approach. The methodology parameters of WEDM procedure were pulse on time (ON), pulse off time (OFF), servo voltage (SV), peak current (IP), wire tension (WT) and water pressure (WP). The impacts of the methodology parameters on surface roughness were assessed by the examination of change (ANOVA). The most essential associations, that impact surface roughness of machined surfaces, are between the pulse on time (ON) and pulse on time(ON), pulse off time(OFF) and Peak current(IP), and between pulse on time(on) and Peak current(IP). The ideal estimation of surface roughness is anticipated at the ideal levels of noteworthy as Pulse on time (A1), pulse off time (B3), peak current (C3) and spark gap set voltage (D1) and wire tension (E3).

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Keywords: wire electrical discharge machine; optimization; Surface roughness; Taguchi design; ANOVA

1. Introduction

Non traditional machining methods are dynamically used to fabricate great mechanical segments. In non traditional

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machining methodology wire electrical discharge machine (WEDM) is a thermo electrical machining process in which the material is expelled from work piece by series of electrical sparks between wire electrode and work piece. The vitality substance of a single spark discharge is communicated as a result of pulse on time and peak current. Vitality contained in a minor sparkle release evacuates as part of work piece material. Extensive number of such time separated minor releases between work piece and wire electrode causes the electro disintegration of the work piece material. Al, brass, zinc covered metal or copper wires are generally used as electrode material. The distance across of the wire electrode is of 0.25mm to 0.50mm measurement .Wire electrical discharge machine will be machine instrument to create parts of perplexing and multifaceted segments in the field of tool and die, aviation, automobile, atomic, machine industry. In the present exploration study WEDM of VANADIS 4E (powder metallurgical cold worked tool steel) has been considered. This material is considered for exploration work because of its both high wear resistant and ductility. VANADIS 4E is a chromium-molybdenum-vanadium alloyed steel which is described by extremely ductility, high abrasive- adhesive wear and compressive strength, great dimensional stability amid heat treatment in service, great machine capacity and drudgery capability. The primary synthetic creation of VANADIS 4e is C-1.4%, Si-0.4%, mn-0.4%, Cr-4.7%, Mo-3.5% and Va-3.5% and the offset is Fe. The density of VANADIS 4E is 7700kg/m3.

2. Literature review

Speeding and Wang (1997) Performed trial study on AISI 420 steel to streamline the strategy parameters in combos by displaying the technique exploitation ANN and described the WEDM machined surface by arrangement system. M.i.gokler et.al. (2000) led investigates Sodic Mark XI A500 EDW WEDM as machine and 1040, 2379 and 2378 steels as work piece materials with a specific end goal to research the consequence of cutting and counterbalance parameters on surface roughness in WEDM process. From the results it totally was finished that, the counterbalance parameters doesn't have an impact on the surface roughness and same result with cutting parameters .If the thickness of the work piece will build, the average feed rate diminishes. Tusan et.al. (2003) utilized AISI 4140 steel as work piece material and Sodic A320/Ex21 WEDM as machine instrument directed tests to audit the varieties of cutting parameters with pulse on time, open circuit voltage, wire velocity and dielectric fluid pressure. The reactions thought-about amid this study were surface roughness and cutting rate. From the results it totally was discovered that the cutting speed and surface roughness were will expand with increment in pulse on time, open circuit voltage and dielectric fluid pressure. Numerical connections between cutting parameters and cutting exhibitions were produced by regression analysis method. The created model was utilized within evaluating execution attributes. Taking into account Anova strategy, the open circuit voltage, pulse duration of time and wire pace were more viable on cutting velocity. While the dielectric liquid weight was immaterial. If there should be an occurrence of surface roughness, the open circuit voltage and pulse duration of time were more successful, wherever as dielectric fluid pressure and wire velocity were ineffectual. Sarkar et.al. (2005) directed probes Electra SUPERCUT 734, SERIES-200 CNC WEDM machine exploitation γ-titanium Aluminide composite as work piece material so made a model they anticipate the cutting speed , surface finish and dimensional deviation as the work of diverse WEDM parameters. Each one surface roughness and dimensional deviation is free of pulse off time. So pulse off time could be fluctuated according to necessity to achieve the higher stability and correctness while not influencing the dimensional deviation and surface finish respectably. They decided the ideal technique parameters by applying unnatural optimization procedure amid which one execution trademark was streamlined considering diverse as stipulations. Taweel et.al.(2005) utilizes AN ELEKTTA Maxicut434 CNC WEDM as machine device and INCONEL-601 as work piece , created a scientific model for associating interrelationship of WEDM system parameters like peak current, duty factor, wire tension, water pressure and reactions mr, wr and sr utilizes RSM approach.Mahapatraet.al. (2006) allocated test studies on Robofil100 WEDM with D2-Tool Steel. They acknowledge relationship between control components and reactions like metal removal rate and surface finish by non linear regression analysis. GA was utilized to improve the WEDM system with various destinations.

3. Design & analysis of experiments

Dr. Taguchi has developed a method predicated on "ORTHOGONAL ARRAY" experiments which gives much reduced " variance " for the experiment with " optimum settings " of control parameters. Thus the espousement of Design of Experiments with optimization of control parameters to obtain BEST results is achieved in the Taguchi Method. "Orthogonal Arrays" (OA) provide a set of well balanced (minimum) experiments and Dr. Taguchi's Signal-to-Noise ratios (S/N), which are log functions of desired output, accommodate as objective functions for optimization, avail in data analysis and presage of optimum results. Taguchi method is utilized in the industry to decrement the product development period for the design and engenderment which withal decrease the costs and increment the profit of the company. Taguchi method withal sanctions controlling the variations caused by the uncontrollable factors which are not taken into consideration at conventional design of experiment. Taguchi converts the objective function values to signal-to-noise (S/N) ratio for measure the performance characteristics of the calibers of control factors against these factors. S/N ratio is defined as the desired signal ratio for the undesired arbitrary noise value and shows the quality characteristics of the experimental data. There are three different functions utilized which are kenned as the objective function and withal defined as S/N ratio: ‘‘the-larger-the-better’’, ‘‘the-smaller-the-better’’ and ‘‘the-nominal-the-best’’. Besides, ANOVA is utilized to determine the statistical paramountcy of the cutting parameters. The optimum cumulation of the cutting parameters is tenacious by the avail of ANOVA and S/N ratios.

Lastly, substantiation experiments are done utilizing the optimum machining parameters which were found by Taguchi optimization method and thereby validation of the optimization is tested. In this study, cutting parameters are optimized for the average surface roughness (Ra) occurred in wire cut EDM machining. Pulse on time (ON), pulse off time (OFF), spark gap set voltage (SV), peak current (IP), wire tension (WT) and water pressure (WP) are culled as cutting parameters (variables). The parameter levels were culled within the intervals recommended by the cutting implement manufacturer. L27 orthogonal array of Taguchi method was utilized in the design of experiment. Variables and their calibers are given in Table 1. The-"smaller-the-better" performance characteristics for Ra were applied in order to obtain the optimal cutting parameters. S/N ratio. The S/N ratios of six factors were calculated for Ra. ANOVA was applied with 95% confidence level to determine the consequentiality level of the variables on Ra. Optimization process predicated on the Taguchi method was performed by Minitab 15 software. Minitab is potent software that solves many statistical quandaries with facileness. This software is frequently used performing statistical analysis and quality amelioration in area of mathematics, statistics, economics, sports and engineering.

In the present study six parameters pulse on time, pulse off time, peak current, spark gap set voltage, wire tension and water pressure were culled as input parameters during machining of work piece. The Experiments were conducted with distilled water as di-electric fluid and its conductivity is 20S, Servo feed is 2150 m/min, wire feed as 8 m/min with a coated brass wire of 0.25 diameter as electrode. The six parameters were assigned values in 3 levels predicated on trail experiments. The preliminary experiments were conducted to cull the range of values for machining parameters.

Table 1: Process parameters their values and ranges

SNO	PROCESS PARAMETERS	SYMBOL	UNITS	LEVEL 1	LEVEL 2	LEVEL 3
1	Pulse On Time	ON	µsec	108	118	128
2	Pulse Off Time	OFF	µsec	47	55	63
3	Peak Current	IP	Amperes	11	13	15
4	Spark gap set voltage	SV	Volts	18	43	68
5	Wire Tension	WT	Grams	2	5	8
6	Water Pressure	WP	Kg/cm^2	8	11	14

4. Experimental set up and preparation of specimens

The Vanadis 4E Implement steel plate of 100mm x 98mm x 24mm size is mounted on the ELECTRONICA ULTIMA 1F WEDM machine implement (Figure 1) and specimens of 7mmx7mmx24mm size are cut. The close up view of plate blank utilized for cutting the specimens is shown mounted on the WEDM machine (Figure 2). A set of cut specimens is shown in Figures 3 and 4. Surface roughness quantification was done utilizing a portable stylus-type profilometer (Taylor Hobson, Surtronic-3+) as shown in figure 5. The profilometer was set to a cut-off length of 0.8 mm and 4mm valuation length. The least count of the profilometer is 0.01 micron.

Fig.1: Electronica Ultima 1F WEDM setup

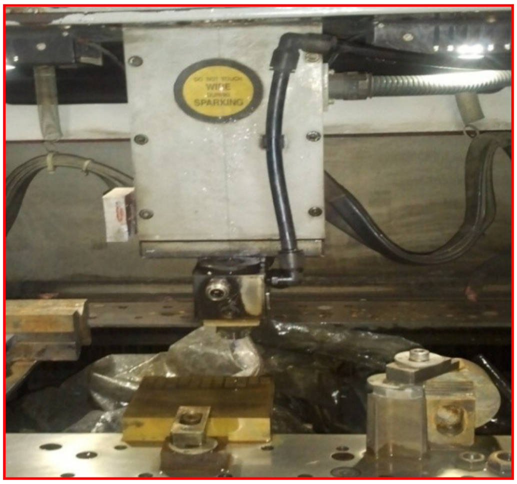

Fig.2: Work piece Mounted on WEDM

Fig.3. Pieces lying in vertical after WEDM

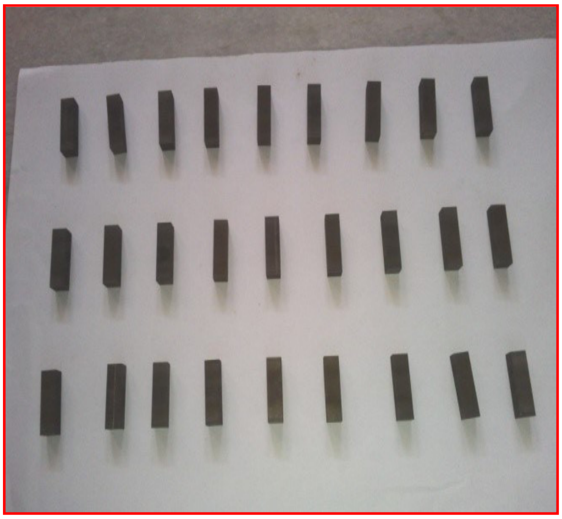

Fig.4. Pieces lying in horizontal after WEDM

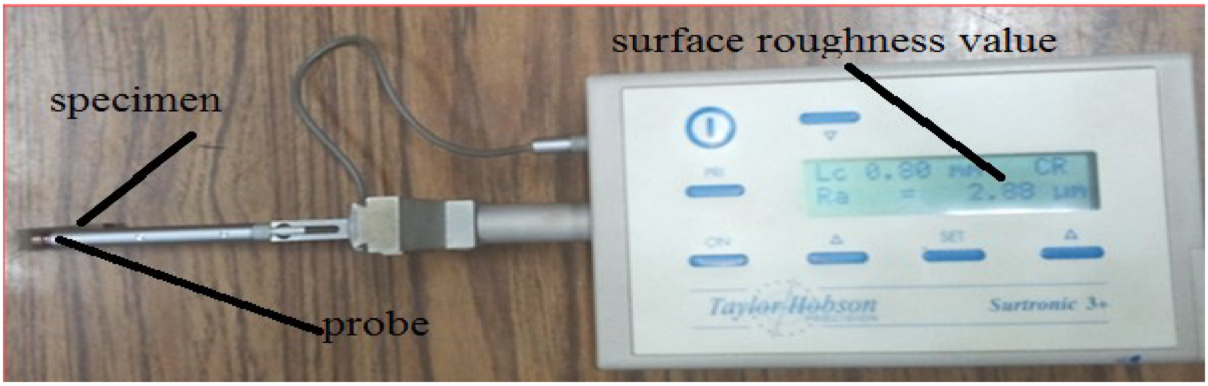

Fig 5. *Taylor-Hobson surface roughness Tester*

5. Result analysis

The 27 experiments were conducted on the work piece as per L_{27} orthogonal array in order to ascertain the effect of machining parameters on surface roughness. The experimental data is shown in table 2. The average values of cutting rate for each parameter level 1, 2 and 3 for raw data.

Table 2: Experimental Results for Surface roughness with cutting conditions and S/N ratio values

Trail No	ON (µsec)	OFF (µsec)	IP (Amps)	SV (Volts)	WT (Grms)	WP (kg/cm^2)	SURFACE ROUGHNESS (µm) R1	R2	R3	S/N RATIO
1	108	47	11	18	2	8	1.98	1.92	2.02	-5.90589
2	108	47	12	43	5	11	1.83	1.83	1.82	-5.23321
3	108	47	13	68	8	14	1.75	1.78	1.8	-4.9927
4	108	55	11	43	5	14	1.88	1.84	1.94	-5.51596
5	108	55	12	68	8	8	1.83	1.82	1.8	-5.18571
6	108	55	13	18	2	11	1.64	1.6	1.69	-4.31669
7	108	63	11	68	8	11	1.96	1.87	1.95	-5.69803
8	108	63	12	18	2	14	1.73	1.65	1.65	-4.49113
9	108	63	13	43	5	8	1.66	1.65	1.69	-4.43743
10	118	47	11	43	8	11	3.08	2.96	3.2	-9.77541
11	118	47	12	68	2	14	2.95	2.98	2.94	-9.41619
12	118	47	13	18	5	8	2.04	2.08	1.99	-6.17982
13	118	55	11	68	2	8	3.11	3.13	3.15	-9.911
14	118	55	12	18	5	11	1.95	1.98	1.98	-5.88955
15	118	55	13	43	8	14	2.27	2.29	2.24	-7.10811
16	118	63	11	18	5	14	2.23	2.26	2.17	-6.92829
17	118	63	12	43	8	8	2.48	2.37	2.49	-7.77364
18	118	63	13	68	2	11	2.18	2.21	2.3	-6.96837
19	128	47	11	68	5	14	3.58	3.47	3.75	-11.1305
20	128	47	12	18	8	8	2.43	2.41	2.4	-7.65246
21	128	47	13	43	2	11	3.25	3.23	3.28	-10.2467
22	128	55	11	18	8	11	2.68	2.74	2.65	-8.59589
23	128	55	12	43	2	14	3.11	3.21	2.97	-9.82227

24	128	55	13	68	5	8	2.99	2.95	3.02	-9.50414
25	128	63	11	43	2	8	3.42	3.4	3.4	-10.6466
26	128	63	12	68	5	11	3.18	3.29	3.2	-10.1671
27	128	63	13	18	8	14	1.88	1.84	1.89	-5.43741

5.1 Effect of surface roughness

The surface roughness increases with increase in pulse on time and peak current and decreases with pulse of time, spark gap set voltage and wire tension . This is because the discharge energy increases with pulse on time and peak current and more sizably voluminous discharge energy engenders a more astronomically immense crater, causing a more immensely colossal surface roughness value on the work piece. When the pulse of time decreases, the number of discharges increases which causes poor surface finish. With increase in spark gap set voltage, the average discharge gap gets widened leading to more preponderant surface precision due to stable machining. As the wire tension increases, the fluctuation of wire gets reduced and it results in more preponderant surface finish on the specimens. The effect of water pressure is not very consequential. It is observed from the figure6 and figure 7 that there is remote interaction between pulse off time and peak current while there is impotent interaction between other parameters in effecting surface roughness since the replications at different calibers of those parameters are virtually parallel. The residuals plots do not show any quandary in the distribution of the data and the model postulations (figure 8 and figure 9)

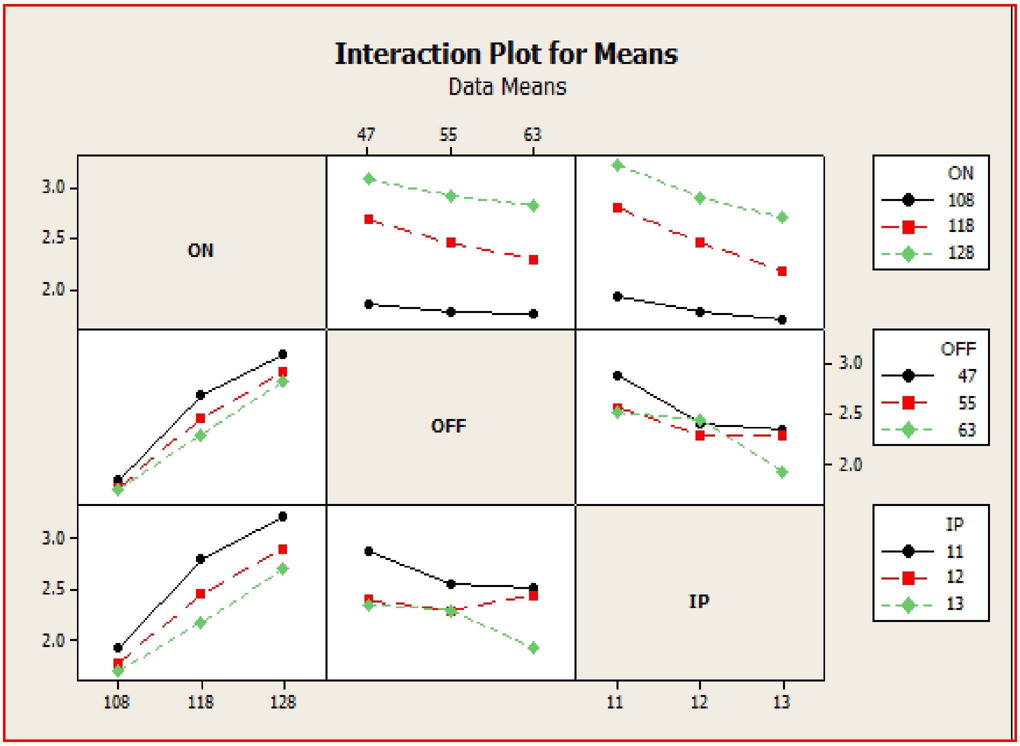

Fig. 6. Effects of Process Parameters Interactions on Surface roughness (Raw Data)

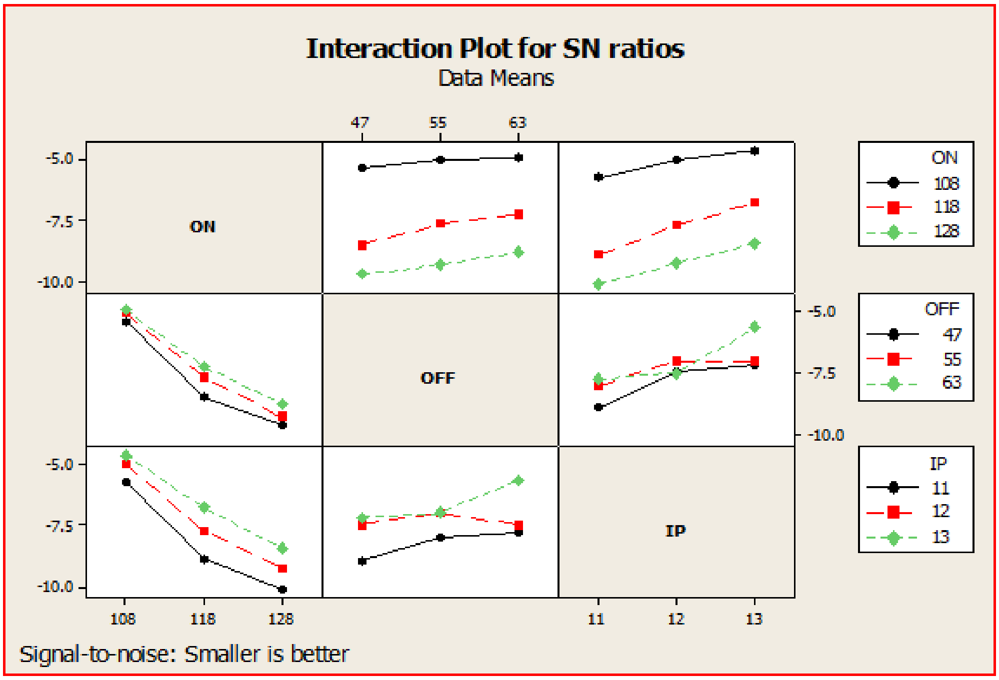

Fig. 7. Effects of Process Parameters Interactions on Surface roughness (S/N Data)

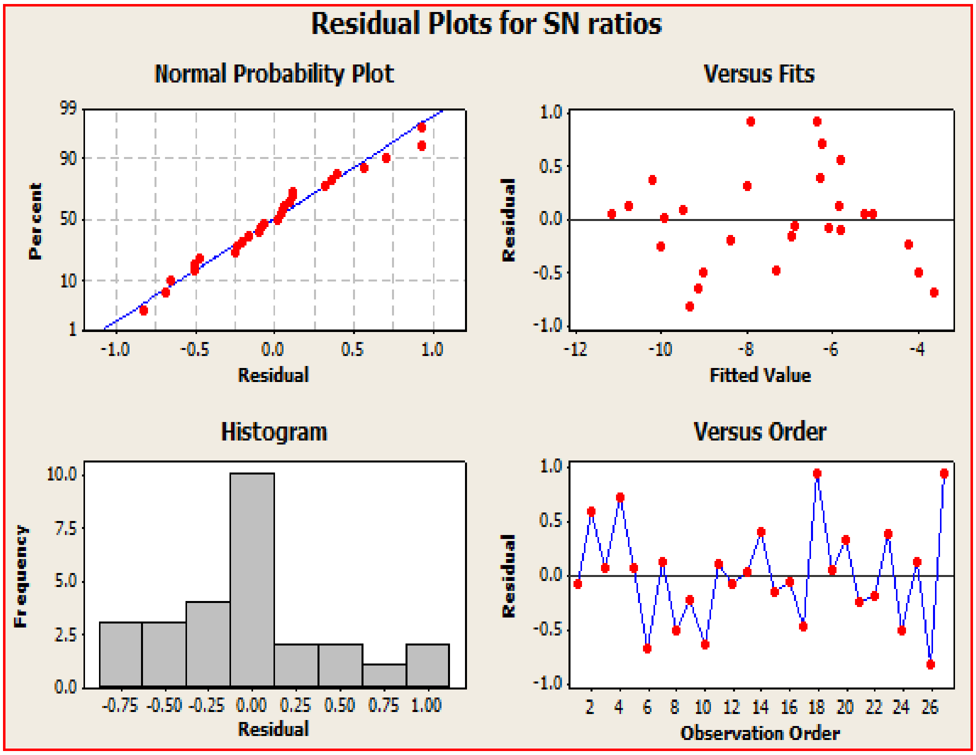

Fig. 8. Residual Plots for Surface roughness (Raw Data)

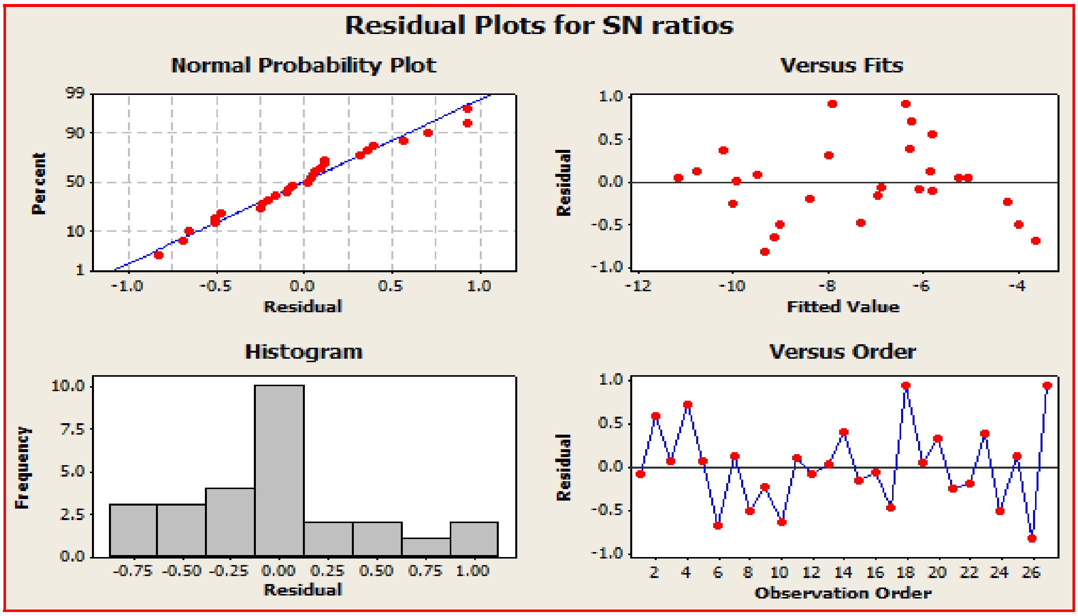

Fig.9:. Residual Plots for Surface roughness (S/N Data)

5.2 Selection of optimum levels

In order to study the paramountcy of the process parameters towards the surface roughness, ANOVA was performed. It was found that water pressure is non paramountcy process parameter for surface roughness. Non Paramountcy parameters were pooled and the pooled versions of ANOVA of the S/N data and raw data for surface roughness are given in table 3 and table 4 respectively.

Table 3: Pooled Analysis of Variance for (S/N ratios)

Analysis of Variance for SN ratios

Source	DF	Seq SS	Adj SS	Adj MS	F	P
ON	2	80.027	80.027	40.0135	115.62	0.000
ON	2	80.027	80.027	40.0135	115.62	0.000
IP	2	12.438	12.438	6.2188	17.97	0.000
SV	2	20.173	20.173	10.0863	29.14	0.000
WT	2	5.312	5.312	2.6560	7.67	0.005
Residual Error	16	5.537	5.537	0.3461		
Total	26	127.064				

DF - degrees of freedom, SS - sum of squares, MS - mean squares(Variance), F-ratio of variance of a source to variance of error, P < 0.05 - determines significance of a factor at 95% confidence level

Table 4: Pooled Analysis of Variance for Means (Raw data)

Analysis of Variance for Means

Source	DF	Seq SS	Adj SS	Adj MS	F	P
ON	2	6.0171	6.0171	3.00856	86.69	0.000
OFF	2	0.2881	0.2881	0.14407	4.15	0.035
IP	2	0.9838	0.9838	0.49190	14.17	0.000
SV	2	1.7316	1.7316	0.86582	24.95	0.000
WT	2	0.5395	0.5395	0.26974	7.77	0.004
Residual Error	16	0.5553	0.5553	0.03470		
Total	26	10.1154				

DF - degrees of freedom, SS - sum of squares, MS - mean squares(Variance), F-ratio of variance of a source to variance of error, P < 0.05 - determines significance of a factor at 95% confidence level

Table 5: Response Table for Signal to Noise Ratios

Response Table for Signal to Noise Ratios Smaller is better					
Level	ON	OFF	IP	SV	WT
1	-5.086	-7.837	-8.234	-6.155	-7.969
2	-7.772	-7.317	-7.292	-7.840	-7.221
3	-9.245	-6.950	-6.577	-8.108	-6.913
Delta	4.158	0.887	1.657	1.953	1.056
Rank	1	5	3	2	4

Table 6: Response Table for Means

Response Table for Means					
Level	ON	OFF	IP	SV	WT
1	1.799	2.546	2.657	2.055	2.596
2	2.482	2.387	2.381	2.548	2.380
3	2.949	2.296	2.192	2.627	2.254
Delta	1.150	0.250	0.465	0.573	0.342
Rank	1	5	3	2	4

From that table it is observed that pulse on time, off time, peak current, spark gap set voltage and wire tension has vigorously affecting the both mean and variation in the surface roughness values. The replication tables (Tables 5 and 6) show the average of each replication characteristic (S/N data and raw data) for each level of each factor. The Tables include ranks predicated 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 predicated on delta values; rank 1 to the highest delta value, rank 2 to the second highest, and so on. The ranks betoken the relative paramountcy of each factor to the replication. The ranks and the delta values for sundry parameters show that pulse on time has the greatest effect on surface roughness and is followed by spark gap set voltage, peak current, wire tension and pulse off time in that order.

As surface roughness is the "lower the better" type quality characteristic, it can be optically discerned that the first level of pulse on time (A1), third level of pulse off time (B3), third level of peak current (C3), first level of spark gap set voltage (D3), and third level of wire tension (E3) result in minimum value of surface roughness. The S/N ratio analysis withal suggests the same levels of the variables (A1, B3, C3, D3 and E3) as the best levels for minimum SR in WEDM process.

5.3 Estimation of optimum response characteristics

In this section, the optimal values of the replication characteristics surface roughness along with their respective confidence intervals have been prognosticated. The results of substantiation experiments are withal presented to validate the optimal results. The optimal levels of the process parameters for the culled replication characteristics have already been identified. The optimal value of each replication characteristic is soothsaid considering the effect of the consequential parameters only. The average values of the replication characteristics obtained through the attestation experiments must lie within the 95% confidence interval, CI_{CE} equation . However, the average values of quality characteristics obtained from the substantiation experiments may or may not lie with in 95% confidence interval, CI_{POP} (calculated for the mean of the population).

5.4 Surface roughness

The optimum value of surface roughness is predicted at the optimal levels of significant variables which have already been selected as pulse on time (A1), pulse off time(B3), peak current (C3) and spark gap set voltage (D3) and wire tension(E3) (Table 4). The estimated mean of the response characteristic surface roughness can be determined (Kumar, 1993 and Roy, 1990) as:

$$\mu_{SR} = \overline{A1} + \overline{B3} + \overline{C3} + \overline{D3} + \overline{E3} - 4\,\overline{T}$$

where
$\overline{T}$= overall mean of cutting rate = (∑R1+∑R2+∑R3)/81 = 2.41 μm

$\overline{A1}$ = Average value of cutting rate at the first level of pulse on time = 1.799259 μm
$\overline{B3}$ = Average value of cutting rate at the third level of pulse off time =2.296296 μm
$\overline{C3}$ = Average value of cutting rate at the third level of peak current = 2.192222 μm
$\overline{D3}$ = Average value of cutting rate at the third level of spark gap set voltage= 2.6274 μm
$\overline{E3}$ = Average value of cutting rate at the third level of wire tension= 2.254074 μm

Substituting the values of various terms in the above equation,

μ_{SR}= 1.799259 +2.296296 + 2.1922229 + 2.6274 + 2.254074 - 4(2.41) =1.526352 μm

The 95 % confidence intervals of confirmation experiments (CI_{CE}) and population (CI_{POP}) are calculated by using the following Equations using the following Equations .

$$CI_{CE} = \sqrt{F_{\alpha}(1, f_e)V_e\left[\frac{1}{n\,eff} + \frac{1}{R}\right]}$$

and

$$CI_{POP} = \sqrt{\frac{F_{\alpha}(1, f_e)V_e}{n_{eff}}}$$

Where, $F_{\alpha}(1, F_e)$ = The F ratio at the confidence level of (1-α) against DOF 1 and error degree of freedom f_e

n_{eff} =N/1+(DOF associated in the estimation of mean response)
$n=\frac{81}{(1+8)} = 9$
N= Total number of results= 27x3=81
R= Sample size of confirmation experiments=3
V_e = Error variance =0.03470 ____ From table(4)
f_e = error DOF = 18
$F_{0.05}(1, 18)$ =4.494 ____ Tabulated F-value, Roy 1990 So,
CI_{CE} = ±0.270477 and,
CI_{POP} =±0.145524
Therefore, the predicted confidence interval for confirmation experiments is:
Mean μ_{SR} - CI_{CE} < μ_{SR} < Mean μ_{SR} + CI_{CE}
1.255875 < μ_{SR} < 1.796829

The 95% confidence interval of the population is:
Mean $\mu_{SR} - CI_{POP} < \mu_{SR} <$ Mean $\mu_{SR} + CI_{POP}$
$1.110351 < \mu_{SR} < 1.401399$

The optimal values of process variables at their selected levels are as follows:

1st level of pulse on time (A1)	: 108 µsec
3rd level of pulse off time (B3)	: 47 µsec
3rd level of peak current (C3)	: 15 Amperes
3rd level of spark voltage (D3)	: 68 volts
3rd level of wire tension (E3)	: 8 grams

5.5 Confirmation experiment

In order to validate the results obtained, three confirmation experiments were conducted for the response characteristics (surface roughness) at optimal levels of the process variables. The average values of the characteristics were obtained and compared with the predicted values. The results are given in Table 7. The values of Cutting Rate obtained through confirmation experiments are within the 95% of CI_{CE} of respective response characteristic. It is to be pointed out that these optimal values are within the specified range of process variables.

Table 7. Predicted Optimal Values, Confidence Intervals and Results of Confirmation Experiments

Performance Measures/ Responses	Optimal Set of Parameters	Predicted Optimal Value	Predicted Confidence Intervals at 95% Confidence Level	Actual Value (Average of Three Confirmation Experiments)
Surface Roughness	A1,B3,C3,D3,E3	1.526352µm	$CI_{CE}=1.255875 < \mu_{SR} < 1.796829$ $CI_{POP}=1.110351 < \mu_{SR} < 1.401399$	1.616352 µm

6. Conclusions

The effects of machining parameters on surface roughness with wire electric discharge machining (WEDM) process has been studied with the aim of minimization of surface roughness utilizing Taguchi's design. An optimal set of machining process variables that yields the optimum quality features to machined components engendered by WEDM process has additionally been obtained. The consequential conclusions from the present research work are summarized in this chapter.

1. Ranges of Wire EDM process parameters have been established predicated on review of literature and by performing the trail run experiments utilizing one factor at a time approach as in table8.

Table:8

SNO	PROCESS PARAMETERS	SYMBOL	RANGE	UNITS
1	Pulse On Time	ON	108-128	µsec
2	Pulse Off Time	OFF	47-63	µsec
3	Peak Current	IP	11-13	Amperes
4	Spark gap set Voltage	SV	18-68	Volts
5	Wire Tension	WT	2-8	Grams
6	Water Pressure	WP	8-14	Kg/cm^2

2. The effects of the process parameters viz. pulse on time, pulse off time, peak current, spark gap set voltage, wire tension and water pressure on replication characteristics cutting rate. The optimal sets of process parameters were obtained for sundry performance measures utilizing Taguchi's design of experiment methodology. The summary results of soothsaid optimal values of the replications and their confidence intervals (both for attestation experiment and population) are given as under.

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