Statistical Analysis Of Wire Electrical Discharge Machining On Surface Finish

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Abstract

With Modernization, Machine tool industry has made exponential growth in its manufacturing capabilities where in the demand for alloy materials having high hardness, toughness and impact resistance increased. To machine them various non traditional machines and machining methods such as WEDM emerged and developed. WEDM is popular and specialized in machining conductive metals of any hardness or that are difficult or impossible to cut with traditional methods into general, complex shapes, contours or fragile geometries. The rough cut operation of WEDM prefers Cutting Speed to Surface Finish, where as finish cut operation prefers Surface Finish, accurate cut rather to Cutting speed. Hence, the optimality problem of process parameters for higher cutting efficiency, accurate cut and good surface finish has attracted the attention of the researchers and practicing engineers. This paper focuses, to optimize the effects of eight input process parameters on Surface Finish during the machining of EN-31 using Taguchi L36($2^1 3^7$) orthogonal array (OA) as design of experiments (DOE).

Keywords: *EN31, Surface Finish, Orthogonal array, WEDM*

1. Introduction

WEDM uses thermal erosion process for material removal from the work piece. The effect is produced when electric sparks are generated between the work piece and a wire electrode(cutting tool) flushed or immersed in the dielectric fluid without tool being in touch with the work piece[1]. The gap between the work piece and wire is flooded with deionized water as localized stream, which acts as the dielectric. By spark discharges Work piece material is eroded ahead of transporting the wire. When each pulse of electricity is delivered from the mains, allows a small spark to jump the shortest distance between the work piece and wire. A small pool of molten metal is formed on the work piece and the wire at the point of the spark. During the process an air/gas bubble forms around the spark and the molten pools. This air/gas bubble collapses whenever the pulse of electricity is off or the spark disappears. Then the cool dielectric rushes and causes the molten metal to be ejected from the work piece and the wire. The process is repeated hundreds of thousands of times per second during WEDM Machining and removes material from the work piece in shapes against to that of wire [2, 3].
The material removal rate(MRR), surface finish(SR) depends on the various input parameters of the WEDM. For better MRR, SR the optimal input of parameters play a vital role in WEDM.WEDM machining process parameters can be optimized by using Taguchi method. To get the desired responses Taguchi s robust design was used in various applications to obtain optimum parametric combinations [4-9]. In most of the manufacturing processes, the surface roughness is one of the most important performance measures. Literature survey revela Several researchers were previously attempted to improve the surface roughness on various materials [10-20]. Experiments wered conducted by Han et al [14] on different materials namely aluminum alloy, brass, alloy steel, cemented carbide at the same conditions to obtain surface roughness.
They concluded the rigidity is a significant factor affecting the surface roughness. The surface

roughness decreases as material rigidity increases. Therefore high rigidity materials will produce finer surfaces and low rigidity materials produces high surface roughness. EN series materials are moderately rigid materials of the steel alloys. This material is rapidly growing its applications because of its high strength and hardness even at higher temperatures this suits most of the engineering requirements today. Apart from this, this is one of the strongest heat treatable alloys. The main purpose of this paper is to investigate effects of eight machining parameters on the Surface Finish of wire EDMed En31 alloy steel.

2. Experimental Set Up and Data Collection

The design of experiments based on Taguchi Orthogonal Array, experimental setup and the method of conducting experiments are discussed in this section.

2.1. Work Material and tool/cutting tool material

The chemical composition of the EN 31 alloy steel, work piece material selected for the experiments, is shown in Table 1. 0.25 mm diameter Brass wire, is a diffused wire of brass of type ELECTRA_Duracut, was used as tool electrode in the present experimental set up. 0.25 mm diameter stratified wire (Zinc coated copper wire) with vertical configuration has been used and discarded once used. High Surface Finish (Ra) in WEDM can be attained by the use of zinc coated copper wire because evaporation of zinc causes cooling at the interface of work piece and wire and a coating of zinc oxide on the surface of wire helps to prevent short-circuits and jerks in cutting (Sho et al., 1989).

Table 1: The chemical composition of EN31 Alloy steel

Material	C	Cr	Mn	Si	Fe
EN31	0.95	1.45	0.60	0.22	Balance %wt

2.2. Schematic of Machining

All the experiments were carried out on SPRINTCUT (AU) WITH PULSE GENERATOR ELPULS 40A DLX CNC Wire-cut EDM machine made by ELECTRONICA Company. All the three axes of the machine are servo controlled and can be programmed to follow a CNC code which is fed through the control panel. All three axes have an accuracy of 1µm. Using NC code, machining can be programmed. During the experimentation the work piece is considered as positive terminal, whereas the tool (wire) is connected to negative terminal of the source. The size of the work piece considered for experimentation on the wire-cut EDM is 125 mm x 25 mm x 5 mm. A small gap of 0.025 mm to 0.05 mm is maintained in between the wire and work-piece. The high energy density erodes material from both the wire and work piece by local melting and vaporizing. The di-electric fluid (de-ionized water) is continuously flashed through the gap along the wire, to the sparking area to remove the debris produced during the erosion. A collection tank is located at the bottom to collect the used wire erosions and then is discarded. The wires once used cannot be reused again, due to the variation in dimensional accuracy.

2.3. Experimental Procedure

The dimension of the work piece material is a rectangle of 5mmx25mmx125mm. Zinc coated copper wire used as a cutting tool, having diameter of 0.20mm, for machining the Work piece. De-ionized water as a dielectric fluid, onto 5mmx5mmx25mm pieces. Each experiment is carried out with different input process parameter combination considering each combination as a separate job to cut one single piece each time. Taguchi Orthogonal Array design used for the parameters. During the machining operation the respective output parameters or responses, cutting speed, surface roughness, and dimensional deviations, machining time, gap current and kerf are gathered. Cutting speed, Gap current, gap voltage were gathered from system display screen and others like MRR, Surface Roughness, dimensional deviations were calculated separately. Surface roughness Ra values were measured using Mitutoyo Surface Tester. Dimensional Deviations were measured using Digital Micro Meter.

2.4. Process parameters and design

Various process parameters TON, TOFF, IP, SV, WT, WF, SF, WP are shown in Table 2. Except Ton(2 levels), all other factors investigated at three levels to determine the optimum settings for the WEDM process. The parameters, their levels were chosen based on the review of literature and as per the few preliminary pilot experiments that were carried out by varying the process parameters, thickness of material to find their significance and relevance to the response parameters. In the present study most important output performances in WEDM surface Finish was considered for optimizing machining parameters. The gathered experimental values are recorded as shown in table 3 in line with the L36 Orthogonal Array design.

3. Experimental Data Analysis

3.1. Analysis of Variance (ANOVA):

It is really hard to know, In any Experimentation with several variables, which variable is exactly influencing and which is not. In WEDM type of experimentation each parameter will have its own control on the other since they are acting together as one unit. In spite of that it is necessary to find, if at all, any variation exists in the experimentation, then by which variable and to take necessary decisions can be made concerning that parameters. ANOVA is used for this reason. ANOVA, is a statistical method, can interpret experimental data. ANOVA categorizes significant and insignificant machining parameters.

3.2. S/N Ratio

In any experimentation the expectation will be that the desired values are to obtained as outputs, if not at least the mean output values correlate to the desired ones. This desired value is termed as signal and the deviation from the desired or signal is termed as noise. The signal is the mean for the response and the square deviation for the output is noise. So, the ratio of mean to square deviation is S/N ratio, which is a logarithmic transformation of the loss function as equation 1. 'The lower value' of the experimental data and its corresponding input parameters are of the optimum machining performance characteristics will satisfy the aim of minimization of Surface Roughness. It is denoted by 'η' with a unit of dB.

$$\eta = -10 \log \frac{1}{n} \sum_{i=1}^{n} y2 \qquad (1)$$

The experimental data was analyzed using MINITAB Software. ANOVA, S/N ratio calculation are calculated using Minitab 15. Table 3 shows the L36 OA along with the experimental Response Surface Finish value and the S/N ratio for the Surface Finish obtained from Minitab. Table 4, 5 shows the S/N ratio, mean S/N ratio of the parameters according to the level of each parameter.

3.2.1 Result Analysis As discussed earlier lower η value corresponds to better performance. The level with minimum/lowest η value is the optimal level of machining parameters. Table 6 is the Anova result. Figures 2, 3 show graphically the effect of the eight control factors on Surface Finish. From the results it is evident that parameters at level **A2B1C3D1E1F1G3H3 optimal level,** gives best Surface Finish. It is also evident from Table 4, 5 that SV,WT WF WP are having less significant impact on the Surface Finish.

4. Confirmation of Experiments

In the DOE process confirmation experiment test is the final step. This is to validate the conclusions drawn during the analysis phase. In this step experiment conducted with a specific combination of the factors and levels previously evaluated. The out put response value is compared with the predicted value of the same with the Minitab. To have more confirmation a mathematical general non-linear regression model of the form given below is considered which gives the relationship between the input variables and response.

Response= C * A^a1 * B^a2 * C^a3…. Where C is constant A, B, C... are the input process variables, and a1, a2, a3… are the coefficients. This is solved by using a custom made Regression code which runs on Fortron. From the available experimental data the suggested model will be as follows:

$$Y= 0.1821E\text{-}04 \times (TON)^{(2.336)} \times (TOFF)^{(0.3060)} \times (IP)^{(-0.1995)} \times (SV)^{(0.1902E-01)} \times (WF)^{(-0.1576E-01)} \times (WT)^{(0.8937E-02)} \times (SF)^{(0.2194E-01)} \times (WP)^{(-0.9002E-03)}$$

With the above equation the response Y is obtained. With optimal parameters. The optimal model obtained above, is also subjected and the value is obtained and compared with the experimental values. The comparative statement of the Predicted Optimal Value, its experimental value, its Math model value are tabled in table 7. Table 8 gives the respective S/N ratio values. From Table7, 8 it is clearly evident that the results obtained from the optimal that optimal suggested value has an edge over.

5. Conclusion

In this study the following are achieved. The effects of TON, TOFF, IP, SV, SF, WT, SF, WP are investigated on the EN31 Alloys Steel for Surface Finish. With the help of ANOVA, S/N ratio and Math model the optimal input parameter combination for the Surface Finish on the WEDM machined arrived, which will be useful for the people who do not have much idea of WEDM can use for the selection of input parameters for better Surface Finish while working on En31 Alloy Material.

Table 2: Levels for various control factors

Sl.No.	PARAMETERS	SYMBOL	LEVEL1	LEVEL2	LEVEL3	UNITS
1	Pulse On time (A)	TON	119	128	--	µ sec
2	Pulse Off time (B)	TOFF	53	58	63	µ sec
3	Peak Current (C)	IP	130	180	230	Ampere
4	Spark gap Voltage(D)	SV	20	30	40	Volts
5	Wire Tension (E)	WT	2	3	4	Kg-f
6	Wire Feed rate (F)	WF	4	5	6	m/min
7	Servo Feed (G)	SF	500	1300	2100	mm/min
8	Dielectric Flushing pressure (H)	WP	2	3	4	Kg/cm^2

Table 3: Experimental results using L_{36} OA

SlNo	TON	TOFF	IP	SV	WF	WT	SF	WP	Ra S/N Ratio
1	1	1	1	1	1	1	1	1	-6.0016
2	1	2	2	2	2	2	2	2	-5.84585
3	1	3	3	3	3	3	3	3	-5.71515
4	1	1	1	1	1	2	2	2	-5.97706
5	1	2	2	2	2	3	3	3	-5.993
6	1	3	3	3	3	1	1	1	-5.42364
7	1	1	1	2	3	1	2	3	-6.08053
8	1	2	2	3	1	2	3	1	-6.14282
9	1	3	3	1	2	3	1	2	-5.2922
10	1	1	1	3	2	1	3	2	-6.31986
11	1	2	2	1	3	2	1	3	-5.68652
12	1	3	3	2	1	3	2	1	-5.79716
13	1	1	2	3	1	3	2	1	-5.74263
14	1	2	3	1	2	1	3	2	-5.55716
15	1	3	1	2	3	2	1	3	-6.56759
16	1	1	2	3	2	1	1	3	-5.4393
17	1	2	3	1	3	2	2	1	-5.34412

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18	1	3	1	2	1	3	3	2	-6.73759
19	2	1	2	1	3	3	3	1	-7.23428
20	2	2	3	2	1	1	1	2	-6.64877
21	2	3	1	3	2	2	2	3	-8.11257
22	2	1	2	2	3	3	1	2	-7.03759
23	2	2	3	3	1	1	2	3	-7.06774
24	2	3	1	1	2	2	3	1	-8.11342
25	2	1	3	2	1	2	3	3	-6.86301
26	2	2	1	3	2	3	1	1	-7.88903
27	2	3	2	1	3	1	2	2	-7.37209
28	2	1	3	2	2	2	1	1	-6.40293
29	2	2	1	3	3	3	2	2	-7.8905
30	2	3	2	1	1	1	3	3	-7.83357
31	2	1	3	3	3	2	3	2	-6.83257
32	2	2	1	1	1	3	1	3	-7.80599
33	2	3	2	2	2	1	2	1	-7.53399
34	2	1	3	1	2	3	2	3	-6.53775
35	2	2	1	2	3	1	3	1	-7.95579
36	2	3	2	3	1	2	1	2	-7.58031

Table 4: S/n ratios with the levels for each parameter

Level	TON	TOFF	IP	SV	WF	WT	SF	WP
1	-5.870	**-6.872**	-6.121	**-6.563**	**-6.683**	**-6.703**	-6.481	-6.632
2	**-7.373**	-6.652	-6.620	-6.422	-6.586	-6.622	-6.608	-6.591
3		-6.840	**-6.724**	-6.280	-6.595	-6.539	**-6.775**	**-6.642**

Table 5: Mean s/n values for each parameter at its levels

Level	TON	TOFF	IP	SV	WF	WT	SF	WP
1	1.968	2.086	2.281	2.143	2.166	2.150	2.120	2.160
2	2.342	2.165	2.153	2.149	2.149	2.155	2.152	2.144
3		2.213	2.029	2.171	2.148	2.159	2.192	2.159

Table 6: Anova

Source	DF	Seq SS	Adj SS	Adj MS	F	P
TON	1	1.25774	1.25774	1.25774	2400.48	0.000
TOFF	2	0.09745	0.09745	0.04873	93.00	0.000
IP	2	0.38156	0.38156	0.19078	364.12	0.000
SV	2	0.00518	0.00518	0.00259	4.94	0.018
WF	2	0.00249	0.00249	0.00125	2.38	0.118
WT	2	0.00050	0.00050	0.00025	0.38	0.328
SF	2	0.03052	0.03052	0.01526	29.12	0.000
WP	2	0.00189	0.00189	0.00095	1.80	0.190
Error	20	0.01048	0.01048	0.00052		
Total	35	1.78781				
S = 0.0228901 R-Sq = 99.41% R-Sq(adj) = 99.37%						

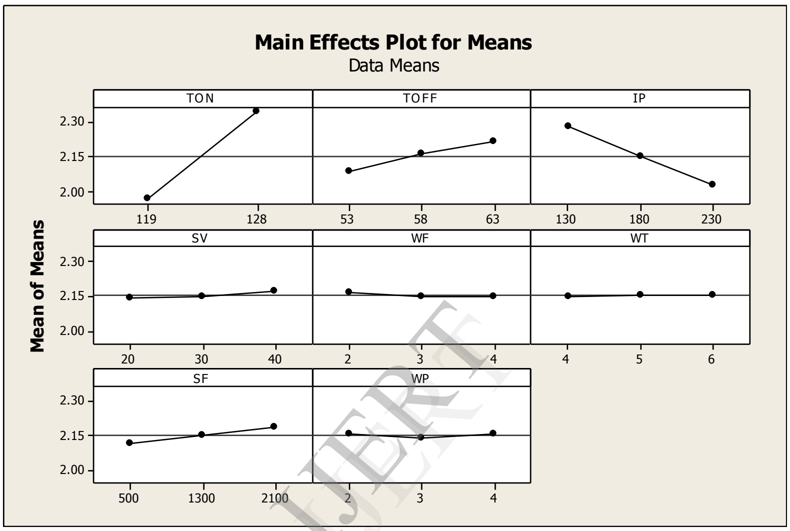

Figure 2: Mean effect values of Surface Finish

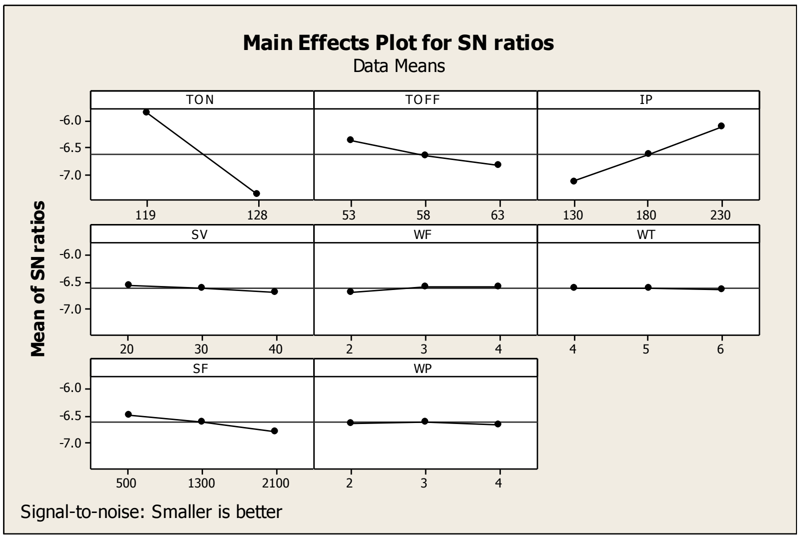

Figure 3: S/N ratios of Surface Finish

Table 7: Results of the confirmation experiment for cutting Speed

Sl No		Experiment	Math Model
1	Surface Finished Value obtained at Initial conditions **A2B2C2D2E2F2G2H2**	2.57	2.33
2	Cutting Speed Value obtained at Optimum Conditions **A2B1C3D1E1F1G3H3**	2.26	2.17
3	Improvement of Surface Finish obtained	1.14 times	1.53 times

Table 8: Results of the confirmation experiment for cutting Speed

Sl No		Experiment	Math Model
1	S/N RATIO Value obtained at Initial conditions	7.33	6.58
2	S/N RATIO Value obtained at Optimum Conditions	8.78	9.08
3	Improvement of S/N RATIO obtained	1.45	3.10

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