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Investigation of Process Parameters on Cutting Rate in Wire EDM using Taguchi Method

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Abstract—*Incoloy 800 is a super alloy of Nickel, Iron and Chromium widely used for heat and corrosion resistant applications. Due to its ultimate chemical properties, it is difficult to machine by conventional machine tools. In this present work, Incoloy 800 has been machined with the help of WEDM. WEDM is an unconventional machine tool used to machine high strength materials with high degree of accuracy. This paper presents an investigation on the optimization of machining parameters in WEDM of Incoloy 800. The main objective of this paper is to find the optimum cutting parameters to achieve high value of Cutting Rate. The cutting parameters considered in this study are Pulse-On Time, Pulse-Off Time, Peak Current and Servo Voltage. The setting of cutting parameters is determined by using Taguchi's L16 Orthogonal Array. Signal to Noise ratio and Analysis of Variance (ANOVA) were used to analyze the effect of parameters on Cutting Rate and identify the optimum cutting parameters. The research revealed that the greatest influencing factors were pulse-on time and pulse-off time for cutting rate. The input parameter peak current was found to be insignificant in the study.*

1. INTRODUCTION

Recent developments in manufacturing industry have fueled the demand for materials having higher strength, hardness and toughness. These materials pose a problem while machining with conventional machines available. The new materials available are lightweight combined with greater hardness and toughness. Sometimes their properties may create major challenges during their machining. The most generalized machine tool to machine these materials is WEDM.WEDM has evolved over time from being just used for manufacturing tools and dies to machining of exotic space-age alloys including Hastelloy, Inconel, titanium, Carbide, Polycrystalline diamond compacts and Conductive ceramics. Fig. 1shows the schematic of WEDM.

WEDM is a non-conventional, thermoelectric process which erodes the material by a series of discrete sparks between a work and tool electrode separated by a very thin film of dielectric fluid (deionized water). The dielectric is fed continuously to the machining zone to allow cooling action as well as to flush away the eroded particles. A very thin wire (generally 0.25mm dia) under tension is used as tool. The wire is guided through a series of tensioning rollers. The wire does not touch the workpiece, so there is no physical force imparted on the workpiece compared to conventional machining processes. Therefore, the work holding forces are minimal in WEDM, preventing damage or distortion of workpiece. The process leaves no residual burrs, so most of the components come out as finished ones and thus eliminating the need for any subsequent finishing operations.

Sparks are formed through a sequence of rapid electrical pulses generated by the machine's power supply and these are thousands of times per second. Each spark forms an ionization channel under extremely high heat and pressure, in which particles flow between the wire electrode and the workpiece, resulting in vaporization of localized sections [1].

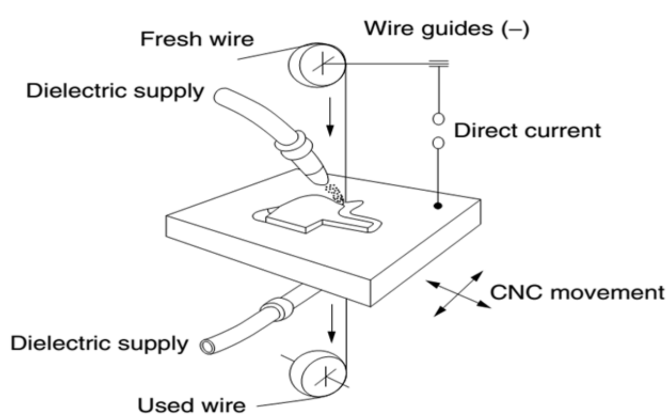

Fig. 1: Schematic of WEDM [2]

2. LITERATURE REVIEW

Huang et al. in 2003 carried out experimental investigation to determine the parameter setting during machining of SKD11 alloy steel by using the Taguchi method (L18 mixed Orthogonal Array) and Grey Relational Analysis. It was concluded that the table feed rate and pulse-on time have significant influence on material removal rate, and pulse-on time also has significant influence on surface roughness and gap width. In their prior investigation in 1997 using Taguchi method and non-linear regression analysis, they concluded that table feed and pulse-on time have significant influence on the MRR, gap voltage and discharge frequency while gap width and surface roughness are mainly influenced by pulse-on time [3, 4].

Mahapatra and Patnaik in 2007 used Taguchi's L27 OA and non-linear regression analysis to design the experiment on various operating parameters. D2 tool steel was used as workpiece material and the response parameters were MRR, surface roughness and kerf width. The conclusion was that the discharge current, pulse duration, dielectric flow rate and the interaction between discharge current and pulse duration were most significant parameters for cutting operation [5].

Tosun and Cogun in 2003 in their investigation on AISI 4140 steel using regression analysis concluded that the wire wear ratio increases with increase in pulse duration and open circuit voltage while decreases with increase in wire speed and dielectric fluid pressure [6].

Chiang and Chang in 2006 machined Al_2O_3 particle reinforced material (6061 alloy) on WEDM and investigated the effects of various input parameters on surface roughness and surface removal rate. They applied Taguchi's L18 mixed OA and Grey Relational Analysis design technique to optimize the results. The main findings of their study was that the arc on-time of discharging, the arc off-time of discharging, the on time of discharge and the servo voltage have greater influence for cutting rate and surface roughness [7].

Singh and Garg in 2009 investigated the effect of various process parameters of WEDM like pulse on time (Ton), pulse off time (Toff), servo voltage (SV), peak current (IP), wire feed (WF) and wire tension (WT) on hot die steel(H-11) using one variable at a time approach. The optimal set of process parameters was predicted to maximize the material removal rate (MRR). It was noticed that the pulse on time and peak current had direct impact while pulse off time had indirect impact on MRR. Wire feed and wire tension had little effect on MRR [8].

Kubade, Jamadade et.al in 2015 optimized the process parametric combinations of pulse on time, pulse off time and wire speed using Taguchi L27 Orthogonal Array on Titanium Dibromide TiB_2. Signal to Noise ratios of the Material removal rate, Surface roughness and Overcut for all experiments were calculated. The results were analyzed using analysis of variance (ANOVA) and response graphs. The optimized result is compared with RSM predicted values and the residual error between the two values was calculated [9].

Harshdeep, Ishu Monga in 2015 used Taguchi L16 Orthogonal Array for investigating the effects of Pulse on time, Pulse off time, wire feed, wire tension and Peak current. They used this design for optimization of output parameters—material removal rate, wire wear ratio, and surface flatness. They further applied multi response (signal to noise ratio) approach to measure the performance characteristics deviating from the actual value [10].

3. EXPERIMENTAL SETUP

In the present work, experiments were carried out on Electronica Sprintcut 734 wire-cut EDM machine tool available in advanced manufacturing laboratory of the Institute. The cutting rate of the machine was studied by varying process variables at different settings. In the present work, only the electrical parameters namely pulse on time (T_{on}), pulse off time (T_{off}), peak current (IP) and servo voltage (SV) have been selected as variable parameters while parameters under the category of wire electrode, dielectric conditions and non-electrical parameters have been kept fixed in experimentation. Taguchi's L16 Orthogonal Array at 4 levels with four input parameters was selected for experimentation. Table 1 shows the various process parameters with their values at four different levels.

Table 1: Process Parameters and Levels

PP	Symbol	Level 1	Level 2	Level 3	Level 4
Ton (µs)	A	106	112	118	124
Toff (µs)	B	36	44	52	60
IP (A)	C	100	130	160	180
SV (V)	D	40	55	70	85

PP: Process Parameters, Ton: Pulse-on Time, Toff: Pulse-off Time, IP: Peak Current, SV: Servo Voltage

3.1 Workpiece Material

Incoloy 800, a nickel-iron-chromium alloy with size 10cm*10cm*1cm was used as a workpiece material. Tables 2 and 3 give the limiting chemical composition and physical constants respectively of Incoloy 800. Rectangular specimens of 5mm*5mm*10mm were prepared from the workpiece using brass wire electrode of 0.25mm diameter. De-ionized water with conductivity maintained between 10-15 mho was used as a dielectric material. Digital stopwatch was used for precise calculation of the time taken to cut the specimen. The experiments were conducted twice to minimize the chances of any error. Cutting Rate was directly determined from the machine monitor.

Table 2: Chemical Composition of Incoloy 800

Element	Ni	Cr	Fe
% value	33.25	21.23	45.52

Table 3: Physical and Mechanical Constants of Incoloy 800

Density	7.94 gm/cm3
Melting Range	1357-1385oC
Specific Heat	460 J/KgoC
Tensile Modulus(@ 20oC)	196.5 GPA
Shear Modulus(@ 20oC)	73.4 GPA
Poisson Ratio	0.339
Electrical Resistivity	0.989µΩm
Thermal Conductivity	11.5 W/moC

4. EXPERIMENTAL DESIGN METHODOLOGY

Taguchi method is an efficient tool for the design of high quality products. Dr. Genichi Taguchi, a Japanese scientist dedicated his entire life for generating methods that could tremendously improvise the performance of manufacturing systems, while working on limited number of resources. For this he developed a method based on orthogonal arrays (OA). In this method quality is measured by the deviation of a characteristic from its target value. A loss function is developed from this deviation. Uncontrollable factors which are also known as noise factors cause such deviations. Taguchi method seeks to minimize the effect of noise because the elimination of noise factors is impractical.

Taguchi's signal to noise ratios is the logarithmic function of desired output. S/N ratio is the ratio of the mean to standard deviation. Here mean refers to signal and standard deviation refers to noise. The ratio depends on the quality characteristic of the product/process to be optimized.

Cutting Rate of machine is "Higher the Better" type of quality characteristic. The S/N ratio is given as follows

$(S/N)_{HB} = -10 \log (MSD)$

Where,

$MSD = (1/y^2_1 + 1/y^2_2 + \ldots\ldots\ldots + 1/y^2_n) * 1/n$

Where, $y_1, y_2, \ldots, y_n$ represent values of n observations in each trial.

5. RESULTS AND DISCUSSIONS

In the present work, L16 Orthogonal Array was selected for experimentation and each experiment was repeated twice. In an OA, the values of parameters are given different settings after each experiment. Table 4 shows the L16 OA.

Table 4: L16 Orthogonal Array

S No.	Ton (µs)	Toff (µs)	IP (A)	SV (V)
1.	106	36	100	40
2.	106	44	130	55
3.	106	52	160	70
4.	106	60	180	85
5.	112	36	130	70
6.	112	44	100	85
7.	112	52	180	40
8.	112	60	160	55
9.	118	36	160	85
10.	118	44	180	70
11.	118	52	100	55
12.	118	60	130	40
13.	124	36	180	55
14.	124	44	160	40
15.	124	52	130	85
16.	124	60	100	70

5.1 Analysis of S/N Ratio

The response values obtained are studied with the help of ANOVA and S/N ratios. Table 5 gives the experimental results for Cutting Rate and the corresponding values of S/N ratio. By using these results, the influence of various parameters on cutting rate is observed. The designs, plots and analysis have been carried out using Minitab 17 software.

Table 5: Cutting Rate Results

S No.	Cutting Rate 1 (mm/min)	Cutting Rate 2 (mm/min)	Mean Cutting Rate (mm/min)	S/N Ratio
1.	1.428	1.393	1.4105	2.9855
2.	0.825	0.866	0.8455	-1.4654
3.	0.354	0.355	0.3545	-9.0077
4.	0.188	0.191	0.1895	-14.4486
5.	1.990	1.978	1.9840	5.9507
6.	0.906	0.895	0.9005	-0.9108
7.	1.566	1.591	1.5785	3.9641
8.	0.744	0.738	0.7410	-2.6038
9.	2.506	2.439	2.4725	7.8603
10.	2.838	2.955	2.8965	9.2322
11.	1.746	1.696	1.7210	4.7129
12.	1.577	1.550	1.5635	3.8810
13.	3.470	3.571	3.5205	10.9294
14.	3.726	3.908	3.8170	11.6270
15.	1.280	1.307	1.2935	2.2339
16.	0.994	0.985	0.9895	-0.0920

Fig. 2 shows the main effects plot for S/N Ratio. It is quite evident from the graph that the cutting rate increases with increase in pulse on time and then decreases slightly. This is due to the fact that pulse discharge energy increases with increase in T_{on} time.

But when pulse off time and servo voltage increase, cutting rate decreases. This is owing to the fact that time between two sparks increased with increasing pulse off time causing reduction in cutting rate. The peak current has very little impact on cutting rate.

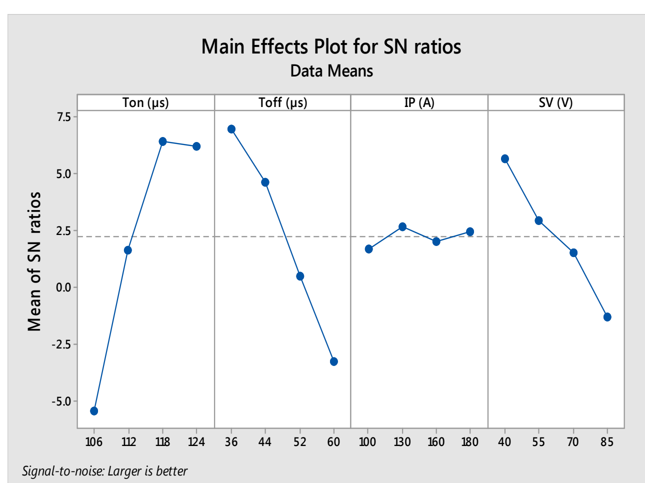

Fig. 2: Main Effects Plot for S/N Ratio

5.2 Analysis of Variance (ANOVA)

The values obtained from the experiment are analysed using ANOVA technique. ANOVA is performed to determine the significant factors that are affecting the cutting rate. Table 6 shows the ANOVA table for Raw Data. ANOVA is performed to control the process variation and to categorize parameters into significant and insignificant ones. In the present investigation 95% confidence level is taken.

Table 6: ANOVA TABLE FOR CUTTING RATE (RAW DATA)

Source	DOF	SS	V	F ratio	P%
A	3	14.862	4.954	96.37	43.61
B	3	11.83	3.9433	76.66	34.72
C	3	3.2254	1.0754	20.90	9.47
D	3	3.181	1.0603	20.61	9.34
Error	19				2.86
Total	31				100

DOF: Degree of Freedom, SS: Sum of Squares, V: Variance, P%: Percentage Contribution

Tables 7 and 8 give the Un-pooled and pooled ANOVA respectively for S/N Ratio.

From Table 7, it can be seen that the percentage contribution (P%) of factor C i.e. Peak Current is quite low. Therefore, peak current is insignificant in this analysis.

Table 7: UNPOOLED ANOVA TABLE FOR CUTTING RATE (S/N RATIO)

Source	DOF	SS	V	F ratio	P%
A	3	372.994	124.331	52.981	51.16
B	3	246.763	82.254	35.65	33.84
C	3	2.342	0.780	0.3323	0.32
D	3	99.93	33.31	14.194	13.71
Error	3				0.97
Total	15				100

Cutting Rate is "Higher the Better" type of quality characteristic, so it is clear from Fig. 2 that third setting of pulse-on time (A3), first setting of pulse-off time (B1) and first setting of servo voltage (D1) are the optimal settings that result in maximum cutting rate.

Table 8: POOLED ANOVA TABLE FOR CUTTING RATE (S/N RATIO)

Source	DOF	SS	V	F ratio	SS'	P%
A	3	372.994	124.331	79.51	368.303	50
B	3	246.763	82.254	52.6055	242.0722	33
D	3	99.93	33.31	21.303	95.2392	13
Error	6	9.3821	1.5636			04
Total	15					

SS': Pure Sum of Squares

6. CONCLUSIONS

In the present analysis, the effect of pulse-on time, pulse-off time, peak current and servo voltage was investigated in machining of Incoloy 800. Taguchi's L16 OA is used to design the experiment while ANOVA and S/N Ratio are used for optimization of result. Based on the experiments, following conclusions can be drawn from the research work:

1. The pulse on time has maximum contribution (43.61%) followed by pulse off time (34.72%) in controlling cutting rate as given in ANOVA for raw data.
2. Cutting Rate increases with increase in pulse-on time while it decreases with decrease in pulse-off time and servo voltage.
3. Pulse on time has 50 % contribution, pulse off time has 33% contribution and servo voltage has 13% contribution to cutting rate as revealed in the S/N ratio analysis.
4. The peak current has little effect on cutting rate.
5. For cutting rate, the optimal parameter setting is A3-B1-D1.

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