# Investigating the Process Parameters for optimization on Inconel 600 using wire cut EDM

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## Abstract

This study presents the investigation on surface roughness and cutting speed using wire electric discharge machine for nickel based alloy (Inconel 600).Taguchi’s design of experiments methodology has been used for scheduling and designing the experimental array.Taguchi’s L-18 orthogonal array was selected and where in taper angle, peak current, pulse-on time, pulse-off time and dielectric flow rate has been considered as variable input parameters during machining. The result of the study reveals that among machining parameters it is preferably to go for increasing the value of peak current and pulse on time for better cutting speed but it is constrained when better surface finish is required. Larger value of taper angle increases cutting speed up to limited extent. The predicted optimal values for CS and SR are found to be 3.08 mm/min, 1.37 µm for single response optimization respectively. The confirmation experiments are also conducted and the values for CS and SR are found to be 3.06 mm/min and 1.29 µm for single response optimization respectively.

## 1. Introduction

Wire Electrical Discharge Machining (WEDM) is a non-traditional, thermoelectric process which erodes material from the work piece by a series of discrete sparks between a work and tool, with de-ionized water as the dielectric medium, produce complex two and three dimensional shapes according to a numerically controlled (NC) path [10]. The schematic representation of the WEDM cutting process is shown in Figure-1. During present days mechanical industry has gone through a radical change, so the need of high strength alloys to meet the circadian demand of materials having high toughness and impact resistance has increased. These materials are difficult to machine with outmoded methods. Wire Electric Discharge Machines (WEDM) are used to machine conductive materials into complex curves, delicate geometries or difficult profiles, irrespective of the hardness or toughness of the material. WEDM is a widely acknowledged process for machining such materials when the principal objective is precision, but it is affected by a large number of input variables which makes it difficult to obtain optimal parametric combinations for machining different materials for various responses like surface roughness, material removal rate and cutting speed [12]. An analysis of effect of various machining characteristics is required for successful utilization of process with high productivity. This study analyses effects of various process parameters (Taper Angle Pulse-on time, Pulse-off time, Peak current, Dielectric flow rate as variable parameters) machining characteristics of CNC WEDM.

In the previous work to solve this task, shah, mevada, khatri [20] used response surface methodology as an efficient approach to determine the optimal machining parameters taking wire speed, peak current, pulse-on time, pulse-off time as variable process parameters. Wire-cut electrical discharge machining of Inconel-600 has been considered in the present set of research work taking taper angle, peak current, pulse-on time, pulse-off time and dielectric flow rate as variable process parameters and wire feed, wire tension, servo voltage, servo feed and pulse peak voltage as constant parameters as their effect is less. Inconel, nickel-chromium-iron alloy 600 is a standard engineering material for applications which require resistance to corrosion and heat. The alloy also has excellent mechanical properties and presents the desirable combination of high strength and good workability. The alloy's strength and oxidation resistance at high temperatures make it useful for many applications in the heat treating industry.

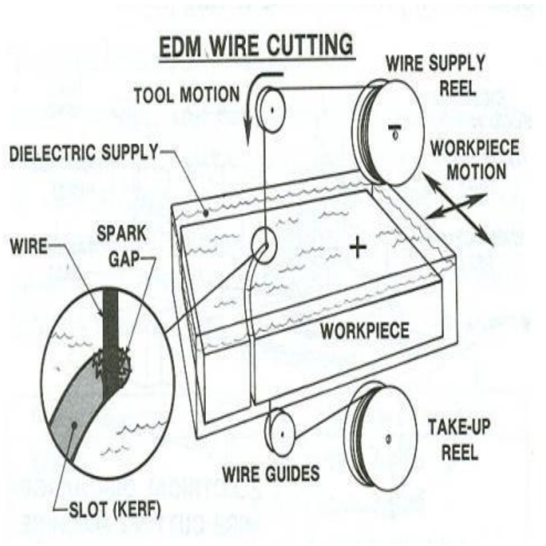

**Fig: 1.** Principal of WEDM [10]

It has been long recognized that cutting conditions such as pulse on time, pulse off time, taper angle, peak

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current and other machining parameters should be selected to optimize the economics of machining operations as assessed by productivity, total manufacturing cost per component or other suitable criterion. The application of DOE required careful planning, prudent layout of experiment and expert analysis of results. Based on years of research and application Dr. Genechi Taguchi has standardized the methods for each of these DOE application steps. Thus, DOE using Taguchi approach has become a much more attractive tool to practicing engineers and scientist. Taguchi recommends orthogonal array (OA) for arranging out of experiments. To design an experiment is to select the most suitable OA and to assign the parameters and interactions of interest to the appropriate columns [20].

## 2. Literature Review

A number of researchers has worked for attainment of better output results such as good surface finish and better material removal rate. Huan and Liao [1] applied Grey relational analyses to determine the optimal selection of machining parameters for the (Wire-EDM) process. It provides an efficient solution to the uncertainty, multi-input and discrete data problem. Based on Taguchi quality design concept, an L18 mixed-orthogonal array table was chosen for the experiments. With both Grey relational analysis and a statistical method, it is found that the table feed rate had a significant influence on the metal removal rate, whilst the gap width and surface roughness were mainly influenced by pulse-on time. Sarkar, Mitra, Bhattacharyya [3] studied the influence of parameters through artificial neural network on WEDM of γ titanium aluminide for the selection of optimum machining parameter combinations for obtaining higher cutting efficiency. Ramakrishnan and Karunamoorty [2] planned experiment as per taguchi’s L16 orthogonal array to study multi response optimization using taguchi’s robust design approach. Sivakiran, Bhaskar, Eswara [10] studied the relationship between control parameters and output parameters (MRR) usingtaguchi’sL16 OA on EN-31 tool steel to achieve maximum metal removal rate. Rajyalakshmi and Ramaiah [12] worked for the attainment of better surface finish during machining of Inconel825 using taguchi’s L18 orthogonal array. Kamal, Sandeep, Aman [9] in their work intricate shapes of WC-5.3%Co composite has been reported. GRA method coupled with entropy measurement method is employed for optimization of multi-machining characteristic using grey relational grade. After observing such extensive study work it has been observed that very still work has been done in finding the correct parameter setting for Inconel600 for better surface finish and high cutting speed. With this aim an attempt has been made in this paper to rectifies problems and achieve better results.

## 3. Experimental Work

The experiments were performed on Ultima-1F wire-cut EDM machine of Electronica Machine Tools Ltd. The ELEKTRA wire-cut Electric Discharge Machine is comprised of a machine tool, a power supply unit (ELPULS) and a dielectric supply unit. The machine tool has a main work table (called as XY table), an auxiliary table (called as U-V table) and a wire drive mechanism. The work piece is mounted and clamped on the main work table. The main table moves along X and Y axes, in steps of 1 micron, by means of servo motors, and also the U-V table moves, in steps of 1 micron, by means of servo motors. U & V axes are parallel to X & Y axes respectively. A traveling wire which is continuously fed from wire feed spool is caused to travel through the work piece and goes finally to the waste-wire box. Along its traveling path, the wire is supported under tension, between a pair of wire guides which are disposed on both (lower and upper) sides of the work piece. Lower wire guide is stationary whereas the upper wire guide is supported by the U-V Table.

## 4. Methodology

Taguchi recommends orthogonal array (OA) for carrying out of experiments. These OA’s are generalized Graeco-Latin squares. To design an experiment is to select the most suitable OA and to assign the parameters and interactions of interest to the appropriate columns. The use of linear graphs and triangular tables suggested by Taguchi makes the assignment of parameters simple. In the Taguchi method the results of the experiments are analysed to achieve one or more of the following objectives:

- To establish the best or the optimum condition for a product or process.
- To estimate the contribution of individual parameters and interactions.
- To estimate the response under the optimum condition.

The analysis of variance (ANOVA) is the statistical treatment most commonly applied to the results of the experiments in determining the percentage contribution of each parameter against a stated level of confidence. In this work, the five parameters have been selected at mixed levels. Thereby, L18 orthogonal array having degrees of freedom less than 18 is considered in present case.

## 5. Result and Discussion

The results obtained are analysed using S/N Ratios, Response table and Response Graphs with the help of Minitab 17 software. Minitab 17 is a computer program designed to perform basic and advanced statistical functions. It is a popular statistical analysis package for scientific applications, in particular for design and analysis of experiments.

**Table: 1.** Process Parameters and their symbols

| Control Parameters | Constant Parameters |
|---|---|
| Peak Current (B) | Wire Tension= 7 |
| Taper Angle (A) | Wire Feed= 5 |
| Pulse on time (C) | Servo Feed= 2100 |
| Pulse off time (D) | Servo Voltage= 35 |
| Dielectric flow Rate (E) | Pulse Peak Voltage= 1 |

**Table: 2.** Various Parameters and their levels

| Symbol | Process Parameters | Units | Level 1 | Level 2 | Level 3 |
|---|---|---|---|---|---|
| A | Taper Angle | Degree | 2 | 1 | -- |
| B | Peak Current | Ampere | 110 | 120 | 130 |
| C | Pulse on | Ms | 109 | 111 | 113 |
| D | Pulse off | Ms | 54 | 58 | 62 |
| E | Dielectric flow Rate | Ltr/min | 10 | 11 | 12 |

**Table: 5.** Experimental Results of Cutting Rate and Surface Roughness

| S.NO | A | B | C | D | E | CS Mean1 | CS SNRA1 | SR Mean2 | SR SNRA2 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 110 | 109 | 54 | 10 | 0.8764 | -1.1460 | 1.5620 | -3.8736 |
| 2 | 2 | 110 | 111 | 58 | 11 | 0.9389 | -0.5476 | 1.7350 | -4.7859 |
| 3 | 2 | 110 | 113 | 62 | 12 | 0.9874 | -0.1101 | 2.0480 | -6.2266 |
| 4 | 2 | 120 | 109 | 54 | 11 | 0.9438 | -0.5024 | 1.7400 | -4.8109 |
| 5 | 2 | 120 | 111 | 58 | 12 | 0.9892 | -0.0943 | 1.9560 | -5.8273 |
| 6 | 2 | 120 | 113 | 62 | 10 | 1.0720 | 0.6039 | 2.0900 | -6.4029 |
| 7 | 2 | 130 | 109 | 58 | 10 | 2.3036 | 7.2481 | 2.6916 | -8.6002 |
| 8 | 2 | 130 | 111 | 62 | 11 | 1.9147 | 5.6420 | 2.5920 | -8.2727 |
| 9 | 2 | 130 | 113 | 54 | 12 | 3.0699 | 9.7425 | 2.7516 | -8.7917 |
| 10 | 1 | 110 | 109 | 62 | 12 | 0.5901 | -4.5815 | 1.2875 | -1.4926 |
| 11 | 1 | 110 | 111 | 54 | 10 | 1.0542 | 0.4585 | 1.7680 | -4.9496 |
| 12 | 1 | 110 | 113 | 58 | 11 | 1.0683 | 0.5739 | 2.0300 | -6.1499 |
| 13 | 1 | 120 | 109 | 58 | 12 | 0.7152 | -2.9114 | 1.5440 | -3.7729 |
| 14 | 1 | 120 | 111 | 62 | 10 | 0.7995 | -1.9436 | 1.7420 | -4.8209 |
| 15 | 1 | 120 | 113 | 54 | 11 | 1.4789 | 3.3988 | 2.1360 | -6.5920 |
| 16 | 1 | 130 | 109 | 62 | 11 | 1.8601 | 5.3907 | 2.4020 | -7.6114 |
| 17 | 1 | 130 | 111 | 54 | 12 | 3.2252 | 10.1711 | 2.6350 | -8.4156 |
| 18 | 1 | 130 | 113 | 58 | 10 | 2.0084 | 6.0570 | 2.5166 | -8.0162 |

## 6. Effect on Cutting Speed

Table 4 shows S/N Ratio response table whereas Table 5 shows response table for means and Table 6 shows result of analysis of variance (ANOVA) for cutting speed. It is clear that the cutting rate increases with the increase of pulse on time, peak current, taper angle and decreases with increase in pulse off time. The effect of dielectric flow rate on cutting rate is not very significant as it increases a bit when flow rate increased and then further decreases when the rate of flow of fluid increases again.

**Table: 4.** Response Table for S/N Ratio (Higher is better)

| Level | A | B | C | D | E |
|---|---|---|---|---|---|
| **1** | 2.3151 | -0.892 | 0.5829 | 3.6871 | 1.8797 |
| **2** | 1.8459 | -0.241 | 2.2810 | 1.7209 | 2.3259 |
| **3** | - | 7.3753 | 3.3776 | 0.8336 | 2.0360 |
| **Delta** | 0.4692 | 8.2674 | 2.7947 | 2.8535 | 0.4462 |
| **Rank** | 4 | 1 | 3 | 2 | 5 |

**Table: 5.** Response Table for Means (Higher is better)

| Level | A | B | C | D | E |
|---|---|---|---|---|---|
| **1** | 1.4551 | 0.9192 | 1.2149 | 1.7747 | 1.3524 |
| **2** | 1.4222 | 0.9998 | 1.4870 | 1.3373 | 1.3674 |
| **3** | - | 2.3970 | 1.6142 | 1.2040 | 1.5962 |
| **Delta** | 0.0329 | 1.4778 | 0.3993 | 0.5708 | 0.2438 |
| **Rank** | 5 | 1 | 3 | 2 | 4 |

**Table: 6.** Results of analysis of variance (ANOVA) for cutting speed

| Source | DF | Adj SS | Adj MS | F-Value | P – Value |
|---|---|---|---|---|---|
| **A** | 1 | 0.0049 | 0.00487 | 0.07 | 0.794 |
| **B** | 2 | 8.2850 | 4.14250 | 61.82 | 0.000 |
| **C** | 2 | 0.4993 | 0.24964 | 3.73 | 0.072 |
| **D** | 2 | 1.0698 | 0.53492 | 7.98 | 0.012 |
| **E** | 2 | 0.2240 | 0.11199 | 1.67 | 0.248 |
| **Error** | 8 | 0.5361 | 0.06701 | | |
| **Total** | 17 | 10.6191 | | | |

| S | R-sq | R-sq (adj) | R-sq (pred) |
|---|---|---|---|
| 0.258871 | 94.95% | 89.27% | 74.44% |

**Fig: 2.** Effects of Process Parameters on Cutting Rate (Raw data)

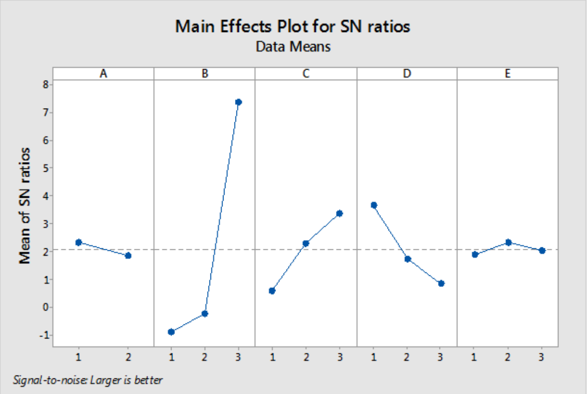

**Fig: 3.** Effects of Process Parameters on Cutting Rate (S/N data)

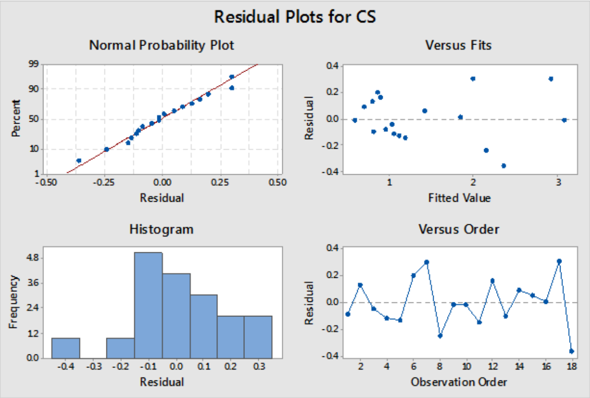

**Fig: 4.** Residual Plots for Cutting Speed

### 6.1 Selection of Optimal Levels for Cutting Speed

Selection of optimum process parameters have been made from the response Table 5. Analysis of variance (ANOVA) was performed, to study the significance of the process variables towards cutting speed. The ranks and the delta values show that peak current has the greatest effect on cutting speed and is followed by pulse off time, pulse on time, taper angle, and dielectric flow rate in that order. As cutting speed is the “higher is the better” type quality characteristic, it can be seen from Figure that the third level of peak current (B3), third level of pulse on time (C3), first level of pulse off time (D1), second level of taper angle (A1) and third level of dielectric flow rate (E3) provide maximum value of cutting speed. The S/N data analysis (Figure 3) also suggests the similar levels of the variables (A1, B3, C3, D1, E2) as the best levels for maximum cutting speed in WEDM process

## 7. Effect on Surface Roughness

In order to see the effect of process parameters on the surface roughness, experiments were conducted using L-18 orthogonal array (Table 3).The average values of surface roughness for each parameter at levels 1, 2 and 3 for mean of S/N ratio and mean of raw data are plotted in Figures 5 and Figure 6 .

**Table: 7.** Response Table for S/N Ratio (lower is better)

| Level | A | B | C | D | E |
|---|---|---|---|---|---|
| **1** | -6.399 | -4.697 | -5.144 | -6.239 | -6.111 |
| **2** | -5.836 | -5.371 | -6.179 | -6.192 | -6.371 |
| **3** | - | -8.285 | -7.030 | -5.922 | -5.872 |
| **Delta** | 0.641 | 3.705 | 2.003 | 0.434 | 0.616 |
| **Rank** | 3 | 1 | 2 | 5 | 4 |

**Table: 8.** Response Table for Means (Lower is better)

| Level | A | B | C | D | E |
|---|---|---|---|---|---|
| **1** | 2.130 | 1.738 | 1.871 | 2.099 | 2.062 |
| **2** | 2.007 | 1.868 | 2.071 | 2.079 | 2.106 |
| **3** | - | 2.598 | 2.262 | 2.027 | 2.037 |
| **Delta** | 0.123 | 0.860 | 0.391 | 0.072 | 0.069 |
| **Rank** | 3 | 1 | 2 | 4 | 5 |

**Table: 9.** Results of analysis of variance (ANOVA) for surface roughness

| Source | DF | Adj SS | Adj MS | F-Value | P-Value |
|---|---|---|---|---|---|
| **A** | 1 | 0.06785 | 0.06785 | 2.66 | 0.141 |
| **B** | 2 | 2.57800 | 1.28900 | 50.61 | 0.000 |
| **C** | 2 | 0.45838 | 0.22919 | 9.00 | 0.009 |
| **D** | 2 | 0.01651 | 0.00826 | 0.32 | 0.732 |
| **E** | 2 | 0.01459 | 0.00729 | 0.29 | 0.758 |
| **Error** | 8 | 0.20376 | 0.02547 | | |
| **Total** | 17 | 3.33909 | | | |

| S | R-sq | R-sq(adj) | R-sq(pred) |
|---|---|---|---|
| 0.15959 | 93.90% | 87.03% | 69.11% |

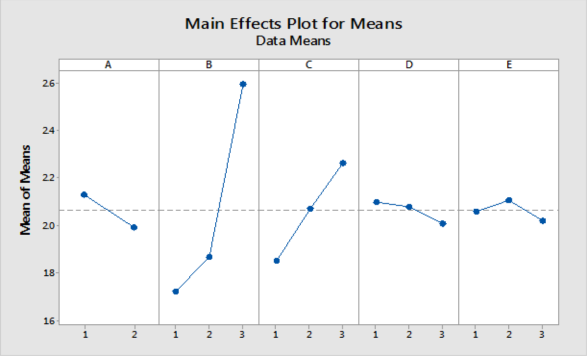

**Fig: 5.** Main Effect Plot for Means (for Surface Roughness)

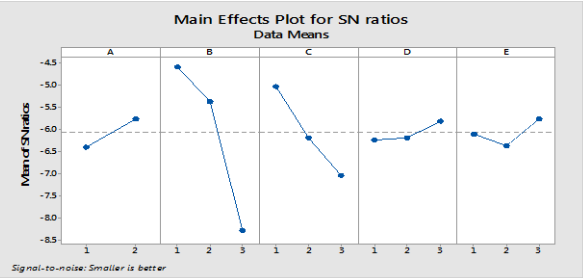

**Fig: 6.** Main Effect Plot for S/N ratios (for Surface roughness)

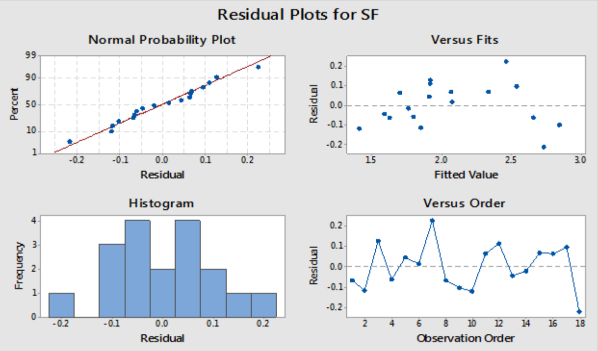

**Fig: 7.** Residual Plots for Surface finish

It is clear from the Figures 5 and Fig 6 that surface roughness increases with the increase of pulse on time, peak current and taper angle and decreases with increase in pulse off time, and dielectric flow. This is because the discharge energy increases with the increase of pulse on time and peak current and larger discharge energy produces a larger crater, causing a larger surface roughness value on the work piece. With the decreases in pulse off time, the number of discharges increases which causes poor surface finish to the work piece. Residual plots in Fig. 7 shows an approximate straight line in normal probability plot and approximate symmetric nature of histogram indicates that the residual are normally distributed. Since residuals exhibit no clear pattern, there is no error due to time or data collection order.

### 7.1 Selection of Optimal Levels

In order to study the significance of the process variables towards cutting rate, analysis of variance (ANOVA) was performed. It was found that dielectric flow rate is not significant process parameters for surface roughness. From these tables, it is clear that pulse on time, peak current, taper angle significantly affect both the mean and the variation in the SR values. The response tables (Tables 7 and 8) show the average of each response characteristic (S/N data, Means) for every level of each factor. Minitab 17 assigns ranks based on delta values. As surface roughness is the “lower the better” type quality characteristic, it can be seen from Figure 5and 6 that the first level of taper angle (A2), first level of peak current (B1),first level of pulse-on time (C1), third level of pulse-off time(D3) and third level of dielectric flow rate (E3) provide minimum value of surface roughness.

## 8. Confirmation Experiment

In order to validate the results obtained, three confirmation experiments were conducted for each of the response characteristics (CS and SR) at optimal levels of the process variables. The average values of the characteristics were obtained and compared with the predicted values. The values of CS & SR obtained through confirmation experiments are within the 95% of CICE of respective response characteristic. It is to be pointed out that these optimal values are within the specified range of process variables. Any extrapolation should be confirmed through additional experiments.

| Response | Optimal Set of Parameters | Predicted Optimal Value | Predicted Confidence Intervals at 95% Confidence Level | (Average of Confirmation Exp.) |
|---|---|---|---|---|
| CS | $A_1,B_3,C_3,D_1,E_3$ | 3.083 | $2.330 \le x \le 3.820$ | 3.069 |
| SR | $A_2,B_1,C_1,D_3,E_3$ | 1.37 | $1.05 \le \mu \le 1.70$ | 1.29 |

**Table: 10.** Predicted Optimal Values, Confidence Intervals and Results of Confirmation Experiments.

## 9. Conclusion

Here Taguchi’s method has been used for single response optimization. And in the present set of study, five control factors have been studied simultaneously to establish the trend of variation of a few important machining criteria with these control factors. From present study, the following conclusions are drawn:

1. The cutting speed (CS) is mostly affected by the peak current, pulse-on time, pulse off-time, and taper angle. The third level of peak current is highly affected the CS.
2. The surface roughness values (SR) are influenced mostly by peak current, pulse-on time, taper angle, pulse off-time, and dielectric flow rate.
3. The comparison of the predicted Surface Roughness and Cutting Speed with the experimental Surface Roughness and Cutting Speed using the optimum process parameters in WEDM has shown a good agreement between the predicted and experimental results but there are error in 0.46% error in cutting speed and 6.02% error in surface roughness respectively.

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