

# Investigation on machinability of Inconel 718 using ZNC EDM with Taguchi approach

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**Abstract-** Currently manufacturing industries are in front challenge from these advanced materials like super alloys, ceramics, and composite material that are not easy to machine, requiring better surface finish thus increase machining cost. In this study, the effects and optimization of process parameters on material removal rate (MRR) and tool wear rate (TWR) in electrical discharge machining (EDM) of Inconel 718 are attempted using ZNC spark erosion machine. Four process parameters namely peak current, pulse on time, pulse of time and gap voltage are considered for experimental study. A Taguchi optimization technique is used for design of experiments. The significant effects of process parameters on MRR and TWR are studies using analysis of variance (ANOVA). Pulse off time and peak current are observed as the most significant factors affecting MRR and TWR respectively. The optimal setting of process parameters are further validated by confirmatory experiment.

**Index Terms-** ZNC EDM, Machining, Cu Electrode, MRR, Taguchi, ANOVA

## INTRODUCTION

Electrical discharge machining (EDM) is a unconventional machining process where a desired shape can be obtained by electrical discharges (sparks). Material is removed from the work piece in the form of microscopic debris by means of recurring electric discharges between work piece and tool, which are immersed in dielectric fluid and subjected to an electric voltage. Peak Current, pulse on-time, pulse off time, gap voltage are used as input machining parameters. This method can be employed to make complicated profiles on work piece. In EDM process, electrical energy converts in thermal energy and material is melted and vaporized by this thermal energy. Due to a high temperature of the sparks both work piece and tool material is melted and vaporized

which is known as tool wear. The tool wear process is relatively similar to the material removal process of the work piece in the EDM process. The removal of material in EDM is allied with the erosive effects when discrete and spatial discharge occurs between the tools. Short sparks are created between electrode and work piece. The discharge process during EDM can be separated into three main phases.

## PROCESS PARAMETERS

1. Pulse On time (TON): It is the time period in micro seconds in which energy removes the metallic particles from the work piece. This energy is really controlled by current and pulse on time.
2. Pulse Off time (TOFF): It is the duration of time in micro seconds between the two pulse on time. In this period machining cannot be take place.
3. Arc gap: It is distance between the electrode and work piece. For good performances suitable gap should be there. Gap width cannot measure by any process, but can be inferred from the normal gap voltage. It is also known as machining gap.

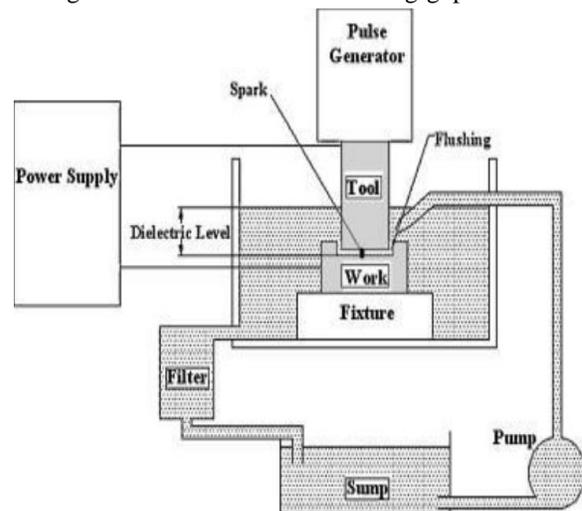


Figure1: Schematic setup diagram of Electric Discharge Machining

4. Peak current ( $I_p$ ): Current is calculated in ampere (A). Current is directly proportional to the material removal rate. It has energy for melting and evaporation. It is most important parameter in EDM.

5. Duty cycle ( $\tau$ ): It is the ratio of the pulse on-time to the total cycle time which is in percentage. This factor is measured by dividing on-time by the total cycle time (on plus off time). If increases duty factor, MRR also increase at constant current, constant pulse on Time. Because increasing duty cycle, the amount of spark increases so MRR increases.

$$\text{Duty cycle} = T_{\text{ON}} / T_{\text{(ON+T\_OFF)}} \dots\dots(1)$$

6. Voltage (V): The input voltage across the tool electrode and work piece is called the open circuit voltage. It can be produced by the power supply in a controlled manner. Voltage is also another main factor which very affect on MRR.

#### REVIEW OF LITERATURE

Hocheng et al. (1997) [1] conducted a preliminary study of material removal in electrical-discharge machining of SiC/Al. They developed a correlation between the electrical current and on-time, and the crater size produced by a single spark for the representative material SiC/Al. Chen et al. (1999) [2] found that during the investigation of EDM of Ti 6Al 4V the MRR was greater and the relative EWR is lower, when using 16 distilled water as dielectric solution. Narendara singh et al. (2000) [3] investigated the electrical discharge machining of Al-10%SiC metal matrix composite. They selected current, pulse on time, flushing pressure as machining parameters. The response to be studied for this study was metal removal rate, tool wear rate, radial over cut and surface roughness. I. Puertas and C.J. Luis (2004) [4] conducted analysis of the influence of EDM parameters on surface quality, MRR and EW of WC-Co. In this work, a study was carried out on the influence of the factors of intensity (I), pulse time ( $t_i$ ) and duty cycle ( $\eta$ ) over the listed technological characteristics. H.K. Kansal et al. (2005) [5] optimized the process parameters of powder mixed electrical discharge machining (PMEDM) on tool steel using Response surface methodology. Pulse on time, duty cycle, peak current and concentration of the silicon powder added into the dielectric fluid of EDM were chosen as variables to study the process performance in terms of material

removal rate and surface roughness. Mohd Amri Lajis et al. (2009) [6] investigated the relationship of process parameters in EDM of Tungsten carbide was used as the work piece material and graphite as electrode. Peak current, voltage, pulse on time and pulse off time are considered as input process parameters and the process performances such as metal removal rate (MRR), electrode wear (EWR) and surface roughness (SR). It was concluded that, the peak current of EDM mainly affects the electrode wear and surface roughness and the pulse on time largely affects the metal removal rate. Velusamy Senthil kumar (2011) [7] evaluates effect of Titanium Carbide particle addition in the aluminium composite on EDM process parameters. The objective of this work is to investigate the effect of current (C), Pulse On-Time (POT) and flushing pressure (P) on Metal Removal Rate (MRR), Tool Wear Rate (TWR) during electrical discharge machining. Analysis of variance (ANOVA) was performed to find the validity of the experimental plan followed in the present work. Raj Mohan et al. (2012) [8] investigated the influence of process parameters and their interactions viz., voltage, pulse on time, current and pulse off time on the material removal rate (MRR) in stainless steel (304) as work piece. Signal to noise ratio (S/N) and analysis of variance (ANOVA) was used to analyze the effect of the parameters on MRR and Taguchi method used to find the optimum cutting parameters. It was concluded that the two main significant factors that affects the MRR are pulse current and pulse on time. Herpreet Singh et al. (2013) [9] studied the influence of operating parameters like pulse-on time and pulse-off-time for responses such as Metal removal rate (MRR) and Tool Wear Ratio (TWR) on the EDM using steel as work piece and cryogenic and non cryogenic electrode of copper material. M.M. Rahman et al. [10] (2014) investigated the effect of the peak current and pulse duration on the performance characteristics of the EDM. The conclusions drawn were: the current and pulse on time greatly affected the MRR, TWR and SR, the MRR increases almost linearly with the increasing current. P Kuppan et al. (2015) [11] electric discharge deep hole drilling of Inconel 718 was experimented with three different commercial tube electrodes viz copper, copper-tungsten and graphite. The machining performance was investigated by

analyzing Material Removal Rate (MRR), Electrode Wear Ratio (EWR) and Surface Roughness (SR).

EXPERIMENTATION

Experiment is designed for Inconel 718 by using L9 orthogonal array from Taguchi's method. Work piece of Inconel 718 and Cu electrode is used for conducting experiment. Process parameters such as peak current, pulse on time, and pulse off time and gap voltage are taken for output responses such as MRR and TWR.

The experiments are conducted by ZNC Electric Discharge Machining at the various conditions as mentioned in table 1. EDM oil used as dielectric fluid (specific gravity-0.763). The levels of four process parameters are taken for experiments are shown in table 2.

Description	Specifications
Work piece	Inconel 718
Electrode	Copper dia 12 mm
Dielectric fluid	EDM oil
Dielectric pressure	1.0 Kg/cm <sup>2</sup> with side flushing
Electrode polarity	Positive

Table1. Experimental Conditions

MACHINING PARAMETER	SYMBOL	UNIT	LEVELS		
			1	2	3
Peak current	Ip	A	6	9	12
Pulse on time	TON	Ms	30	60	90
Pulse off time	TOFF	Ms	15	45	90
Gap voltage	V	V	40	50	60

Table 2.Parameters level for experiments



Figure 2: Work piece of Inconel 718 after machining with Cu electrode

Taguchi Technique in EDM are brought-out in the following to decide the material removal rate and roughness by Parametric Optimization, experiments

and analyzing of process parameters in relation to work piece using orthogonal array method. Anova concept is used for contribution of every input factor which is taken such as peak current, pulse on time, pulse of time and gap voltage on output response.

Table 3 shows Experimental DOE with actual values.

Si. no.	Peak current (A)	Pulse on time (µs)	Pulse off time (µs)	Gap voltage (V)
1	6	30	15	40
2	6	60	45	50
3	9	30	45	60
4	12	60	15	60
5	12	90	45	40

Table 3: Experimental DOE with actual values

Formula of MRR calculation

The material removable rate (MRR) is expressed as the ratio of the difference of weight of the work piece before and after machining to the machining time. It is expressed as,

$$MRR = (W_{bm} - W_{am}) / t \text{ gm/min} \dots\dots\dots (2)$$

Where,

W<sub>bm</sub> = Work piece weight before machining.

W<sub>am</sub> = Work piece weight after machining.

t = time (min).

Formula of TWR calculation

The tool wear rate (TWR) is expressed as the ratio of the difference of weight of the tool electrode before and after machining to the machining time. It is expressed as,

$$TWR = (W_{bm} - W_{am}) / t \text{ gm/min} \dots\dots\dots(3)$$

Where,

W<sub>bm</sub> = Electrode weight before machining. W<sub>am</sub> = Electrode weight after machining.

t = time (min).

RESULTS AND DISCUSSION

The effects of process parameter such as Peak current, Pulse on time, Pulse off time and Gap voltage on MRR and TWR of Inconel 718 machined work piece with copper tool is analysed and find out which parameter is most important for better machinability of Inconel material with the help of Taguchi design. Table 4 shows DOE with experimental results for MRR with copper electrode.

Run no.	Peak current (A)	Pulse on time (µs)	Pulse off time (µs)	Gap voltage (V)	MRR (gm/m)	MRR <sub>2</sub> (gm/m)	MRR <sub>3</sub> (gm/m)	Mean MRR (gm/m)	S/N Ratio
1	6	30	15	40	0.0562	0.0537	0.0513	0.0537	-25.4005
2	9	30	45	60	0.0209	0.0240	0.0213	0.0220	-33.1515
3	9	90	15	50	0.2011	0.2222	0.2018	0.2083	-13.6262
4	12	60	15	60	0.1620	0.1904	0.1905	0.1809	-14.8512
5	12	90	45	40	0.1708	0.1681	0.2104	0.1831	-14.7462

Table 4: DOE with Experimental Results for MRR with Cu electrode

Figure 3 shows that MRR at 12 A peak current, 90 µs pulse on time, 15 µs pulse off time and 40 V voltage correspondingly gives the best results on input parameters.

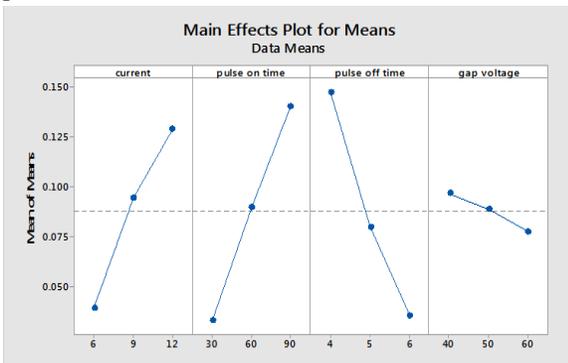


Figure 3: Mean plot of MRR (gm/min) versus four input factors

The SN ratios for MRR are calculated from equation which is given below.

$$LB: \eta = -10 \log_{10} \left[ \frac{1}{n} \sum_{i=1}^n (y_i)^{-2} \right] \quad \dots(4)$$

Table 5 shows that percentage contribution of pulse off time (TOFF), is about 40.87 % which has large impact on MRR in EDM process. The parameters such as pulse on time (TON), current (A) and gap voltage (V) has very small impact on MRR.

Source	Degree of freedom	Sum of Squares	Mean Squares	F	% Contribution
Peak current	2	86.70	43.35	1.4759	0.1709
Pulse on time	2	182.26	91.13	3.1028	0.3594
Pulse off time	2	207.29	103.65	3.5291	0.4087
Gap voltage	2	30.81	15.41	0.5246	0.0607

Table 5: ANOVA of SN ratios for MRR

The parameters are taken to optimize maximum MRR. The best setting of input process parameters

for maximum MRR should be within the special range and these values are taken by figure 4.

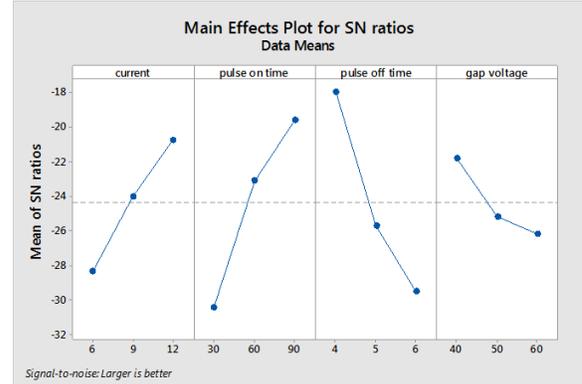


Figure 4: Mean plots for SN Ratio (MRR)

Optimal machining parameters for MRR were determined. The percentage deviation between experimental and predicted result is 16.70 %.

Table 6 shows DOE with Experimental Results for TWR with Cu Electrode.

Run no.	Peak current (A)	Pulse on time (µs)	Pulse off time (µs)	Gap voltage (V)	TWR <sub>1</sub> (mg/m)	TWR <sub>2</sub> (mg/m)	TWR <sub>3</sub> (mg/m)	Mean TWR (mg/m)	S/N Ratio
1	6	30	15	40	0.0012	0.0017	0.0007	0.0012	58.4164
2	6	60	45	50	0.0009	0.0014	0.0003	0.0008	61.9382
3	9	30	45	60	0.0024	0.0048	0.0023	0.0031	50.1728
4	12	60	15	60	0.0065	0.0046	0.0052	0.0054	45.3521
5	12	90	45	40	0.0013	0.0011	0.0017	0.0013	57.7211

Table 6: DOE with Experimental Results for TWR with Cu Electrode

Figure 5 shows that TWR at 6 A peak current, 30 µs pulse on time, 45 µs pulse off time and 40 V voltage correspondingly gives the best results on input parameters.

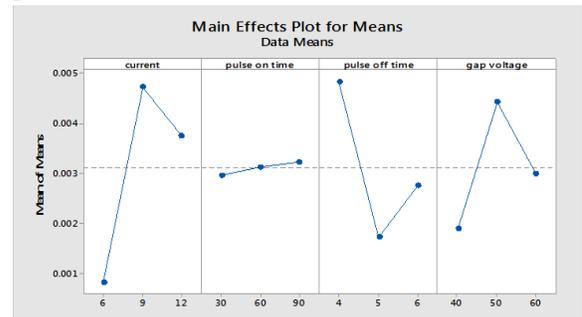


Figure 5: Mean plot of TWR (mg/min) versus four input factors

The SN ratios for TWR are calculated from equation which is given below.

$$SB: \eta = -10 \log_{10} [1/n \sum_{i=1}^n (y_i)^2] \dots (5)$$

Table 7 shows that percentage contribution of peak current is about 69.52 % which has large impact on tool wear rate in EDM process. The parameters such as pulse off time (TOFF), voltage (V) and pulse on time (TON) has very small impact on TWR.

Source	Degree of freedom	Sum of Squares	Mean Squares	F	% Contribution
Peak current	2	372.72	186.36	12.0232	0.6952
Pulse on time	2	20.75	10.37	0.6690	0.0387
Pulse off time	2	101.33	50.67	3.2690	0.1890
Gap voltage	2	41.26	20.63	1.3309	0.0769

Table 7: ANOVA of SN ratios for TWR

The parameters are taken too optimized to achieve minimum TWR. The best setting of input process parameters for minimum TWR should be within the special range and these values are taken by figure 6.

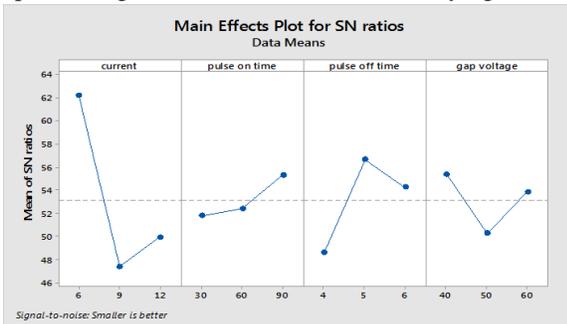


Figure 6: Mean plots for SN Ratio (TWR)

Optimal machining parameters for TWR were determined. The percentage deviation between experimental and predicted result is 20 %.

### CONCLUSION

1. In this study, percentage contribution of pulse off time (TOFF) is about 40.87 % which has maximum impact on MRR in EDM process. The parameters like pulse on time (TON), current (A) and gap voltage (V) have minimum impact on MRR. The analysis states that the efficiency of the pulse off time on MRR with Cu electrode in EDM process.

2. The percentage contribution of peak current is about 69.52 % which has maximum impact on TWR in EDM process. The parameters like pulse off time (TOFF), voltage (V) and pulse on time (TON) have minimum impact on TWR. The analysis states that the efficiency of the peak current on TWR with Cu electrode in EDM process.

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