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# Optimization of Material Removal Rate in WEDM of Nimonic-80A Alloy using Taguchi Approach

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## Abstract

*Nimonic-80A alloy* is a material of high demand which covers a broad range of industrial applications. In this research article, experiments have been performed on *Nimonic-80A alloy* using Wire EDM process by employing Taguchi's DOE approach in form of L9 orthogonal array in order to design the experiments. Material removal rate has been experimentally studied and analyzed by using Analysis of Variance. Different process variables investigated are; pulse on-time ($T_{on}$), pulse off-time ($T_{off}$), and spark gap voltage (SV). Parameters, pulse on-time ($T_{on}$), and pulse off-time ($T_{off}$) have been observed to be most significant for the material removal rate. The optimum setting for material removal pulse on-time ($T_{on}$) is 122 µs, pulse off-time ($T_{off}$) is 35 µs, and spark gap voltage (SV) is 50 V.

**Keywords:** MRR, nimonic alloy, process variables, taguchi method, WEDM.

## 1. Introduction

WEDM process performs the machining of electrically conductive workpiece with the help of electro-thermal energy developed in the machining zone, consisting of the gap between continuously moving wire and workpiece flushed with dielectric (de-ionized water). The plasma channel is built up across the machining gap due to ionization of dielectric. High frequency pulses of AC or DC current developed between wire and workpiece cause higher amount of heat energy responsible for melting and evaporation of the workpiece resulting in formation of craters.

Muthu Kumar. V et al. [1] applied Grey-Taguchi method (using L-9 orthogonal array) for multi-response optimization of WEDM of incoloy800 superalloy. It was analyzed that the material removal rate increased from 0.05351 g/min to 0.05765 g/min, surface roughness decreased from 3.31µm to 3.10 µm and kerf width increased from 0.324to 0.296 mm as a result of the process optimization. Another study described that tool wears out rapidly when cutting speed exceeds beyond 60 m/min during machining with conventional processes. The tool materials such as ceramics, diamond and cubic boron nitride (CBN) are highly reactive with Ti alloy at higher temperatures causing deteriorated machinabilty. The binderless CBN tools were reported to have higher tool life at enhanced cutting speed. Sharif and Rahim compared the machining performance of uncoated WC/CO and Ti-AlN-PVD coated carbide twist drills during drilling operation of Ti alloys. The tool life was observed to be improved when the drilling operation was performed at 25 m/min cutting speed. Apart from tool life, surface roughness was also found to be improved for coated drill. Guo et al. [2] compared the machinability of steel with $Al_2O_3$p particle-reinforced material (6061) using Taguchi's L16 orthogonal array. It was found that while the voltage increases from 60 V to 100V, the cutting rate of steel is maintained constant whereas, for 6061 alloy, it gets increased rapidly due to removal of conductive and nonconductive particle together with the help of discharge force. The surface roughness gets decreased while increasing voltage (for 6061 alloy) due to insufficient energy to melt or remove the dielectric particles. Similar studies [3-6] have also reported a comparison of the machinability of Ti alloy (Ti-6Al-4V and Ti-5Al-5Mo-5V). Machinability of Ti-5Al-5Mo-5V was found to be poor as compared to Ti-6Al-4V. A close relationship was observed between machinability rating and mechanical properties of work material, tool wear and component forces. Fang and Wu reported the comparative study of cutting forces in high speed machining of Ti-6Al-4V and Inconel 718 with a round cutting edge tool. It was reported that cutting force and thrust force consumption are higher for Inconel 718 than Ti-6Al-4V alloy due to higher shear strength of Inconel 718. The parametric optimization of machining responses helps to solve real life industrial problems [7-18].

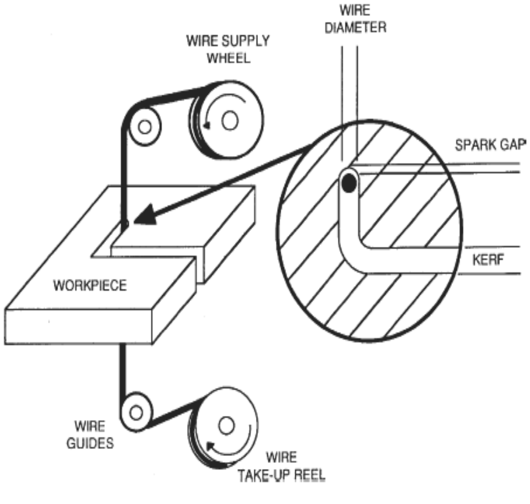


**Figure 1 Basic diagram of WEDM process**

## 2. Experimentation

The experimentation work was performed on a four-axis CNC type wire cut electrical discharge machine (make-Electronica). For the present research work, a rectangular piece of Nimonic-80A alloy was chosen as work material. The workpiece utilized for machining was having dimensions of

120 mm × 100 mm × 20 mm. The following parameters were selected for the study based on the availability of these parameters.

1. **Pulse on time**
2. **Pulse off time**
3. **Spark gap voltage**

The other parameters were made to be fixed during experimentation.

**TABLE 1: PARAMETERS USED ON WEDM SET-UP**

| Control factor | Symbol |
|---|---|
| Pulse on time ($T_{ON}$) | Factor A |
| Pulse off time ($T_{OFF}$) | Factor B |
| Spark gap voltage (SV) | Factor C |

In this experimental study, each control factor used having three levels. Details of each factor level are shown below in Table 2:

**TABLE 2: VARIOUS FACTORS AND THEIR LEVELS (MACHINE UNIT)**

| S. No. | Symbol | Factors | Level 1 | Level 2 | Level 3 | Unit |
|---|---|---|---|---|---|---|
| 1 | A | $T_{ON}$ | 108 | 115 | 122 | µs |
| 2 | B | $T_{OFF}$ | 35 | 45 | 55 | µs |
| 3 | C | Spark Gap Voltage | 30 | 50 | 70 | V |

Taguchi's L9 orthogonal array has been used for designing the experimentation. The whole experimentation replicated twice and the mean value of responses has been provided here.

**TABLE 3: CONTROL LOG FOR EXPERIMENT (TAGUCHI'S L9 OA)**

| Experiment No. | Factors | | |
|---|---|---|---|
| | $T_{ON}$ | $T_{OFF}$ | Spark Gap Voltage (SV) |
| **1** | 108 | 35 | 30 |
| **2** | 108 | 45 | 50 |
| **3** | 108 | 55 | 70 |
| **4** | 115 | 35 | 50 |
| **5** | 115 | 45 | 70 |
| **6** | 115 | 55 | 30 |
| **7** | 122 | 35 | 70 |
| **8** | 122 | 45 | 30 |
| **9** | 122 | 55 | 50 |

**TABLE 4: TEST DATA FOR MATERIAL REMOVAL RATE (MRR)**

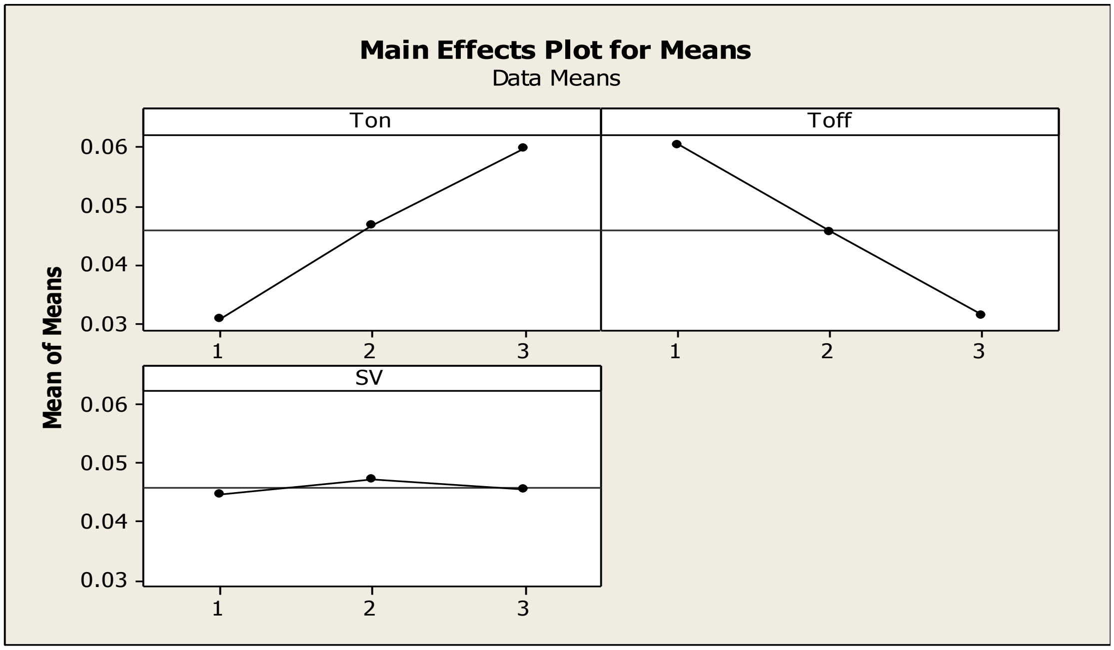
| **Exp. No.** | **$T_{ON}$** | **$T_{OFF}$** | **Spark Gap Voltage (SV)** | **MRR mean value (g / min)** | **MRR S/N ratio (db)** |
|---|---|---|---|---|---|
| 1 | 108 | 35 | 30 | 0.0379 | -28.4287 |
| 2 | 108 | 45 | 50 | 0.03595 | -28.8867 |
| 3 | 108 | 55 | 70 | 0.0184 | -34.7071 |
| 4 | 115 | 35 | 50 | 0.06515 | -23.7219 |
| 5 | 115 | 45 | 70 | 0.0399 | -27.9819 |
| 6 | 115 | 55 | 30 | 0.03515 | -29.0822 |
| 7 | 122 | 35 | 70 | 0.078 | -22.1583 |
| 8 | 122 | 45 | 30 | 0.0608 | -24.3222 |
| 9 | 122 | 55 | 50 | 0.0406 | -27.8315 |

## 3. Results and Discussions

It can be seen for the figure 2 that, pulse on-time ($T_{on}$), and pulse off-time ($T_{off}$) are the most significant for the material removal rate (MRR). The different input parameters used in the experimentation can be ranked in order of decreasing effect as; pulse on-time ($T_{on}$), pulse off-time ($T_{off}$), and spark gap voltage (SV).

For the mean values of responses, the percentage contribution of pulse on-time ($T_{on}$) is 46.64 %, pulse off-time ($T_{off}$) is 46.23 %, and for the spark gap voltage (SV) the contribution is only 0.39 % with regard to MRR.

The analyses of results showed that the **A3 B1 C2** is the optimal parameters setting for the material removal rate. In the study we concluded that the optimal input parameters setting for the, ***pulse on-time ($T_{on}$) is 122 µs, pulse off-time ($T_{off}$) is 35 µs, and spark gap voltage (SV) is 50 V***, while WEDM of *Nimonic-80A alloy* as far as the MRR is concerned.



**Optimal combination A3 B1 C2**

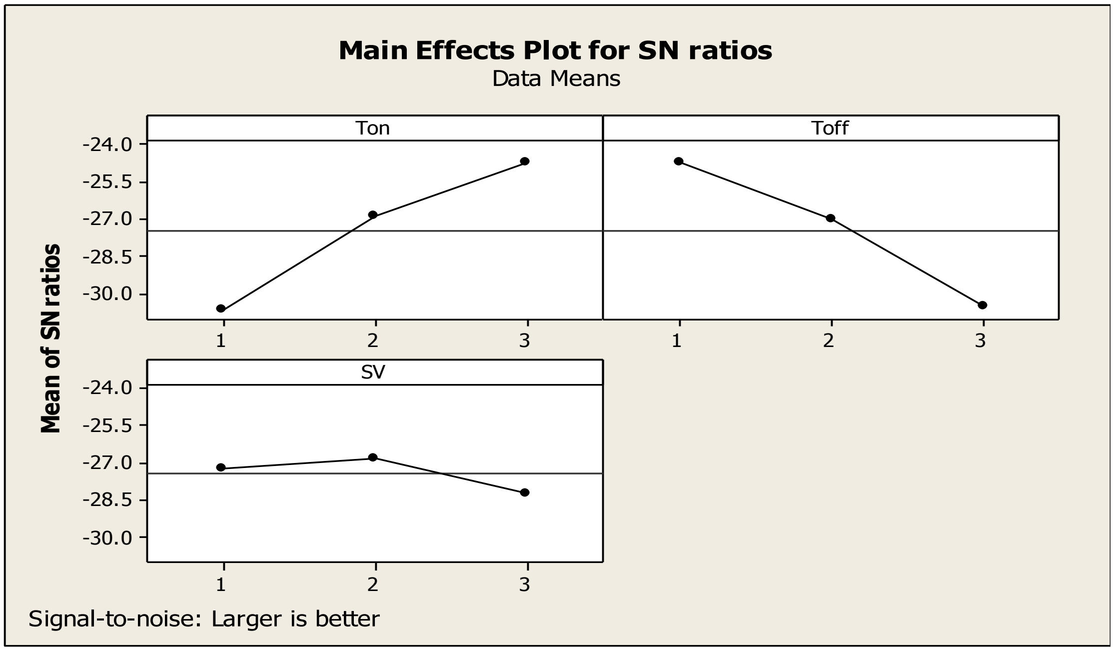


**Figure 2: Mean Effect Plots for *Material Removal Rate (MRR)* - raw data and S/N ratio**

**TABLE 5: ANOVA RESULTS FOR MATERIAL REMOVAL RATE (MRR) (RAW DATA)**

| Source | dof | Seq. SS | Adj. SS | Adj. MS | F | P | % contribution |
|---|---|---|---|---|---|---|---|
| $T_{ON}$ | 2 | 0.0025402 | 0.0025402 | 0.0012701 | 38.16 | 0.000 | 46.64% |
| $T_{OFF}$ | 2 | 0.0025176 | 0.0025176 | 0.0012588 | 37.82 | 0.000 | 46.23% |
| SV | 2 | 0.0000215 | 0.0000215 | 0.0000108 | 0.32 | 0.731 | 0.39% |
| Error | 11 | 0.0003662 | 0.0003662 | 0.0000333 | | | 6.72% |
| Total | 17 | 0.0054455 | | | | | |

## 4. Prediction of Mean

The estimate of the mean (μ) is only a point estimate based on the average of results obtained from the experiment. It is therefore customary to represent the values of a statistical parameter as a range within which it is likely to fall, for a given level of confidence (Ross, 1996). This range is termed as the confidence interval (CI). In other words, the confidence interval is a maximum and minimum value between which the true average should fall at some stated percentage of confidence (Ross, 1996).

The Taguchi approach for predicting the mean performance characteristics and determination of confidence interval for the predicted mean has been applied. The average value of performance characteristics obtained through the confirmation experiments must be within the 95% confidence interval (α= 0.05).

For calculation of $CI_{CE}$, the following equation has been used.

$$CI_{ce}=\sqrt{Fa(1,fe)Ve\left[\frac{1}{neff}+\frac{1}{R}\right]} \qquad \text{.......} \ (5.1)$$

Where $Fa(1,fe)$ =the F ratio at a confidence level of against DOF 1, and error degree of freedom $f_e$.

$$n_{eff} = \frac{N}{1+[Total\ DOF\ associated\ \ in\ the\ estimate\ \ of\ the\ mean\ ]}$$

N = Total number of results

R = Sample size for confirmation experiment

Ve = error variance

For ***Material Removal Rate (MRR);***

$T_{on}$ and $T_{off}$ are identified as the significant factors for the material removal rate. Hence, the predicted (optimal) value of MRR is computed using Minitab 16.

$\mu_{MRR}$ = 0.0759 (using Minitab 16)
$Fa$ = 4.84
$Ve$ = 0.0000333 (from ANOVA results)
$n_{eff}$ = 2.5714
N = No. of experiments conducted in total (9×2 = 18)
R = 2

Hence, putting all the values in equation (5.1)

$CI_{CE(MRR)} = \pm 0.01197$

The 95% confidence level for $\mu_{MRR}$ is

**$CI_{CE\,(MRR)} = 0.06393 < \mu_{MRR} < 0.08787$**

The predicted optimum values and the confidence interval have been tabulated in table 6. Experiments were conducted at optimum setting of process parameters for all the response factors.

**TABLE 6: COMPARISON OF PREDICTION AND EXPERIMENTAL RESULTS FOR MRR**

| RESPONSE | | PREDICTED VALUE | EXPERIMENTAL VALUE | $CI_{CE}$ |
|---|---|---|---|---|
| **MRR** | g/min | 0.0759 | 0.0701 | $0.06393 < \mu_{MRR} < 0.08787$ |

This could be observed from the table 6 that, the values from the confirmation experiments were contained well within the confidence interval for MRR. Hence, the optimization results were validated.

## 5. CONCLUSION

Based on the experiments conducted the following conclusions have been drawn:

1. Pulse on-time ($T_{on}$), and Pulse off-time ($T_{off}$) significantly affects the ***Material Removal Rate (MRR)*** in Wire EDM of Nimonic-80A alloy. With regarding to the average response $T_{on}$ and $T_{off}$ are more significant as compare to spark gap voltage (SV).

2. For the mean values of responses, the percentage contribution of pulse on-time ($T_{on}$) is 46.64 %, pulse off-time ($T_{off}$) is 46.23 %, and for the spark gap voltage (SV) the contribution is only 0.39 % with regard to MRR.

3. The analyses of results showed that the **A3 B1 C2** is the optimal parameters setting for the material removal rate. In the study we concluded that the optimal input parameters setting for the, ***pulse on-time ($T_{on}$) is 122 µs, pulse off-time ($T_{off}$) is 35 µs, and spark gap voltage (SV) is 50 V***, while WEDM of *Nimonic-80A alloy* as far as the MRR is concerned.

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