Study of the output responses using Utility concept coupled with Taguchi Philosophy during EDM machining of nickel-based superalloy Inconel 718

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Abstract. The primary objective of this research paper is to get the optimum combination of input process parameters such as peak current (IP), open voltage (Vg), pulse-on-time(Ton) & duty factor(τ) for EDM machining of Inconel 718. The output process parameters that we got and studied after experiments were materials removal rate (MRR), electrode wear rate (EWR), and surface roughness (SR). An orthogonal array of process parameters was created, using Minitab software as the design of experiments (DOE). For a single domain of multiple output response parameters, we used the utility method. After that, we used the Taguchi optimization method to find out the optimal parameter setting for higher materials removal rate (MRR), lower electrode wear rate (EWR), and lower surface roughness (SR).

Keywords: EDM, Inconel 718 Super Alloy, Copper tool, Utility Method, Taguchi Philosophy.

1. Introduction: Background and Motivation

This experiment proved a challenge to the modern machining process and led to the Advanced Machining Process in the field of Technology of Manufacture. Inconel 718 is a nickel-based alloy, which is a relevant material. The key benefits of using this Inconel 718 material are improved yield strength, tensile strength, and high-temperature resistance capacity. This Inconel 718 alloy is used during the manufacturing of jet engines and various airplane parts such as blades, discs, etc. A most significant and remarkable technology Electro Discharge Machine (EDM) is used in doing this experiment with Inconel 718. Here, in this technology, place both the tool and the electrolyte in the dielectric and then apply a high potential, thereby producing a high pulse spark. A large amount of heat will generate and dissipates, which, in turn, melt the workpiece. We use EDM for doing this experiment because Inconel 718 is a tough material, and it cannot be melt by another machining process.

Rahul et al. [1] have studied the surface roughness and metallic properties of Inconel 825 during EDM machining using CTT and NTT. He found a set of parameters for which surface crack density is less while EDM machining using CTT concerning NTT. Further, he has studied the factors affecting the tool life. Singh et al. [2] has done the experimental study on Inconel 601 in EDM using RSM and studied that the increase in current MRR increases, and surface finish varies directly with the current. Vishnu et al. [3] have presented an experiment with Inconel 718 using EDM for predicting the MRR, SR, and EWR. Jeykrishnan et al. [4] studied on Inconel 625 using Electro Discharge Machine to find the MRR and studied that surface finish is directly proportional to the current. Kumar et al. [5] studied on Inconel 825 using Electro Discharge Machine and studied the
machinability of Inconel 825 using Graphene Nanopowder and predict the results of MRR, EWR, and \( R_a \). Raju et al. [6] have presented an experimental study on Inconel 600 using micro-electro Discharge Machine (EDM) to find the optical parameter for the EDM Drilling process. Tanjilul et al. [7] have presented an experimental study on Inconel 718 using Electro Discharge Machine (EDM) for drilling holes on Inconel 718 through Spark erosion. Basha et al. [8] have presented an experimental study on Inconel X-750 using Electro Discharge Machine (EDM) to investigate the MRR, TWR, SR and also studied the influence of this parameter on the tungsten-copper electrode. Rahul et al. [9] also studied the optimization of Inconel 601, 625, 718, and 825 superalloy parameters were carried out by a 5 factor 4 L16 (OA) based EDM machine, and the best results were calculated using the Topsis and Taguchi methods. Rahul et al. [10] did experimental study on the processability of processing Inconel 718 with copper tools. They conducted research based on L25 OA by adopting various parameters such as Vg, Ip, Ton, \( \tau \), and Flush pressure and received various responses like TWR, Ra, SCD, and WLT.

The primary objective of this experimental work is to investigate the output responses like Material removal rate (MRR), Electrode Wear Rate (EWR), Surface Roughness (Ra) on a nickel-based alloy Inconel 718 using Electro Discharge Machine (EDM) by giving input process parameters like Peak Current (Ip), Open Voltage (Vg), Pulse-on time (Ton) & Duty Factor (\( \tau \)).

2. Experimental details and data collection

Inconel 718, which is a super hard nickel-based alloy, the square workpiece having a dimension (50 mm\( \times \)5 mm) is used as a workpiece Fig.1. The tool electrode of Copper (20mm diameter) has been used Fig.2. An experimental study has been done on EDM (Model: ELEKTRA EMS 5535 Machine, Pune, India) setup Fig.3. For dielectric fluid, EDM oil 30 is used. The EDM fluid has the viscosity of 36 ssu at a temperature of 38°C. The polarity of the workpiece has been chosen as a positive. The experimental design is taken as per 4-factor-4-level L_16 Orthogonal Array (OA). Here peak current, voltage, pulse on time, and duty factor are considered as the input process parameters where each of these varied at four different levels of affecting experiments (Table.1). For every machining process, time taken as 30 minutes. Then the output parameters like MRR, EWR, SR are studied and recorded for every experiment.

![Fig. 1. EDM Inconel](image1)

![Fig. 2. Copper tool](image2)

![Fig. 3. EDM Machine](image3)

**Table 1.** The domain of experiments

| Input Parameters | Unit   | Symbol | 1   | 2  | 3  | 4  |
|------------------|--------|--------|-----|----|----|----|
| Peak Current \( (I_p) \) | Amperes | A      | 8.5 | 10.5 | 12.5 | 14.5 |
| Open Voltage \( (V_g) \) | Volts  | B      | 16  | 21  | 26  | 31 |
| Pulse-On-Time \( (T_{on}) \) | \( \mu \) secs | C      | 52  | 102 | 152 | 202 |
| Duty Factor \( (\tau) \) | %      | D      | 49  | 66  | 83  | 100 |
3. Methodology

3.1. Utility Method

The definition of utility is the aptness of any job or any procedure concerning the consumer’s level of expectancy. The appraisement and calculation of any machining process lie upon various characteristics of output. Hence, an integrated measure is required to collect its overall execution that makes sure that the correlative performance of all quality features should take into account. We have to first calculate the individual utility of a product; then, we have to calculate the overall utility of a process, which is represented by the composite index. This utility method gives a method to construct a frame for the calculation of substitute characteristics, which is made by any person, firm, and organization. The actual meaning of utility is the satisfaction provided by all attributes to a decision-maker. Hence, utility theory takes an assumption that every decision should be formed based on the principle of maximization of utility, which means that the ideal option should be made that gives the best satisfaction to any judgment maker. So, utility theory says the best choice is such, which provides the best satisfaction to the decision-maker.

The preference number can be expressed as:

\[ P = A \times \log \left( \frac{X_i}{X_i^*} \right) \]

Here, \( P \) is performance number; \( A \) is constant, \( X_i = \) measurement of any quality characteristic or attribute \( i \) and \( X_i^* \) is a receivable value of quality characteristic or attribute \( i \).

\[ A = \frac{9}{\log \left( \frac{X_i^*}{X_i} \right)} \]

Here, \( X_i^* \) is the optimum value.

Now, overall utility function can be written as:

\[ U = \sum_{i=1}^{n} W_i P_i \]

Here, \( P_i \) is the performance number for each attribute, and \( W_i \) is weightage of each attribute.

4. Data Analysis: Results and Discussions

The main purpose of this work is to find the optimal set of parameters for high metal removal rates (i.e., peak current, gap voltage, pulse on time, and duty cycle), but electrode wear rate and surface roughness are low. In this utility method, an individual utility for each response, such as MRR, EWR, and SR is calculated. Then overall utility is calculated by taking equal weightage of each response (Table.2). Here we have used the Taguchi method to find the optimum values of the overall utility function (U_{overall}) (Table.3). As the U_{overall} is required to be the highest, so, Higher-is better (HB) property is used for S/N ratio calculation (Fig.4).

| Sl. no | Individual Utility | Overall Utility | Corresponding S/N ratio | Predicted S/N ratio |
|-------|--------------------|-----------------|-------------------------|---------------------|
|       | U_{MRR} | U_{EWR} | U_{SR} | U_{Overall} | dB | dB | dB |
| 1     | 6.492986 | 0.000000 | 7.214865 | 4.523591 | 4.523590 | 7.793980 |
| 2     | 7.962413 | 3.890880 | 5.781202 | 5.819383 | 5.819380 |
| 3     | 5.832318 | 7.756115 | 7.238679 | 6.872947 | 6.872950 |
| 4     | 5.832436 | 8.062941 | 6.084117 | 5.651157 | 5.651160 |
| 5     | 9.004931 | 3.890880 | 4.228906 | 5.651157 | 5.651160 |

Table 2. Calculations of utility value corresponding to each response
Table 3. Response table for means of $U_{overall}$

| Level | A     | B     | C     | D     |
|-------|-------|-------|-------|-------|
| 1     | 5.952 | 4.913 | 4.228 | 5.464 |
| 2     | 6.181 | 5.033 | 5.704 | 5.039 |
| 3     | 3.747 | 5.759 | 6.199 | 5.584 |
| 4     | 5.885 | 6.060 | 5.634 | 5.678 |
| Delta | 2.434 | 1.147 | 1.970 | 0.640 |
| Rank  | 1     | 3     | 2     | 4     |

Fig. 4. S/N Ratio Plot: Evaluation of Optimal Setting (Optimization of $U_{overall}$) [Optimal Setting: $A_2B_4C_3D_4$] (Inconel 718)
5. Conclusion
The key points of this research work have been summarized below.
- In this research work, utility function integrated with Taguchi's philosophy used to determine an optimum set of EDM parameters (i.e., gap voltage, peak current, pulse-on-time, and duty factor) such that MRR will be highest, but EWR and SR will be lowest simultaneously. The proposed utility function was instrumental in integrating multiple responses into an equivalent single index (i.e., $U_{overall}$ in the present case), which was optimized finally by the Taguchi method. The optimal process parameters setting appears as $(A_2B_4C_3D_4)$ i.e. $I_p = 10.5$ A, $V_g = 31$ V, $T_{on} = 152$ μs and $\tau = 100\%$.
- The mean response table (mean S/N ratio of $U_{overall}$) shows that the peak current ($I_p$) is the most significant parameter to influence machining performances.

6. References

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