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# Optimization of Wire EDM Performance on High Carbon and High Chromium Steel using Taguchi and TOPSIS Method

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***Abstract*—Wire Electrical Discharge Machining (WEDM) is a crucial non-traditional machining technology that enables high-speed cutting and precision machining, widely used in the automotive industry, press stamping die manufacturing, and prototype part production. This study investigates the influence of four key process parameters—pulse On time, pulse OFF time, spark gap voltage, and input current—on the cutting performance of WEDM. Experiments were conducted using a 0.18 mm molybdenum wire as the electrode and D2 tool steel (130 × 50 × 16 mm) as the work material. The performance measures considered include material removal rate (MRR) and surface roughness (Ra). Taguchi's L27 orthogonal array design was employed to conduct the experiments under various parameter settings. The objective of this research is to determine the optimal combination of WEDM parameters for machining D2 steel to achieve improved surface quality and material removal efficiency.**

***Keywords*—Wire Electrical Discharge Machining (WEDM), D2 Tool Steel, Molybdenum Wire Electrode, Material Removal Rate (MRR), Surface Roughness (Ra), Taguchi Method, L27 Orthogonal Array, TOPSIS, Multi-Criteria Decision Making (MCDM), Process Optimization.**

## I. INTRODUCTION

Electrical Discharge Machining (EDM) is a controlled metal-removal process that is used to remove metal by means of electric spark erosion. In this process an electric spark is used as the cutting tool to cut (erode) the workpiece to produce the finished part to the desired shape. The metal-removal process is performed by applying a pulsating (ON/OFF) electrical charge of high-frequency current through the electrode to the workpiece. This removes (erodes) very tiny pieces of metal from the workpiece at a controlled rate. Puertas and Luis (2005), investigated the optimization of machining parameters used for EDM of Boron carbide of conductive ceramic materials. It is these conditions were determined the important characteristics as surface roughness, electrode wear, and MRR. Wang and Lin (2000), The Taguchi method and L18 orthogonal array to obtain the polarity, peak current, pulse duration, duty factor, rotary electrode rotational speed, and gap load voltage in order to explore the material removal rate, electrode wear rate, and surface roughness. Miller et.al (2005), determined the WEDM is a complex machining process controlled by a large number of process parameters such as the pulse duration, discharge frequency and discharge current. Tosun et al (2003) modelled the variation of response variables with the machining parameters using regression analysis method and then applied simulated annealing searching for determination of the machining parameters that can simultaneously optimise all the performance measures, e.g. kerf and MRR.

Several attempts were made to perform a parametric study from time to time (Han et al 2007 , Jin et al 2008, Kanlayasiri et al 2007, Liao et al 2004). Mahapatra and Patnaik (2007) established the relationship between various processes. (Han et al 2007, Jin et al 2008, Kanlayasiri et al 2007, Liao et al 2004). Mahapatra and Patnaik (2007) established the relationship between various process parameters and responses using non-linear regression analysis and then employed genetic algotithm to optimize the WEDM process.Chiang and Chang (2006) optimised the surface roughness and Material Removal Rate of a WEDM process for Al2O3 particle reinforced material based on Grey Relational Analysis method. chiang and chang (2006) used Grey Relational analysis to determine optimal WEDM parameters for machining Al2O3 particle reinforced material with multiple performance characteristics. Different materials even when they are machined under the same machining conditions exhibit different machining characteristics. It is difficult to control and predict the machining characteristics in WEDM. There are very few studies on this on this subject so far. Almost the studies concerned with material, deal with the effect of electrode materials on machinability in WEDM (prohaszka et al 1997). Levy and magi (1990) have compared the influence of material properties of different steels on machining characteristics, but only qualitatively. It is extremely difficult to conclude and pinpoint definite physical quantity that can fully reflect the material properties for WEDM, and use it to predict machining characteristics (Dibitonto et al 1989, Dijck 1972, Eubank et al 1993) . This paper was reported to the shortest machining time whilst at the different time satisfying the requirements of MRR and surface roughness by using Taguchi's Method.

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## II. EXPERIMENTAL DETAILS

### A. Process Parameters Selection

The experiments were carried out on a Wire Electro Discharge Machine (WEDM) ELECTRONICA "SIMOS CNC SC 32 ST" of ECLAT EDM SOLUTIONS Installed at The TIE BALANAGAR, Hyderabad, Telangana, India. The discussions related to the measurement of WEDM Experimental Parameters, material Removal Rate (MRR), Surface Roughness are given in the following Table I.

TABLE I. PROCESS PARAMETERS OF WIRE-EDM

| SI.No | Paramters | Range |
|---|---|---|
| 1 | Wire Material | Molybdenum wire |
| 2 | Wire Size (mm) | Ø 0.18 |
| 3 | Generator | Elplus-40 A DLX |
| 4 | Dielectric | Deionised water |
| 5 | Table feed rate (mm/min) | 220 |
| 6 | Work Piece | D2 steel |

### B. Material Removal Rate (MRR)

For WEDM, MRR is a desired characteristic and it should be high as possible to give less machine cycle time leading to increased productivity in the present study MRR is calculated as MRR = ( D*P*t)/T

Where, D = Wire diameter,

P = Perimeter of the cross section,

t = Thickness of material,

T = Time taken for machining..

### C. Selection of the Work Piece

TABLE II. TYPICAL COMPOSITIONAL RANGES OF GRADE D2 STEEL

| Grade Wt.% | C | Mn | Si | P | S | Cr | Mo |
|---|---|---|---|---|---|---|---|
| ***D2*** | 1.58 | 0.565 | 0.352 | 0.024 | 0.028 | 11.30 | 0.77 |

TABLE III. TYPICAL MECHANICAL PROPERTIES OF GRADE D2 STEEL

| Grade | Tensile Strength (M pa) min | Yield Strength(M pa) min | Elongation (% in 50mm)min | Hardness (BHN) |
|---|---|---|---|---|
| ***D2*** | 1054 | 1500 | 10 | 220 |

### D. Taguchi design experiments in MS Excel

Both static and dynamic response experiments in a static response experiment are determined using MS Excel. the quality characteristic of interest has a fixed level. MS Excel calculates response tables and generates. A Taguchi design or an Orthogonal array the method is designing the experimental procedure using different types of design like, two, three, four, five, and mixed level. In the study, a three factor mixed level setup is chosen with a total of twenty-seven numbers of experiments to be conducted and hence the OA L27 was chosen. This design would enable the two factor interactions to be evaluated. As a few more factors are to be added for further study with the same type of material, it was decided to utilize the L27 setup, which in turn would reduce the number of experiments at the later stage. In addition, the comparison of the results would be simpler. This project makes use of Taguchi's method for designing the experiments. Hence L27 mixed Orthogonal array was selected for the present investigation. Parameters and their levels selected for final experimentation has been given in Table IV.

### E. Taguchi Design

It is an engineering method for product or process design that focuses on minimizing variation and/or sensitivity to noise. When used properly, Taguchi designs provide a powerful and efficient method for designing products that operate consistently and optimally over a variety of conditions. Taguchi proposed several approaches to experimental designs that are sometimes called "Taguchi Methods."

### F. Multi criteria decision making (MCDM)

In this work, the parameters to be optimized are material removal rate and surface roughness.Here, both the parameters are given the equal weightage and the method that is adopted to achieve the optimal values of parameters is TOPSIS (Technique for Order Preference by Similarly to Ideal Solution). The basic concept of this method is that the selected substitute should have the shortest distance from the ideal solution and the farthest away from the negative- ideal solution in some geometrical sense. The TOPSIS method assumes that each criterion has a tendency of monotonically increasing or decreasing utility. Therefore, it is easy to define the negative-ideal solutions and ideal. Euclidean distance approach was proposed to evaluate the relative closeness of the alternatives to the ideal solution. Thus, the preference order of the alternatives can be derived by a series of comparisons of these relative distances.

### G. TOPSIS Methodology

The TOPSIS method first converts the various criteria dimensions into non-dimensional criteria as was the case with the ELECTRE method. As a remark, it should be stated that in the ELECTRE and TOPSIS methods the Euclidean distance represent some plausible assumptions. Other alternative distance measures could be used as well, in which case it is possible for one to get different answers for the same However, it is reasonable to assume here that for the benefit criteria, the decision maker wants to have a maximum value among the alternatives. Mathematically the application of the TOPSIS method involves the following steps.

Stage 1: First, we must construct decision matrix by using the information available in the criteria. In which decision matrix gives the performance of ith alternative with respect to jth criterion.

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Stage 2: Then get normalized decision matrix, with equation given below:

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \quad \text{(i)}$$

Stage 3: Assign weights to the parameters. Here both the parameters are given the equal weightage so

MRR=50% SR=50%

Stage 4: In this stage, we must find weighted normalized matrix:

$$V_{ij} = W_{ij} r_{ij} \quad \text{(ii)}$$

Stage 5: Find out PIS and NIS values by the following equations: (iii)

$$V^- = \{(\Sigma_i^{min} V_{ij}/j \in J), (\Sigma_i^{max} V_{ij}/j \in \hat{J})/ 1,2..N\}$$

$$V^+ = \{(\Sigma_i^{max} V_{ij}/j \in J), (\Sigma_i^{min} V_{ij}/j \in \hat{J})/ 1,2..N\}$$

Stage 6: Acquire the separation values namely $S^+$ and $S^-$

$$S_i^+ = {}_{j=1}\sum^n (v_{ij} - v_j^+)^2$$

$$S_i^- = {}_{j=1}\sum^n (v_{ij} - v_j^-)^2 \quad \text{(iv)}$$

Stage 7: Find relative closeness values for each alternative and it is calculated as follows:

$$C_i^+ = S_i^- / (S_i^+ + S_i^-) \quad \text{(v)}$$

Stage 8: Now arrange these $C^+$ values for each alternative in descending order and prepare rankings from highest to lowest and the highest value is the one which is closer to ideal solution.

## III. EXPERIMENTAL DESIGN

In this work, TOPSIS (Technique for Order Preference by Similarly to Ideal Solution) was adopted to evaluate the optimal values of the input parameters Pulse On time (T-ON), Pulse off time (T-OFF), input current and spark gap voltage. The methodology of TOPSIS is shown above. the four process parameters each at three levels have been decided. It is desirable to have three minimum levels of process parameters to reflect the true performance of the output parameters of the study. The process parameters are renamed as factors and they are given in the adjacent column. The levels of individual input factors are given in Table IV.

TABLE IV. LEVELS OF INPUT VARIABLES

| S. No | Process parameters | symbol | Level-1 | Level-2 | Level-3 |
|---|---|---|---|---|---|
| *1* | *Pulse-on time* | *T-on (μs)* | 40 | 45 | 50 |
| *2* | *Pulse-off time* | *T-off (μs)* | 6 | 7 | 8 |
| *3* | *Spark gap voltage* | *SV (volts)* | 20 | 25 | 30 |
| *4* | *Input current* | *IP (Amps)* | 2 | 4 | 6 |

## IV. RESULTS AND DISCUSSION

In this paper, the Research is related to the influences of MRR, Surface Roughness, finding the result that factors discharge current, pulse duration are most important with the help of the Taguchi method. The response table for MRR and Surface Roughness is shown in Table 4 along with the input factors. In this investigation, the effects of WEDM essential parameters such as peak current (A), Pulse ON time (Ton), Pulse OFF time (Toff), and gap voltage (V) were varied to determine their effects on material removal rate (MRR) and surface roughness (SR). Here, both the outputs, i.e, Material Removal Rate (MRR) and Surface Roughness (SR), are given equal importance and are assigned equal weights. To obtain the optimal values of the input parameters, we adopt one of the multi-criteria decision-making methods i.e; TOPSIS (Technique for Order Preference by Similarity to Ideal Solution).

As per Taguchi experimental design philosophy by using the experimental input responses sequence for conducting 27 experiments and values are mentioned below table V. By applying these values as set of input responses to the EDM machine the output responses are noted and those values are substituted in TOPSIS method to find the optimal input response to attain the maximum material removal rate and minimum surface roughness.

The experimental values of the Material removal rate(MRR) and Surface roughness(SR) for the L27 taguchi method are given in the below table V. It is evident from the table V that the Material Removal Rate (MRR) increases with the increase in the pulse ON time. Taguchi method is used to obtain the nominal output response (i.e, Maximum Material removal rate( MRR) and Minimum Surface Roughness(SR)).

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Vol. 14 Issue 05, May-2025

TABLE V. RESPONSE TABLE

| S.No | Pulse-on time (µs) | Pulse-off time (µs) | Spark gap set voltage (Volts) | Input current(Amps) | Time (min) | MRR (mm^3/sec) | SR (µm) |
|---|---|---|---|---|---|---|---|
| 1 | 40 | 6 | 20 | 2 | 12.07.27 | 0.158459 | 4.96 |
| 2 | 40 | 6 | 25 | 4 | 7.35.41 | 0.253187 | 5.46 |
| 3 | 40 | 6 | 30 | 6 | 14.04.87 | 0.136493 | 3.92 |
| 4 | 40 | 7 | 20 | 4 | 8.32.52 | 0.225 | 6 |
| 5 | 40 | 7 | 25 | 6 | 15.56.94 | 0.120502 | 3.8 |
| 6 | 40 | 7 | 30 | 2 | 16.37.39 | 0.115547 | 3.81 |
| 7 | 40 | 8 | 20 | 6 | 16.10.44 | 0.118763 | 4.41 |
| 8 | 40 | 8 | 25 | 2 | 17.29.54 | 0.109819 | 4.01 |
| 9 | 40 | 8 | 30 | 4 | 10.30.25 | 0.182857 | 5.3 |
| 10 | 45 | 6 | 20 | 2 | 11.23.16 | 0.168668 | 4.12 |
| 11 | 45 | 6 | 25 | 4 | 10.09.03 | 0.189163 | 7.6 |
| 12 | 45 | 6 | 30 | 6 | 13.13.48 | 0.145271 | 4.12 |
| 13 | 45 | 7 | 20 | 4 | 8.23.42 | 0.229026 | 7.58 |
| 14 | 45 | 7 | 25 | 6 | 14.37.11 | 0.131357 | 4.43 |
| 15 | 45 | 7 | 30 | 2 | 15.17.19 | 0.125627 | 4.54 |
| 16 | 45 | 8 | 20 | 6 | 15.11.69 | 0.126454 | 4.2 |
| 17 | 45 | 8 | 25 | 2 | 16.26.05 | 0.116836 | 4.22 |
| 18 | 45 | 8 | 30 | 4 | 10.39.78 | 0.180282 | 5.88 |
| 19 | 50 | 6 | 20 | 2 | 10.40.76 | 0.18 | 4.38 |
| 20 | 50 | 6 | 25 | 4 | 15.53.00 | 0.120881 | 7.86 |
| 21 | 50 | 6 | 30 | 6 | 12.55.62 | 0.148645 | 4.52 |
| 22 | 50 | 7 | 20 | 4 | 8.48.50 | 0.218182 | 6.62 |
| 23 | 50 | 7 | 25 | 6 | 13.51.22 | 0.138628 | 4.31 |
| 24 | 50 | 7 | 30 | 2 | 14.46.63 | 0.130023 | 4.5 |
| 25 | 50 | 8 | 20 | 6 | 14.09.36 | 0.135689 | 4.56 |
| 26 | 50 | 8 | 25 | 2 | 15.22.88 | 0.124946 | 4.32 |
| 27 | 50 | 8 | 30 | 4 | 10.34.16 | 0.181703 | 5.54 |

International Journal of Engineering Research & Technology (IJERT)
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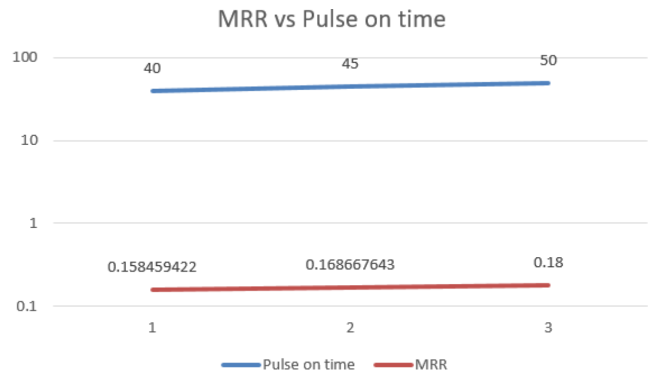


Fig. 1. plot showing MRR vs Pulse On time

The graph showing the relationship between the Material Removal Rate(MRR) and pulse ON time is given in Fig.1 above. Another output parameter that is taken in consideration is Surface roughness (SR) and Pulse On time has a good impact on the Surface roughness. Initially, Surface roughness decreases with the increase in the value of Pulse On time i.e, the final workpiece gets smoother initially by increasing the Pulse On time, but further increasing the value of Pulse On time the surface roughness of the final workpiece increases. i.e, the final workpiece gets rough. The relationship between the surface roughness and pulse on time is given in Fig.2 below.

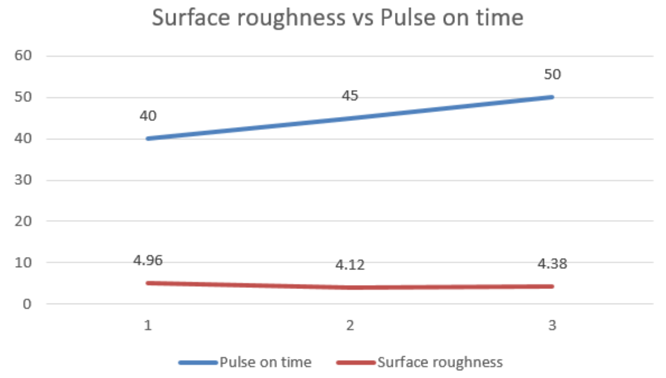


Fig. 2. plot showing Surface roughness vs Pulse On time

Surface roughness initially increases with an increase in the value of input current. When input current changes from 2 amperes to 4 amperes, nominal value of surface roughness increases from 4.96 µm to 5.46 µm. and on further increasing from 4 amperes to 6 amperes the surface roughness changes from 5.46 µm to 3.92 µm. so initially on increasing the value of current the final workpiece becomes rougher and on further increasing the input current the final workpiece gets smoother. The relation between surface roughness and input current is given in Fig.3.

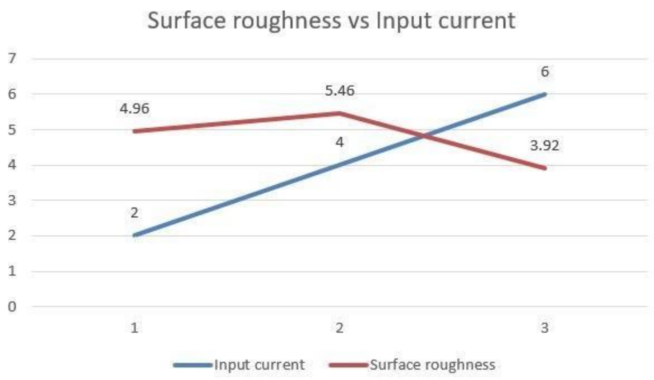


Fig. 3. plot showing surface roughness vs input current

Now, let's discuss the relationship between material removal rate (MRR) and input current from Fig.4. Initially, increasing the input current from 2 amperes to 4 amperes raises the material removal rate from 0.158 mm³/sec to 0.253 mm³/sec; that is, as the input current increases, the time taken to machine the workpiece reduces, resulting in a higher material removal rate. However, when further increasing the current from 4 amperes to 6 amperes, the material removal rate decreases from 0.253 mm³/sec to 0.136 mm³/sec; thus, as the input current continues to rise, the time taken to machine the workpiece increases, leading to a reduction in the material removal rate.

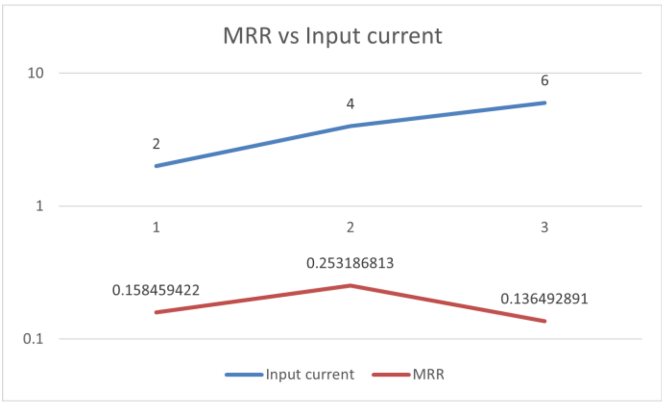


Fig. 4. plot showing MRR vs input current

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