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# INVESTIGATION OF PROCESS PARAMETERS CONTRIBUTION AND THEIR MODELING IN WEDM FOR D-2 TOOL STEEL USING ANOVA

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## Abstract

Wire electric discharge machine (WEDM) is a non conventional machining method to cut hard to machine material with the help of a wire electrode. Response surface methodology is used for the planning of experiments and D-2 tool steel is used as a work-piece. D-2 tool steel used in tools, punches and die industries. The main objective of this study is to investigate the significant process parameters along with the percentage contribution of each parameter. ANOVA is used to find the percentage contribution of significant process parameters. The analysis of results indicates that pulse on servo voltage have the maximum effect in single parameter compared to pulse off time and peak current during the investigation of cutting rate on WEDM for D-2 tool steel.

**Keywords:** *ANOVA, D-2 tool steel, modeling, Response surface Methodology, WEDM.*

## 1. Introduction And Literature Review

Wire cut Electrical-discharge machining (WEDM) is widely used un-conventional machining process for hard to cut conductive materials. It is used for the aerospace, automobile, medical industries, tool, mould, and die industries. The mechanism of WEDM constitutes the erosion of material due to discrete spark discharge between wire tool and job immersed in a liquid dielectric medium. Very high frequency pulses are generated with the help of DC power supply. The electrical discharge melts or erodes the material in a very small amount which is flushed away by dielectric. The schematic diagram of WEDM has been visualized in figure 1.The work piece and wire electrode is separated by deionised water. The deionized water works as dielectric fluid and flushes out the eroded or melted material [1]. WEDM is rarely able to achieve optimal performance due to large number of variables and their stochastic nature. This problem can be solved by determining the relationship between performance of the process and its input parameters using designed experiments. The literature review has been given in following paragraphs. Jangra [3] presented a study on unmachined surface area named as surface projection in the die cutting after rough cut in WEDM. Using scanning electron microscope images, length of unmachined surface projections have been determined. In order to minimize these surface projections from small cavities having complex geometries, trim cutting operation is the best alternative. Result shown that using more than one trim cut with appropriate wire offset value, surface projections can be minimized, successfully. Jangra concluded that increasing discharge energy results in increase in unmachined surface area on work surface. Nicolae, Monica, Alexandru and alina [4] discussed the draft cutting and finishing cutting in the paper and they observed that EDM wire cutting process performance can be improved and measured with dimensional accuracy, surface roughness and the rate of material removal. In 2012 Sharma et al. [5] investigate the effect of parameters on cutting rate for WEDM using HSLA as work piece and brass wire as electrode. It is seen that cutting rate increases with increase in pulse on time and peak current. Cutting rate decrease with increase in pulse off time and servo voltage. The response surface methodology (RSM) is used to formulate a mathematical model which correlates the independent process parameters with the desired cutting rate. Experiments have concluded that for cutting rate. The predicted values of the response are in close agreement with experimental results and wire mechanical tension has not much effect on cutting rate.

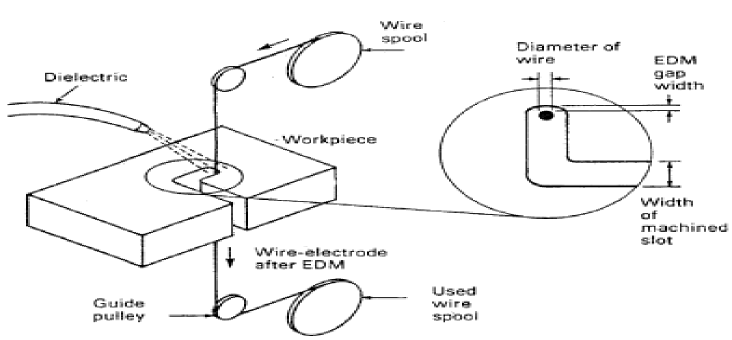


**Figure 1: Schematic Diagram of WEDM [2]**

In 2012 Gupta et al. [6] investigated the effect of parameters on kerf width for WEDM using HSLA as work piece. They revealed that kerf width decreases with increase in pulse on time, pulse off time, spark gap voltage and peak current. Response Surface Methodolgy (RSM) was used to formulate a mathematical model which correlates the independent process parameters with the desired kerf width. Kerf width increases with in wire tension. With increase of peak current kerf width increases. In 2005 Albert J. Shih et al. [7] investigated the Effects of WEDM process parameters, particularly the spark cycle time and spark on-time on thin cross-section cutting of Nd–Fe–B magnetic material, carbon bipolar plate, and titanium. The micro EDM has been studied extensively by Masuzawa and his research group in the past two decades [8-10].In 2005 Taweel et al. [11] highlights the development of mathematical models for correlating the inter-relationships of various WEDM machining parameters of Inconel 601 material such as: peak current, duty factor, wire tension and water pressure on the metal removal rate, wear ratio and surface roughness.Sharma et al. [12] optimized the process parameters of WEDM for multi-responses using response surface methodology. Mathematical model is developed for the solution of this. HSLA-100 steel has been used for the experimentation purposes on WEDM.

There is little research has been carried out using D-2 tool steel as a die material. As it is hard, wear resistant corrosion resistant, so D-2 tool steel is choosing as a workpiece for experimentation. To evaluate the effects of machining parameters on performance characteristic, and modeling of process parameters with the percentage contribution of control factors Response surface methodology is used.

## 2. Process Parameters of WEDM

Based on the findings of the many researchers, process parameters for WEDM process based on the quality of the machining are grouped in various categories. The process parameters, their designated symbols and range are given in Table 1.

**Table 1: Process Parameters, Symbols and their Ranges**

| Process Parameters | Symbol | Range (machine units) |
|---|---|---|
| **Pulse on Time** | $T_{on}$ (μs) | 105-124 |
| **Pulse off time** | $T_{off}$ (μs) | 25-55 |
| **Spark gap voltage** | SV (V) | 30-80 |
| **Peak Current** | IP (A) | 110-190 |

The range of all the process parameters is selected for the present study based on the results obtained from preliminary experiments.

### 2.1 Experimental Set-up

The experimental studies were performed using Electronica Sprintcut wire cut ED machine as shown in Figure 2. During the experiments the cutting of the work piece was done. The work material, electrode and the other machining condition are as follows:

- Work piece : D-2 tool steel
- Electrode (tool) : 0.025 mm $\varphi$
- Workpiece size : Square 5 x 5x15 mm
- Conductivity : 20 mho
- Cutting voltage (V) : 80V
- Die-electric temperature: 34 $^{O}$C
- Peak Voltage (VP) : Setting 2
- Servo feed : 2050 units


**Figure 2: WEDM machine Tool**

### 2.2 Response Surface Methodology

For the present work, RSM has been applied for developing the mathematical models in the form of multiple regression equations for the quality characteristics of WEDM process. In applying the response surface methodology, the dependent parameter was viewed as a surface to which a mathematical model is fitted. For the development of regression equations related to various quality characteristics of WEDM process, the second order response surface has been assumed as:

$$Y = b_0 + \sum_{i=1}^{k} b_i x_i + \sum_{i=1}^{k} b_{ii} x_i^2 + \sum_{i<j=2}^{k} b_{ii} x_i x_j + e_r \quad (1)$$

This assumed surface Y contains linear, squared and cross product terms of parameters $x_i$'s. In order to estimate the regression coefficients, a number of experimental design techniques are available. Box and Hunter [13] have proposed a scheme, based on central composite rotatable design, which fits the second order response surfaces very accurately. Also no replication is needed to find error mean square. The error mean square can be found out by replicating the centre points.

## 3. Results and Discussion

A total of 21 experiments were performed according to the central composite second order rotatable design for investigating cutting rate (CR). The experimental data along with the experimental design matrix [14] are given in Table 2.

**Table 2: Design Matrix**

| Std Order | Run Order | A:Ton | B:Toff | C:SV | D:IP | CR |
|---|---|---|---|---|---|---|
| | | us | us | V | A | mm/min |
| 1 | 19 | 124 | 55 | 80 | 110 | 1.2 |
| 2 | 9 | 124 | 55 | 30 | 110 | 1.21 |
| 3 | 5 | 124 | 25 | 80 | 190 | 1.25 |
| 4 | 13 | 105 | 55 | 30 | 190 | 0.54 |
| 5 | 16 | 124 | 25 | 30 | 190 | 1.43 |
| 6 | 12 | 105 | 25 | 80 | 110 | 0.66 |
| 7 | 8 | 105 | 55 | 80 | 190 | 0.25 |
| 8 | 17 | 105 | 25 | 30 | 110 | 0.9 |
| 9 | 3 | 98.52 | 40 | 55 | 150 | 0.73 |
| 10 | 7 | 130.48 | 40 | 55 | 150 | 1.42 |
| 11 | 1 | 114.5 | 14.77 | 55 | 150 | 0.79 |
| 12 | 21 | 114.5 | 65.23 | 55 | 150 | 0.77 |
| 13 | 4 | 114.5 | 40 | 12.96 | 150 | 1.09 |
| 14 | 15 | 114.5 | 40 | 97.04 | 150 | 0.8 |
| 15 | 20 | 114.5 | 40 | 55 | 82.73 | 1.05 |
| 16 | 11 | 114.5 | 40 | 55 | 217.27 | 1.15 |
| 17 | 10 | 114.5 | 40 | 55 | 150 | 1.1 |
| 18 | 14 | 114.5 | 40 | 55 | 150 | 1.1 |
| 19 | 18 | 114.5 | 40 | 55 | 150 | 1.1 |
| 20 | 6 | 114.5 | 40 | 55 | 150 | 1.11 |
| 21 | 2 | 114.5 | 40 | 55 | 150 | 1.11 |

For analyzing the data, the checking of goodness of fit of the model is very much required. The model adequacy checking includes test for significance of the regression model, test for significance on model coefficients and test for lack of fit. For this purpose, analysis of variance (ANOVA) is performed.

### 3.1 Analysis of Cutting Rate

The fit summary recommended that the quadratic model is statistically significant for analysis of CR. The pooled ANOVA for CR is given in Table 3. From the pooled ANOVA analysis, the value of $R^2$ and adjusted $R^2$ is over 95%. This means that regression model provides an excellent explanation of the relationship between the independent variables (factors) and the response cutting rate. The associated *p*-value for the model is lower than 0.05 which indicates that the model is considered to be statistically significant. The lack-of-fit term is non significant as it is desired. Further A-Pulse on time, B-Pulse off time, C-Servo Voltage, D- Peak current, Interaction between pulse on time and pulse off time, pulse on time and peak current, pulse on time and servo voltage, pulse off time and servo voltage, pulse off time and peak current and servo voltage and peak current also the second order factors of pulse on time, pulse off time and servo voltage having significant effect. The other model terms are said to be insignificant. To fit the quadratic model for cutting rate appropriate, the insignificant terms are eliminated by backward elimination process.

**Table 3: Pooled ANOVA after pooling insignificant terms**

| **Source** | **SS** | **%age contribution** | **DF** | **MS** | **F- Value** | **Prob > F** | |
|---|---|---|---|---|---|---|---|
| **Model** | 1.7 | | 13 | 0.13 | 2659.23 | < 0.0001 | significant |
| **A** | 0.24 | 14.11765 | 1 | 0.24 | 4835.95 | < 0.0001 | |
| **B** | 2.00E-04 | 0.011765 | 1 | 2.00E-04 | 4.06 | 0.0837 | |
| **C** | 0.11 | 6.470588 | 1 | 0.11 | 2169.68 | < 0.0001 | |
| **D** | 5.00E-03 | 0.294118 | 1 | 5.00E-03 | 101.57 | < 0.0001 | |
| **$A^2$** | 1.06E-03 | 0.062353 | 1 | 1.06E-03 | 21.48 | 0.0024 | |
| **$B^2$** | 0.19 | 11.17647 | 1 | 0.19 | 3872.23 | < 0.0001 | |
| **$C^2$** | 0.044 | 2.588235 | 1 | 0.044 | 900.87 | < 0.0001 | |
| **AB** | 0.028 | 1.647059 | 1 | 0.028 | 572.63 | < 0.0001 | |
| **AC** | 0.014 | 0.823529 | 1 | 0.014 | 293.55 | < 0.0001 | |
| **AD** | 0.051 | 3 | 1 | 0.051 | 1035.97 | < 0.0001 | |
| **BC** | 1.80E-03 | 0.105882 | 1 | 1.80E-03 | 36.57 | 0.0005 | |
| **BD** | 0.063 | 3.705882 | 1 | 0.063 | 1270.16 | < 0.0001 | |
| **CD** | 6.05E-03 | 0.355882 | 1 | 6.05E-03 | 122.9 | < 0.0001 | |
| **Residual** | 3.45E-04 | 0.020294 | 7 | 4.92E-05 | | | |
| **Lack of Fit** | 2.25E-04 | 0.013235 | 3 | 7.49E-05 | 2.5 | 0.199 | not significant |
| **Pure Error** | 1.20E-04 | 0.007059 | 4 | 3.00E-05 | | | |
| **Cor Total** | 1.7 | | 20 | | | | |
| **Std. Dev.** | **0.007016** | | | | **R-Squared** | | **0.9997** |
| **Mean** | **0.988571** | | | | **Adj R-Squared** | | **0.9994** |
| **C.V.** | **0.709717** | | | | **Pred R-Squared** | | **0.9913** |
| **PRESS** | **0.014707** | | | | **Adeq Precision** | | **205.4373** |

The reduced model results indicate that the model is significant ($R^2$ and adjusted $R^2$ are 99.97% and 99.94% respectively), lack of fit is non significant as p value is 0.199 (and significant value is less than 0.05), Figure 3 displays the normal probability plot of the residuals for CR. It is noticed that the residuals are falling on a straight line, which means that the errors are normally distributed. Further, predicted versus residual are given in Figure 4. It can be seen that the value are distributed randomly, which indicates that the model is OK. After eliminating the non-significant terms, the final response equations for coded factors and actual factors for CR are given in equations (2) and (3):

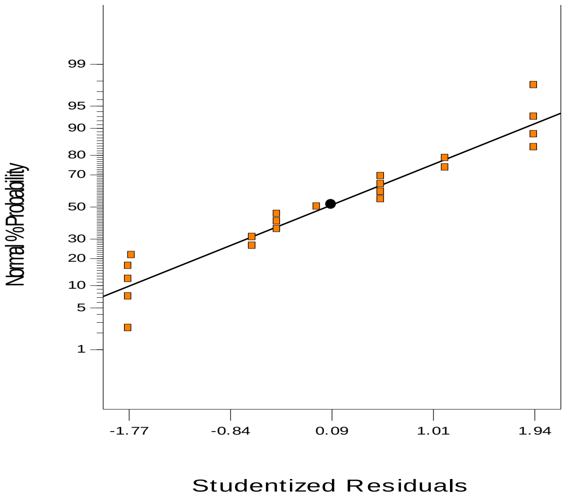


Fig 3: Normal probability plot of residuals For CR

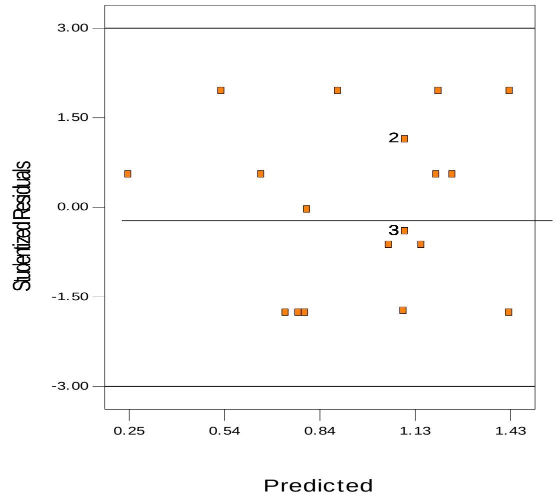


Fig 4: Plot of residual v/s pred. response of CR

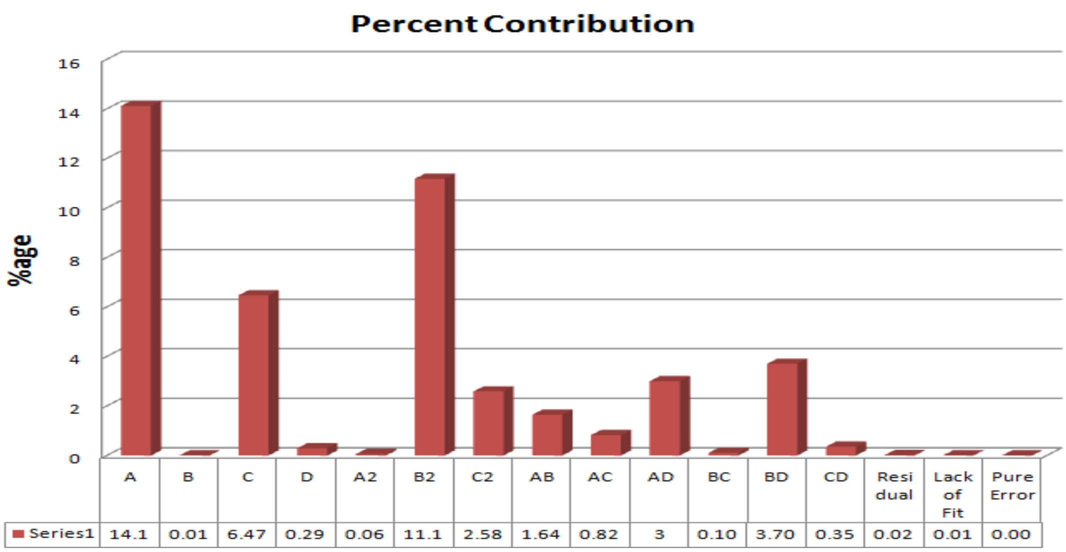


**Figure 5: Percent Contribution of Process Parameters**

**Final Equation in Terms of Coded Factors:**

$$CR = +1.10+0.21*A-5.946E-003*B-0.088*C+0.030*D-8.393E-003*A^2-0.11*B^2-0.054*C^2+0.092*A*B+0.042*A*C+0.12*A*D+0.015*B*C-0.14*B*D-0.027*C*D \quad (2)$$

**Final Equation in Terms of Actual Factors:**

$$CR=+4.63108-0.041809*T_{on}-2.29561E-003*T_{off}-0.011935*SV-0.025966*IP-9.30005E-005*T_{on}^2-5.00851E-004*T_{off}^2-8.69684E-005*SV^2+6.47229E-004*T_{on}*T_{off}+1.78947E-004*T_{on}*SV+3.26458E-004*T_{on}*IP+4.00000E-005*T_{off}*SV-2.28936E-004*T_{off}*IP-2.75000E-005*SV*IP \quad (3)$$

In figure 5 and table 3 it has been shown that the pulse on time has maximum percent contribution i.e. 14.11% during the cutting rate of D-2 tool steel on WEDM followed by $T_{off}^2$ (11.1%), Servo voltage (SV) 6.47%, interaction of pulse off time and peak current 3.70%, interaction of pulse on time and peak current 3%, quadratic of servo voltage 2.58%. Similerly the percent contribution of each parameter is given in table 3 and shown in figure 5.

## 4.Conclusions

In this paper influence of process parameters on cutting speed is investigated. The parameters and their combinations affecting the process were obtained using ANOVA. From the analysis, it is concluded that:

1. Pulse on time has maximum percent contribution i.e. 14.11% during the cutting rate of D-2 tool steel on WEDM followed by $T_{off}^2$ (11.1%), Servo voltage (SV) 6.47%, interaction of pulse off time and peak current 3.70%, interaction of pulse on time and peak current 3%, quadratic of servo voltage 2.58%.

2. The model which has been created for the prediction of cutting rate is given as
***Cutting Rate*** $=+4.63108-0.041809*T_{on}-2.29561E-003*T_{off}-0.011935*SV-0.025966*IP-9.30005E-005*T_{on}^{2}-5.00851E-004*T_{off}^{2}-8.69684E-005*SV^{2}+6.47229E-004*T_{on}*T_{off}+1.78947E-004*T_{on}*SV+3.26458E-004*T_{on}*IP+4.00000E-005*T_{off}*SV-2.28936E-004*T_{off}*IP-2.75000E-005*SV*IP.$
3. The "Pred R-Squared" of 0.9914 is in reasonable agreement with the "Adj R-Squared" of 0.9994.

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