# OPTIMIZING THE MATERIAL REMOVAL RATE AND SURFACE FINISH IN WEDM USING RESPONSE SURFACE METHODOLOGY

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**Abstract -** *WEDM is widely used in many industries for machining conductive materials. In this paper, parametric optimization of wire electrical discharge machining (WEDM) of OHNS (Oil Hardened Non - Shrinking) die steel is studied. Selection of optimum machining parameter combinations for obtaining higher cutting efficiency and accuracy is a challenging task in WEDM due to presence of large number of process variables and complicated stochastic process mechanisms. In general, no perfect combination exists that can simultaneously result in both the best cutting speed and the best surface finish quality. This paper presents an attempt to develop an appropriate machining strategy for a maximum process criteria yield. The DOE is done in Response Surface Method (Box – Behnken method). The two parameters – Material removal rate and Surface roughness have been considered as measures of the process performance with four different control parameters. Finally, the Null hypothesis is met for the significant value using ANOVA.*

**Key Words: , WEDM, MRR, Surface Roughness, RSM – (Box Behnken), OHNS, ANOVA**

## 1.INTRODUCTION

In recent years, the technology of wire electrical discharge machining (WEDM) has been improved significantly to meet the requirements in various manufacturing fields, especially in the precision die industry[1,2]. WEDM is a thermo-electrical process in which material is eroded from the work piece by a series of discrete sparks between the work piece and the wire electrode (tool) separated by a thin film of dielectric fluid (demineralised water) that is continuously fed to the machining zone to flush away the eroded particles[3]. The movement of wire is controlled numerically to achieve the desired three-dimensional shape and accuracy of the work piece. It is evident from Fig. 1 that it is absolutely essential to hold the wire in signed position against the object because the wire repeats complex oscillations due to electro-discharge between the wire and work piece. Normally, the wire is held by a pin guide at the upper and lower parts of the work piece[4,5]. In most cases, the wire will be discarded once used. However, there are problematic points that should be fully considered in order to enhance working accuracy[6]. The fundamental limits on machining accuracy are dimensional consistency of the wire and the positional accuracy of the worktable[7].

## 2. MATERIAL SELECTION

This research work investigates the Machining properties of Oil-Hardening Non-Shrinkable (OHNS). Chemical composition of the work material before machining was measured with an optical emission spectrometer, and it is given in Table 1. Oil-hardening cold work tool steels, designated as group "O" steels in the AISI classification system, derive their high hardness and wear resistance from high carbon and modest alloy contents. The high carbon content makes possible the formation of martensite of high hardness, and the alloying elements provide sufficient hardenability to make possible hardening of sections of reasonable size by oil quenching. Hardening is done by oil quenching from austenitizing temperatures, followed by two cycles of tempering to remove internal stresses and maximize the transformation of austenite to martensite. They are used for making dies and punches for blanking, trimming, flanging, and forming, broaches reamers, knurling tools, slitting saws, and coining dies. Original micro hardness of the work piece was measured at six different places, and the average value was found to be 615 HV or 58 HRC. Microstructure of hardened and tempered OHNS die steel is shown in Fig. 2. For these reasons OHNS has been chosen for the further work.

## 3.0 BOX – BEHNKEN (RSM) EXPERIMENTAL DESIGN

The Input Control factors such as Pulse-ON-time (A), Pulse-OFF-time (B), Current (C), Frequency (D), and their levels arrived through literature survey are presented in table 2.

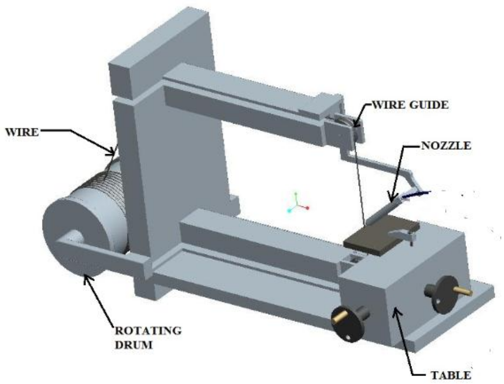



**Fig -1**: WEDM Setup -Details

For making Design of experiment Box – Behnken method (Response Surface Method) is chosen. The control factors are used to select the best conditions for stability in design of manufacturing process

**Table 1** Chemical composition of OHNS die steel

| Element | Composition (wt.%) |
|---|---|
| Carbon | 0.82 |
| Silicon | 0.18 |
| Manganese | 0.52 |
| Chromium | 0.49 |
| Tungsten | – |
| Vanadium | 0.19 |
| Molybdenum | 0.13 |
| Nickel | 0.05 |
| Iron | Balance |

**Table 2**: Machining parameters and their levels

| Symbol | Control Factors | Unit | Level 1 | Level 2 | Level 3 |
|---|---|---|---|---|---|
| A | PulseON time | µs | 15 | 25 | 35 |
| B | Pulse OFF time | µs | 2 | 3 | 4 |
| C | Current | amps | 2 | 3 | 4 |
| D | Frequency | Hz | 2 | 2.5 | 3 |

Table 3 shows the thirty experimental runs with the assigned levels of the process parameters according to the Box – Behnken design.

In this study, most important response measures in WEDM - Material Removal Rate (MRR), and Surface Roughness (Ra) were considered for optimizing the machining parameters.

The material removal rate (MRR) is calculated as,

$$MRR = V_c \times B \times h \qquad (mm^3/min)$$

Where,

$V_c$ = Machining speed (mm/min),

$B = (2W_g + d)$,

**B**= breath of cut (mm)

$W_g$ is the spark gap(mm),

**d**= wire dia (mm)

**h**= the thickness of specimen (mm)

**Table 3:** Box- Behnken Design & Experimental Results

| Std | Run | Factor 1<br>A:Pulse ON | Factor 2<br>B:Pulse Interval | Factor 3<br>C:Current | Factor 4<br>D:frequency | Response 1<br>MRR (mm3/min) | Response 2<br>Ra (µm) | TIME<br>mins |
|---|---|---|---|---|---|---|---|---|
| 7 | 1 | 25 | 3 | 2 | 3 | 3.5313 | 3.466 | 31.09 |
| 6 | 2 | 25 | 3 | 4 | 2 | 9.6916 | 2.448 | 11.21 |
| 5 | 3 | 25 | 3 | 2 | 2 | 3.1064 | 2.21 | 35.25 |
| 1 | 4 | 15 | 2 | 3 | 3 | 7.6923 | 3.276 | 14.18 |
| 3 | 5 | 15 | 4 | 3 | 3 | 4.7048 | 1.956 | 23.23 |
| 8 | 6 | 25 | 3 | 4 | 3 | 9.9927 | 3.512 | 11.05 |
| 9 | 7 | 25 | 3 | 3 | 3 | 6.8922 | 2.438 | 15.58 |
| 10 | 8 | 25 | 3 | 3 | 3 | 6.9256 | 3.666 | 15.33 |
| 2 | 9 | 35 | 2 | 3 | 3 | 9.5519 | 2.325 | 11.31 |
| 4 | 10 | 35 | 4 | 3 | 3 | 5.973 | 2.96 | 18.25 |
| 14 | 11 | 35 | 3 | 3 | 3 | 7.3255 | 2.296 | 15.01 |
| 13 | 12 | 15 | 3 | 3 | 3 | 5.7591 | 2.846 | 19.06 |
| 17 | 13 | 25 | 2 | 4 | 3 | 13.1217 | 2.264 | 8.23 |
| 19 | 14 | 25 | 3 | 3 | 3 | 6.875 | 2.788 | 16 |
| 18 | 15 | 25 | 4 | 4 | 3 | 8.13 | 1.93 | 13.32 |
| 16 | 16 | 25 | 4 | 2 | 3 | 2.8011 | 2.35 | 39.16 |
| 20 | 17 | 25 | 3 | 3 | 3 | 6.7073 | 3.182 | 16.24 |
| 15 | 18 | 25 | 2 | 2 | 3 | 4.3392 | 3.45 | 25.21 |
| 12 | 19 | 35 | 3 | 3 | 2 | 7.1895 | 2.662 | 15.18 |
| 11 | 20 | 15 | 3 | 3 | 2 | 5.7351 | 3.034 | 19.11 |
| 21 | 21 | 15 | 3 | 2 | 3 | 2.8379 | 1.738 | 38.46 |
| 29 | 22 | 25 | 3 | 3 | 3 | 6.736 | 2.634 | 16.2 |
| 26 | 23 | 25 | 4 | 3 | 2 | 5.1886 | 2.784 | 21.06 |
| 27 | 24 | 25 | 2 | 3 | 3 | 8.6614 | 3.32 | 12.42 |
| 22 | 25 | 35 | 3 | 2 | 3 | 3.4375 | 2.496 | 31.55 |
| 28 | 26 | 25 | 4 | 3 | 3 | 5.5884 | 2.756 | 19.41 |
| 23 | 27 | 15 | 3 | 4 | 3 | 8.2089 | 2.83 | 13.24 |
| 30 | 28 | 25 | 3 | 3 | 3 | 6.8322 | 3.098 | 16.06 |
| 25 | 29 | 25 | 2 | 3 | 2 | 8.1723 | 2.788 | 13.28 |
| 24 | 30 | 35 | 3 | 4 | 3 | 10.476 | 2.628 | 10.3 |

The Surface Roughness value (µm) is measured by using Mitutoyo SJ -201P surface roughness tester.

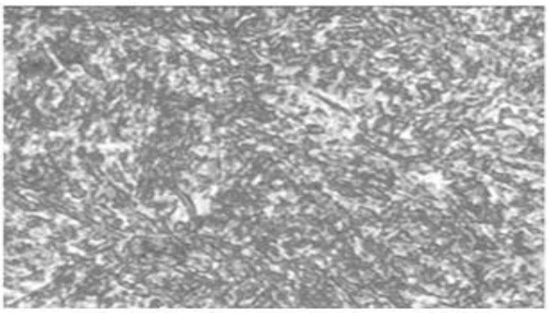


**Fig 2 :** Microstructure of OHNS die steel

## 4.0 EXPERIMENTAL RESULTS & DISCUSSION

From the Table 3, the main effect plots for MRR and SF is drawn and the graphs are shown below

From the graph 3 we found that the Optimal solution for the MRR is $A_3B_1C_3D_3$and the corresponding optimal MRR value is 13.1217 mm3/min. From the graph 4 the Optimal solution for the Ra is $A_1B_3C_1D_1$ and the corresponding optimal $R_a$ value is 1.956 µm.

**Fig 3:** Main effects of MRR

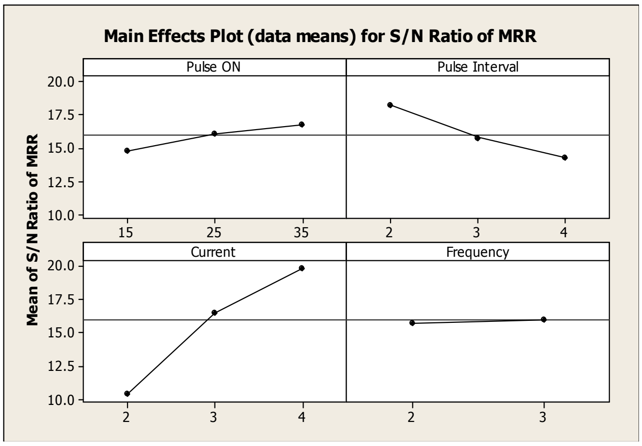
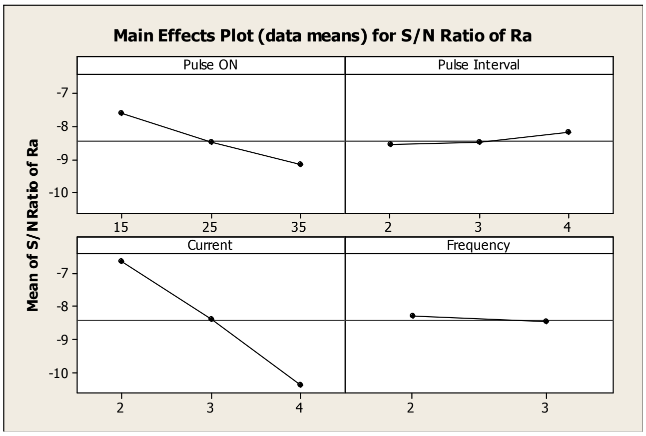



**Fig 4:** Main effects of MRR




ANOVA is performed to find out the standard deviation values and the sum of squares values.

Analysis of Variance for MRR :
MRR = - 0.848 + 0.0622 A - 1.49 B + 3.08 C+ 0.269 D
S = 0.517178 R-Sq = 95.6% R-Sq(adj) = 94.9%

| Source | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| Regression | 4 | 145.424 | 36.356 | 135.92 | 0.00 |
| Residual Error | 25 | 6.687 | 0.267 | | |
| Total | 29 | 152.11 | | | |

Analysis of Variance for Ra :

| Source | DF | Seq SS |
|---|---|---|
| Pulse ON | 1 | 4.647 |
| Pulse Interval | 1 | 26.739 |
| Current | 1 | 113.691 |
| Frequency | 1 | 0.34 |

Ra = - 0.572 + 0.0350 A - 0.0460 B + 0.582 C + 0.302 D
S = 0.157023 R-Sq = 90.7% R-Sq(adj) = 89.2%

| Source | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| Regression | 4 | 5.9944 | 1.4986 | 60.78 | 0.000 |
| Residual Error | 25 | 0.6164 | 0.0247 | | |
| Total | 29 | 6.6108 | | | |

| Source | DF | Seq SS |
|---|---|---|
| Pulse ON | 1 | 1.4683 |
| Pulse Interval | 1 | 0.0254 |
| Current | 1 | 4.0629 |
| Frequency | 1 | 0.4378 |

### 5.0 MULTI OBJECTIVE OPTIMIZATION OF WEDM PARAMETERS

Machining settings that satisfy multiple objectives of maximization of MRR and SF and need to be determined. The mathematical model suggested here is in the following form using MINITAB 14.

The Interaction plot for the Responses like MRR & Ra is also drawn in Fig 5 and Fig 6.

**Fig 5:** Interaction plot for MRR

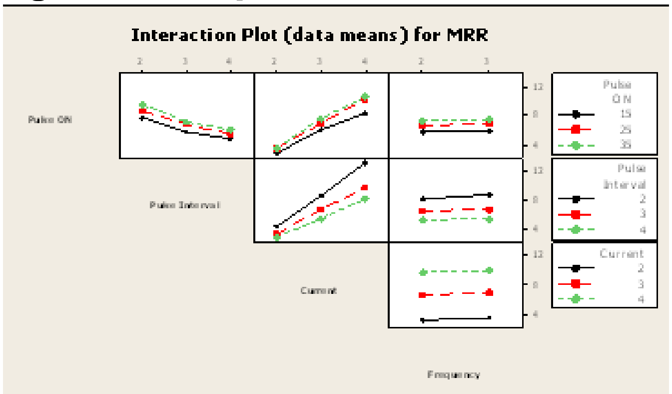



**Fig: 6** Interaction plot for Ra

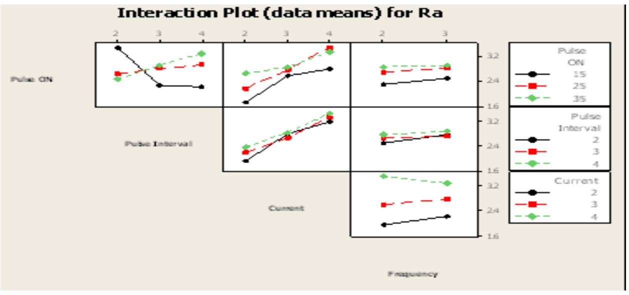
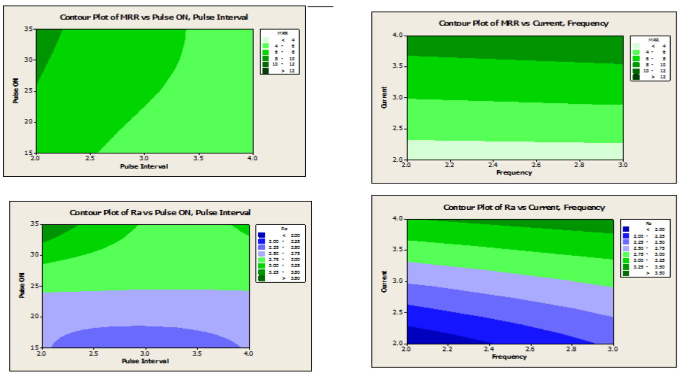



**Fig: 7 Interaction plot for MRR & Ra**




MRR = - 0.848 + 0.0622 Pulse ON - 1.49 Pulse Interval + 3.08 Current + 0.269 Frequency --------(1)

Ra = - 0.572 + 0.0350 Pulse ON - 0.0460 Pulse Interval + 0.582 Current + 0.302 Frequency ---------(2)

**6.0. CONCLUSIONS**

In this work, an attempt was made to determine the important machining parameters for performance measures like MRR, SF in the WEDM process. Factors like Pulse ON time, Pulse Interval, and Current and Frequency and their interactions have been found to play a significant role in rough cutting operations for maximizations of MRR, minimization of surface roughness. Box – Behnken (RSM) is method issued to obtain optimum parameter combinations. In order to optimize the two objectives, mathematical models are developed using (MINITAB) the linear regression method. From the S/N ratio graph 3 & 4 the optimal MRR value is 13.1217 mm3/min and the optimal $R_a$ value is 1.956 µm is found from ANOVA

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