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EVALUATION OF SURFACE ROUGHNESS AND MATERIAL REMOVAL RATE OF TI6AL4V IN WIRE CUT EDM PROCESS USING RESPONSE SURFACE METHODOLOGY

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Abstract: The highest objective of this work is to estimate the Material Removal Rate (MRR), Surface Roughness (Ra) of Ti6Al4V in Wire cut Electrical Discharge Machining process by Response surface Methodology. Wire electrical discharge machining process is a vastly complex, time changing & stochastic process. The process output is pretentious by large no of input variables. Therefore a suitable selection of input variables for the wire electrical discharge machining (WEDM) process relies profoundly on the operative's technology & knowledge because of their abundant & diverse range. WEDM is extensively used in machining of conductive materials when precision is of prime importance. Full factorial design is considered with three process parameters: TON, TOFF and IP each to be varied in three different levels. Data related to material removal rate (MRR) and surface roughness (Ra) have been measured for each experimental run; with RSM analysis Response is predicted and percentage of error has been calculated. The variation of output responses with process parameters were mathematically modeled by using non linear regression analysis. The replicas were tested for their adequacy. Result of confirmation experiments showed that the established mathematical models can predict the output responses with reasonable accuracy

***Index Terms* -Material Removal Rate (MRR), Surface Roughness (Ra), Wire cut Electrical Discharge Machining, Response surface Methodology**

I. INTRODUCTION

In the wire EDM process, the wire carries one side of an electrical charge and the work piece carries the other side of the charge. When the wire gets close to the part, the attraction of electrical charges creates a controlled spark, melting and vaporizing microscopic particles of material. The spark also removes a miniscule chunk of the wire, so after the wire travels through the work piece one time, the machine discards the used wire and automatically advances new wire. The process takes place quickly—hundreds of thousands of sparks per second—but the wire never touches the work piece

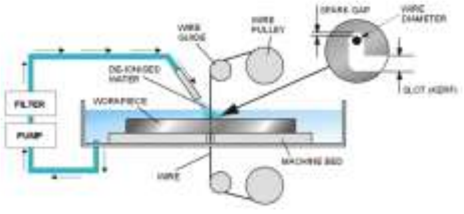


Figure 1: Principle of Wire EDM

1.1Material Removal Rate:

It is the amount of material removed per unit time i.e., volume of material removed per unit time. Material removal rate is given by

$$MRR = (2W_g + D) \times t \times V_c \quad \text{mm3/min}$$

Where:
Wg = Spark gap, varies from 0.04mm to 0.06mm,
D = diameter of the wire = 0.25mm
t = Thickness of the work piece in mm
Vc = Cutting speed in mm/min

1.2 Selection Of Material

By studying various projects titanium is selected for machining operation. The composition of titanium is :

- 6% aluminium
- 4% vanadium
- 0.25% (maximum)iron
- 0.2% (maximum)oxygen

Dimensions of the work piece is 10mm*25mm dia

II.DESIGN OF EXPERIMENTS:

2.1 Design of Experiments in Coded form:

Expt NO	T-on	T-off	Ip
1	1	2	2
2	3	1	3
3	1	2	3
4	3	3	1
5	1	1	3
6	2	1	1
7	3	2	3
8	3	3	3
9	3	3	2
10	1	1	1
11	1	1	2
12	2	3	2
13	1	2	1
14	2	2	1
15	2	1	3
16	3	2	1
17	1	3	1
18	3	1	2
19	3	2	2
20	2	1	2
21	2	3	1
22	2	2	2

23	3	1	1
24	2	3	3
25	1	3	2
26	1	3	3
27	2	2	3

Table1: Design of Experiments in coded form

2.2 Design of Experiments in uncoded units

T-ON	T-OFF	IP
100	45	10
100	50	11
100	55	10
100	50	10
100	55	12
100	50	12
100	50	11
100	55	10
105	45	10
110	45	11
110	55	12
100	55	12
100	55	11
110	45	12
110	55	11
110	50	11
105	45	12
105	45	11
105	50	10
110	50	11
110	50	10
110	55	10
100	45	12
105	50	12
110	45	10

100	45	11
105	55	11

Table 2: DOE in Minitab

2.3 Experimental Setup And Machining

The project was done in 3 stages

- Design of experiments was done using full factorial method
- Cycle time was calculated by machining the work piece on CNC lathe machine
- Analysis of results was done using MATLAB 15.1.30

2.4 Selection of process variables

A total of 3 process variables and 3 levels are selected for experimental procedure

The deciding process variables are

- Ton
- Toff
- Ip
- Speed of the spindle, i.e. the speed at which the spindle rotates the tool
- Feed is the rate at which material is removed from the work piece
- Depth of cut is the depth up to which the tool is emerged from one cycle.

2.5 Selection Of Levels

Since it is a three level design by observing the parameters taken in various projects the level of factors are designed as follows

FACTORS	LEVEL 1	LEVEL 2	LEVEL 3
Ton – Pulse on Time	100	105	110
Toff – Pulse off Time	45	50	55
IP	10	11	12

Table 4.1: Selection of process variables

2.6 CNC Programming Codes

Fixed cycle codes

- G81- drilling cycle
- G82- spot drilling cycle
- G83- deep hole drilling cycle standard
- G73- deep hole drilling cycle high standard
- G84- tapping cycle- standard
- G74- tapping cycle- reverse
- G85- boring cycle
- G86- boring cycle
- G87- back boring cycle
- G88- boring cycle
- G89- boring cycle
- G76- precession boring cycle
-

GOMETRIC CODES (G codes)

- G00- rapid interpolation
- G01- linear interpolation
- G02- circular interpolation in clockwise direction
- G03- circular interpolation in anti clockwise direction
- G04- dwell
- G15- polar coordinate system cancel
- G16- polar coordinate system on
- G17- x, y working plane and z tool axis

- G18- y, z working plane and x tool axis
- G19- x, z working plane and y tool axis
- G20- inch programming method
- G21- metric programming method
- G54- G59- zero work offset coordinates
- G90- absolute coordinate system on
- G91- incremental coordinate system on
- G28- go to reference position

MISCELLANEOUS CODES (M codes)

- M00- program stop (unconditionally)
- M01- program stop (conditionally)
- M02- program end
- M03- spindle rotation in clockwise direction
- M04- spindle rotation in anti clockwise direction
- M05- spindle stop
- M06- tool changing using tool changer
- M07- coolant on (internally)
- M08- coolant on (externally)
- M09- coolant off
- M30- program reset or rewind
- M98- sub program call
- M99- sub program end

MATERIAL REMOVAL RATE

- The material removal rate of the work piece is calculated by using the formula
- $MRR = (2W_g + D) \times t \times V_c$ mm3/min
- Where: Wg = Spark gap, varies from 0.04mm to 0.06mm,
- D = diameter of the wire = 0.25mm
- t = Thickness of the work piece in mm
- Vc = Cutting speed in mm/min

2.7 CNC Drawing for Wire EDM

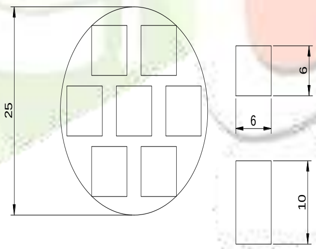


Figure 2: Drawing for EDM

2.8 List of experimental surface roughness and MRR values

The surface roughness values are measured and calculated MRR are tabulated as follows:

Ton	Toff	IP	MRR	Ra
100	45	10	12.21	3.56
105	50	11	13.53	4.24
105	55	10	12.54	3.185
100	50	10	12.87	4.64
105	55	12	12.87	4.08
100	50	12	12.54	3.69
100	50	11	13.45	3.105
105	55	10	12.54	3.185
105	45	10	11.81	3.88
110	45	11	14.19	4.085
110	55	12	12.87	4.24
100	55	12	10.56	3.945
100	55	11	10.45	3.765
110	45	12	12.54	4.205
110	55	11	12.54	3.96
110	50	11	11.55	4.625
105	45	12	11.55	4.485
105	45	11	13.2	3.345
105	50	10	12.21	3.84
110	50	11	11.55	4.625
110	50	10	14.52	4.775
110	55	10	11.88	3.57
100	45	12	12.54	4.31
105	50	12	13.53	5.235
110	45	10	15.475	3.635
100	45	11	14.484	3.205
105	55	11	12.21	3.33

Table 5 : Experimental values of surface roughness and MRR

III. RESULTS AND DISCUSSIONS

$$Y = \beta_0 + \sum_{i=1}^{k} \beta_i x_i + \sum_{i=1}^{k} \beta_{ii} x_{i^2} + \sum \sum_{i<j} \beta_{ij} x_i x_j + \varepsilon$$

Y is the corresponding response 3.2 Estimated coefficients generated in Minitab are as follows

CodCoded coef	Effect	Coef	SE Coef	T-Value	P-Value	VIF
Constant		4.124	0.223	18.46	0.000	
Ton	0.543	0.272	0.111	2.46	0.025	1.04
Toff	-0.171	-0.086	0.107	-0.80	0.434	1.03
IP	0.577	0.289	0.110	2.62	0.018	1.03
Ton*Ton	0.135	0.068	0.184	0.37	0.717	1.07
Toff*Toff	-1.235	-0.617	0.185	-3.35	0.004	1.03
IP*IP	0.657	0.328	0.182	1.81	0.089	1.05
Ton*Toff	-0.020	-0.010	0.138	-0.07	0.944	1.06
Ton*IP	0.205	0.103	0.146	0.70	0.493	1.06
Toff*IP	0.082	0.041	0.132	0.31	0.760	1.05

Table 7: Estimated coefficients for Ra using Minitab

Graphs Obtained For Ra:

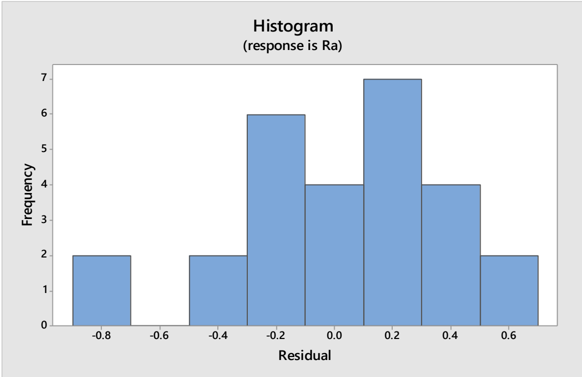


Figure 3 : Histogram for Ra

Normal plot of residuals:

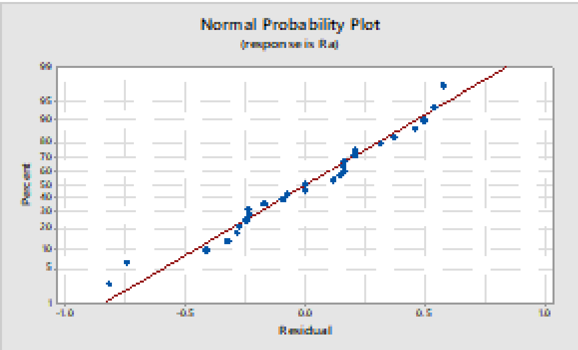


Figure 4:Normal Probability Plot for Ra

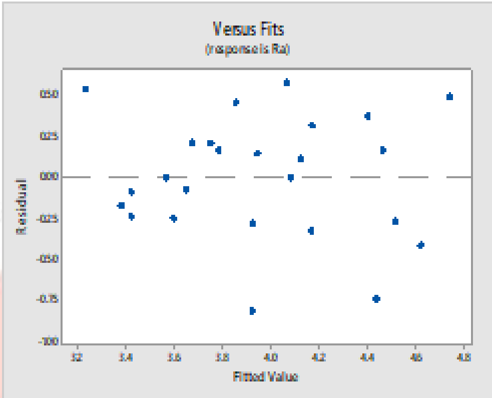


Figure 5:Residual Vs Fits for Ra

Main Effects Plot for Ra

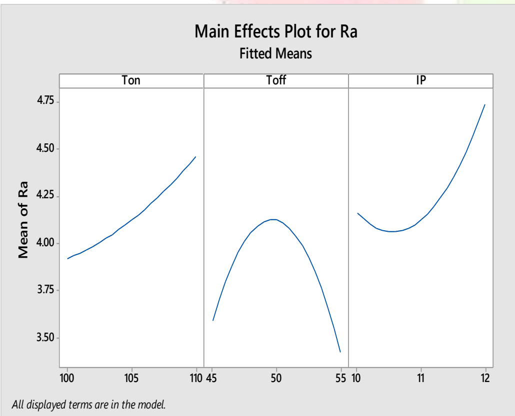


Figure 6:Main effects plot for surface roughness

Interaction plot for Ra

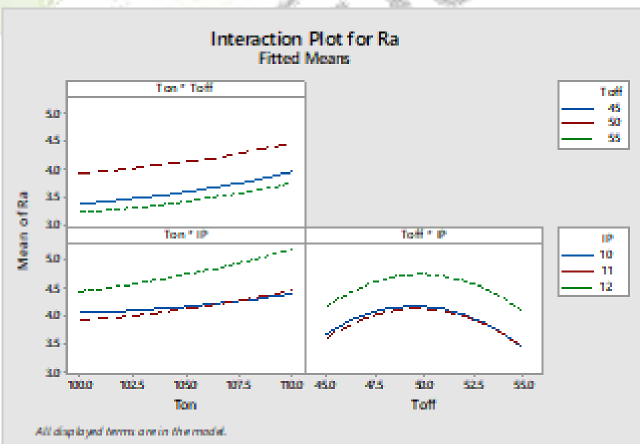


Figure 7:Interaction Plot for Ra

3.3 Material Removal Rate (MRR)

- Statistical Analysis of All Linear, Square And Interaction Terms For Material Removal Rate

Predictor	Coefficient	P value
Constant	12.899	0.000
Ton	0.359	0.246
Toff	-0.581	0.060
IP	-0.195	0.522
(Ton)2	-0.082	0.871
(Toff)2	-0.271	0.594
IP2	-0.066	0.895
Ton*Toff	0.192	0.614
Ton*IP	-0.283	0.485
Toff*IP	0.260	0.475

Table 8: Analysis of all linear, square and interaction terms for MRR

S	R-Sq	R-sq(adj)	R-sq(pred)
1.2094	28.58%	0.00%	0.00%

3.4 Mathematical Relationship between the Input Parameters and MRR

The mathematical relationship between the input parameters and MRR has been obtained as follows

MRR = -54+ 0.99 Ton - 0.41 Toff+ 4.6 IP- 0.0033 Ton*Ton - 0.0108 Toff*Toff- 0.066 IP*IP+ 0.0077 Ton*Toff- 0.0565 Ton*IP + 0.0520 Toff*IP

3.5 Response Surface Regression: MRR versus Ton, Toff, IP

Estimated coefficients generated in Minitab are as follows:

Term	Effect	Coef	SE Coef	T-Value	P-Value	VIF
Constant		12.899	0.604	21.36	0.000	
Ton	0.719	0.359	0.299	1.20	0.246	1.04
Toff	-1.162	-0.581	0.289	-2.01	0.060	1.03
IP	-0.389	-0.195	0.298	-0.65	0.522	1.03
Ton*Ton	-0.163	-0.082	0.497	-0.16	0.871	1.07
Toff*Toff	-0.541	-0.271	0.499	-0.54	0.594	1.03
IP*IP	-0.131	-0.066	0.491	-0.13	0.895	1.05
Ton*Toff	0.385	0.192	0.374	0.51	0.614	1.06
Ton*IP	-0.565	-0.283	0.396	-0.71	0.485	1.06
Toff*IP	0.520	0.260	0.356	0.73	0.475	1.05

Table 9 : Estimated coefficients for MRR using Minitab

Graphs obtained for MRR

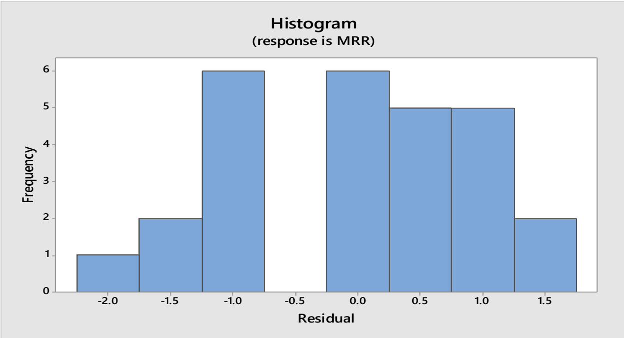
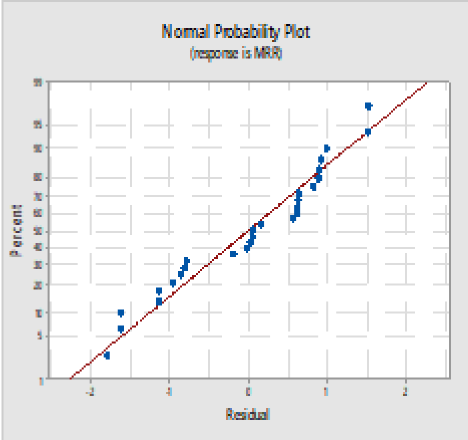


Figure 8:Histogram for MRR

Normal Plot of Residuals



Figur 9:Normal probability Plot

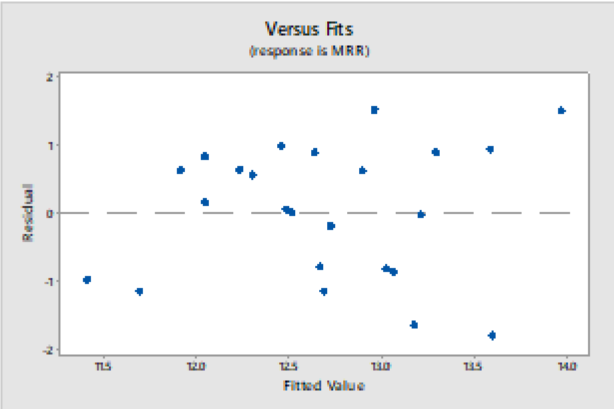


Figure 10:Graph between residual and fitted values

3.6 MAIN RESPONSE PLOT FOR MRR:

A main effect occurs when the mean response changes across the levels of a factor. Main effect plots are used to compare the relative strength of the effects across factors.

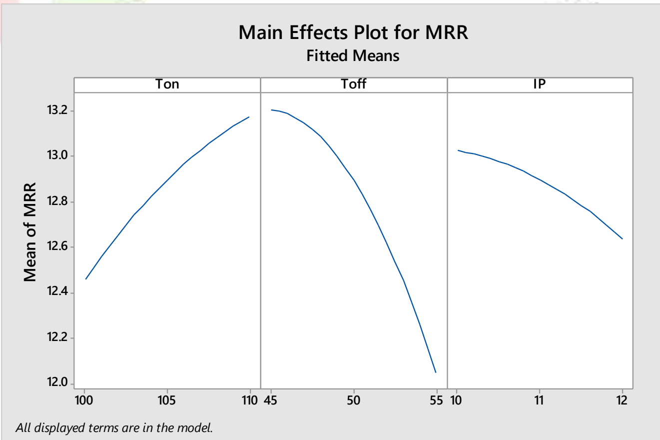


Figure 11:Main Response Plot For MRR

3.7 List of experimental and predicted values

T-On	T-Off	IP	MRR	MRR Predict	% Error	Ra	Ra Predict	%Error
100	45	10	12.21	12.63	3.44	3.56	3.52775	0.91
105	50	11	13.53	12.449	7.99	4.24	4.07825	3.81
105	55	10	12.54	11.49	8.37	3.185	3.3805	6.14
100	50	10	12.87	11.9	7.54	4.64	4.025	13.25
105	55	12	12.87	11.641	9.55	4.08	4.0195	1.48
100	50	12	12.54	12.096	3.54	3.69	4.377	18.62
100	50	11	13.45	12.064	10.3	3.105	3.873	24.73
105	55	10	12.54	11.49	8.37	3.185	3.3805	6.14
105	45	10	11.81	13.105	10.97	3.88	3.6405	6.17
110	45	11	14.19	12.754	10.12	4.085	3.90075	4.51
110	55	12	12.87	11.771	8.54	4.24	4.45275	5.02
100	55	12	10.56	11.346	7.44	3.945	3.72175	5.66
100	55	11	10.45	11.054	5.78	3.765	3.17675	15.62
110	45	12	12.54	11.961	4.62	4.205	4.56875	8.65
110	55	11	12.54	12.044	3.96	3.96	3.70275	6.5
110	50	11	11.55	12.669	9.69	4.625	4.419	4.45
105	45	12	11.55	12.216	5.77	4.485	4.1155	8.24
105	45	11	13.2	12.7265	3.59	3.345	3.55	6.13
105	50	10	12.21	12.5675	2.93	3.84	4.12775	7.49
110	50	11	11.55	12.669	9.69	4.625	4.419	4.45
110	50	10	14.52	13.07	9.99	4.775	4.366	8.57
110	55	10	11.88	12.185	2.57	3.57	3.60875	1.09
100	45	12	12.54	12.306	1.87	4.31	3.79775	11.89
105	50	12	13.53	12.1985	9.84	5.235	4.68475	10.51
110	45	10	15.475	13.415	13.31	3.635	3.88875	6.98
100	45	11	14.484	12.534	13.46	3.205	3.33475	4.05
105	55	11	12.21	11.6315	4.74	3.33	3.372	1.26

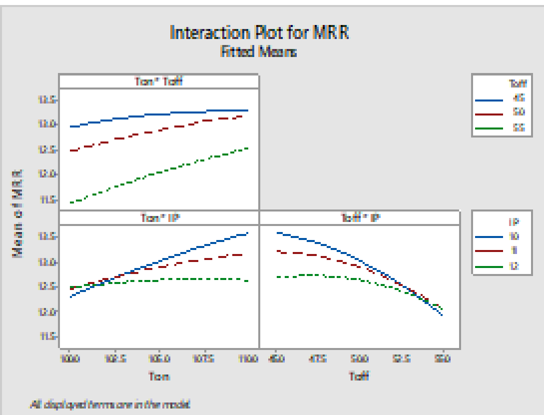


Figure 11:Interaction plot for MRR

3.8 Response optimization

Stat > DOE > Response surface > Response optimizer

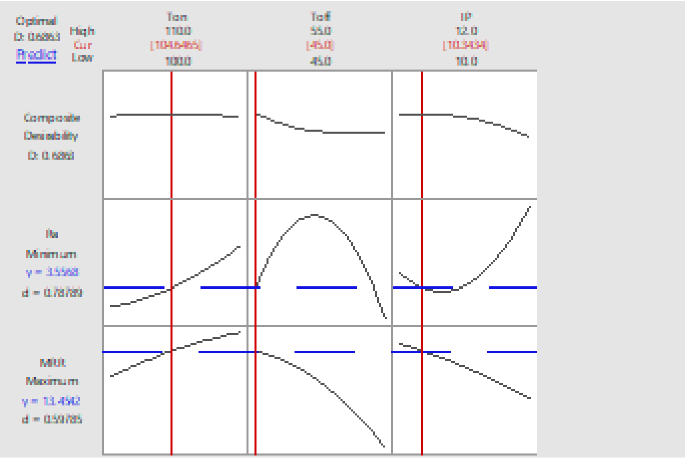


Figure 12:Optimization plot for Ra and MRR

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