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Mathematical modeling and analysis of process parameters on machining of tungsten carbide in EDM through Response Surface Methodology

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Abstract— Electrical Discharge Machine (EDM) is now become the most important accepted technologies in manufacturing industries since many complex 3D shapes can be machined using a simple shaped tool electrode. Electrical discharge machine (EDM) is an important 'non-traditional manufacturing method', developed in the late 1940s and has been accepted worldwide as a standard processing manufacture of forming tools to produce plastics moldings, die castings, forging dies and etc. New developments in the field of material science have led to new engineering metallic materials, composite materials, and high tech ceramics, having good mechanical properties and thermal characteristics as well as sufficient electrical conductivity so that they can readily be machined by spark erosion. At the present time, Electrical discharge machine (EDM) is a widespread technique used in industry for high precision machining of all types of conductive materials such as: metals, metallic alloys, graphite, or even some ceramic materials, of whatsoever hardness.
Keywords— EDM, Tungsten carbide, RSM, MRR, TWR, SR.

I. INTRODUCTION

In 1970 the English scientist, Priestly, first detected the erosive effect of electrical discharge on metals. More recently, during research the soviet scientists, Lazarenko and lazarenko, decided to exploit the destructive effect of an electrical discharge and develop a controlled method of metal machining. In 1943 they announced the construction of the first spark erosion machine. The spark generator used in 1943 , known as lazarenko circuit , has been employed over many years in power supplies for EDM machines and an improved form is being used in many current applications. The EDM process can be compared with the conventional cutting process, except that in this case, a suitable shaped tool electrode, with a precision controlled feed movement is employed in place of cutting tool, and the cutting energy is provided by means of short duration electrical pulses EDM has found ready application in the machining of hard metals or alloys which cannot be machined easily by conventional methods. It thus plays a major role in the machining of dies, tools, etc, made of tungsten carbide, satellites or hard steels. Alloys used in aeronautics industry, for example, hastalloy, nimoic, etc, could also be machined conveniently by this process. This process has added advantage of being capable of machining complicated component

A. Process parameters

1) *Discharge Voltage* -Discharge voltage in the EDM is related to the spark gap and breakdown strength of the dielectric.
2) *Peak Current*-This is the amount of power used in discharge machining, measured in units of amperage and is the most important machining parameter in EDM. During each on-time pulse, the current increases until it reaches a preset level, which is expressed as the peak current.
3) *Pulse On-time & Off-time*-Each cycle has an on-time and off-time that is expressed in units of microseconds. Since all the work is done during on-time, the duration of these pulses and the number of cycles per second are important. Metal removal is directly proportional to the amount of energy applied during the on-time. The energy is controlled by the peak current and the length of the pulse on-time. Off time will affect the speed and stability of the cut. Shorter the off-time, the faster will be the machining operation.

II. PROBLEM STATEMENT

In EDM, the selection of parameters play a main role in producing good surface quality, high material removal rate and less electrode wear. This research aim is to investigate the proper selection of parameters in EDM for machining hardened material and studies these selected different parameters which are able to deliver better results in terms of surface quality of tungsten carbide (WC), material removal rate and electrode wear. The problem might be interfere the result in this experiment when the selection of the parameters are not suitable and un proper to investigate on these machining characteristics.

III. LITERATURE REVIEW

S. Assarzadeh et al [1] works on to made to model and optimize process parameters in Electro-Discharge Machining (EDM) of tungsten carbide-cobalt composite (Iso grade: K10) using cylindrical copper tool electrodes in planning machining mode based on statistical techniques. MunmunBhaumik et al [2] investigates the influence of EDM parameters on Tool Wear Rate (TWR), Material Removal Rate (MRR), Surface Roughness (Ra) while machining of Stainless Steel (AISI 304) material. The parameters considered are pulse-on time (Ton), peak current (Ip), duty factor (t) and gap voltage (Vg).B. C. Routaraet al [3] studied the influence of machining parameters of EDM for machining of tungsten carbide (WC) using electrolyte copper of negative polarity on machining characteristics. The second order mathematical models in terms of machining parameters were developed for surface roughness prediction using response surface methodology (RSM) V.Chandrasekaranet al [4] developed the mathematical models for the modelling and analysis of the effects of machining parameters on the performance characteristics in the EDM process of WC/5Ni, Which is produced through powder metallurgy route. Manabhanjan Sahoo1 et al [5] was used Response surface methodology to investigate the relationships and parametric interactions between the three controllable variables discharge current(Ip), pulse duration(Ton) and duty cycle(τ) on the material removal rate (MRR) and electrode wear rate(EWR). S.H.Tomadi et al [6] studied the influence of operating parameters of tungsten carbide on the machining characteristics such as surface quality, material removal rate and electrode wear.

IV. EXPERIMENTATION

The experimentations be there performed by operating on Electric Discharge Machine "Electra R-50 ZNC Die-Sinking Machine" whose polarization on the electrode be located as negative whereas that of work piece be located as positive.

Fig 1 EDM Machine

A. *Selection of work piece*

In this experiment tungsten carbide of size 100×23×12.5 mm3 plate is chosen for conducting the experiment.

Fig 2 Tungsten carbide work piece

B. *Selection of tool material*

In this experiment copper-tungsten is used as a electrode. Composition is given in table 3.2 as below

Fig 3 Copper-tungsten electrode

Table 1-Composition of Copper-tungsten electrode

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Material	%
Tungsten	70
Copper	30

C. *Response Surface Methodology*

The study of Response Surface Methodology is required for having an idea how the relations among the process parameters are generated for a particular response parameter. RSM is a regression technique used for prediction, determination and optimization of machine performances [4]. RSM is collection of statistical and mathematical technique required for developing, improving and optimizing a process. It is used in those circumstances where the output is dependent on many parameters. The multi parameter related output is called response. And denoted by formula,

$$\eta = \beta_0 + \sum_{j=1}^{k} \beta_j x_j + \sum_{j=1}^{k} \beta_{jj} x_j x_j + \sum_{i<j}^{k} \beta_{ij} x_i x_j$$

D. *Mechanism of MRR*

Mechanism behind material removal of EDM process is based on the conversion of electrical energy to thermal energy that categorized it to electro thermal process. During machining both the surfaces may have present smooth and irregularities causes minimum and maximum gap in between tool and work piece. At a given instant at minimum point suitable voltage is developed produces electrostatic field for emission of electrons from the cathode there electrons accelerated towards the anode.
Formula of MRR calculation
MRR is calculated as the proportion of the change of weight of the work piece before and after machining to the product of machining period and density of the material.

$$\text{MRR} = \frac{Wbm - Wam}{t \times \rho}$$

Whereas:

Wbm = Weight of work piece before machining.
Wam = Weight of work piece after machining.
t = Machining period
ρ = Density of Tungsten carbide work piece = 15.63 g/mm3

E. *Mechanism of TWR*

The concept of EW can be defined in many ways, the present study define the EW according to the ratio in weight of the electrode and the work piece where expressed as percentage. Similar procedure for measuring the weight of work piece will be used to determine the weight of the electrode before and after machining.
The following equation is used to determine the EW value:

EW = (Wbm-Wam)/t
where:
Wbm = Weight of electrode before machining.
Wam = Weight of electrode after machining.
t = Machining period

F. *Design of experiment*

The levels of experiment parameters and discharge current (Ip), spark on time (Ton) and applied voltage (V) are shown in Table 3.3 and the design matrix is represented in Table 3.4. The levels were fed into Minitab[9] Software for generating the Run Order

Table 2. Levels of experiment

Machining Parameter	Symbol	Unit	Levels	
			Low	High
Discharge current	Ip	A	20	30
Voltage	V	V	20	30
Pulse on time	Ton	µs	4	7.5

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Table 3 Design matrix and Observation table

Std Order	Run Order	Pt Type	Blocks	Current	Voltage	TON
7	1	1	1	20	30	7.5
10	2	-1	1	33	25	5.75
3	3	1	1	20	30	4
12	4	-1	1	25	30	5.75
20	5	0	1	25	25	5.75
11	6	-1	1	25	16	5.75
13	7	-1	1	25	25	2.80
18	8	0	1	25	25	1.83
2	9	1	1	30	20	4
19	10	0	1	25	25	5.75
4	11	1	1	30	30	4
1	12	1	1	20	20	4
15	13	0	1	25	25	5.75
14	14	-1	1	25	25	5
5	15	1	1	20	20	7.5
9	16	-1	1	20	25	5.75
8	17	1	1	30	30	7.5
17	18	0	1	25	25	5.75
16	19	0	1	25	25	5.75
6	20	1	1	30	20	7.5

V. RESULT

A. Modelling of EDM characteristics on tungsten carbide

The experiments are conducted according to central composite full design and the average values of MRR, TWR and Ra along with design matrix are tabulated in Table III. For analysis of 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.

Table 4 Response table

Std Order	Run Order	Current	Voltage	TON	MRR	TWR	SR
7	1	20	30	7.5	1.377	0.02412	1.063
10	2	33	25	5.75	2.8321	0.0209	1.078
3	3	20	30	4	1.9593	0.01352	1.31
12	4	25	30	5.75	1.8746	0.0143	1.06
20	5	25	25	5.75	2.1	0.01525	1.168
11	6	25	16	5.75	1.7563	0.0136	1.287
13	7	25	25	2.80	2.2314	0.01568	1.14
18	8	25	25	1.83	1.8385	0.0152	1.086
2	9	30	20	4	1.6563	0.0149	1.032
19	10	25	25	5.75	1.7914	0.0133	1.18
4	11	30	30	4	2.6588	0.0187	1.013
1	12	20	20	4	1.9833	0.0148	1.7547
15	13	25	25	5.75	1.8036	0.0144	1.321
14	14	25	25	5	2.2998	0.0136	1.164
5	15	20	20	7.5	2.7855	0.02092	1.199
9	16	20	25	5.75	2.108	0.0152	1.321
8	17	30	30	7.5	1.751	0.0205	1.281
17	18	25	25	5.75	2.0378	0.016	1.164
16	19	25	25	5.75	2.1071	0.01413	1.088
6	20	30	20	7.5	2.4152	0.0148	1.054

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B. Analysis for material removal rate (mrr)

The fit summary recommended that the quadratic model is statistically significant for analysis of MRR. The ANOVA table for the quadratic model for MRR is shown in Table IV. The lack-of-fit term is not significant as it is desired. The results of the quadratic model for MRR are given in Table

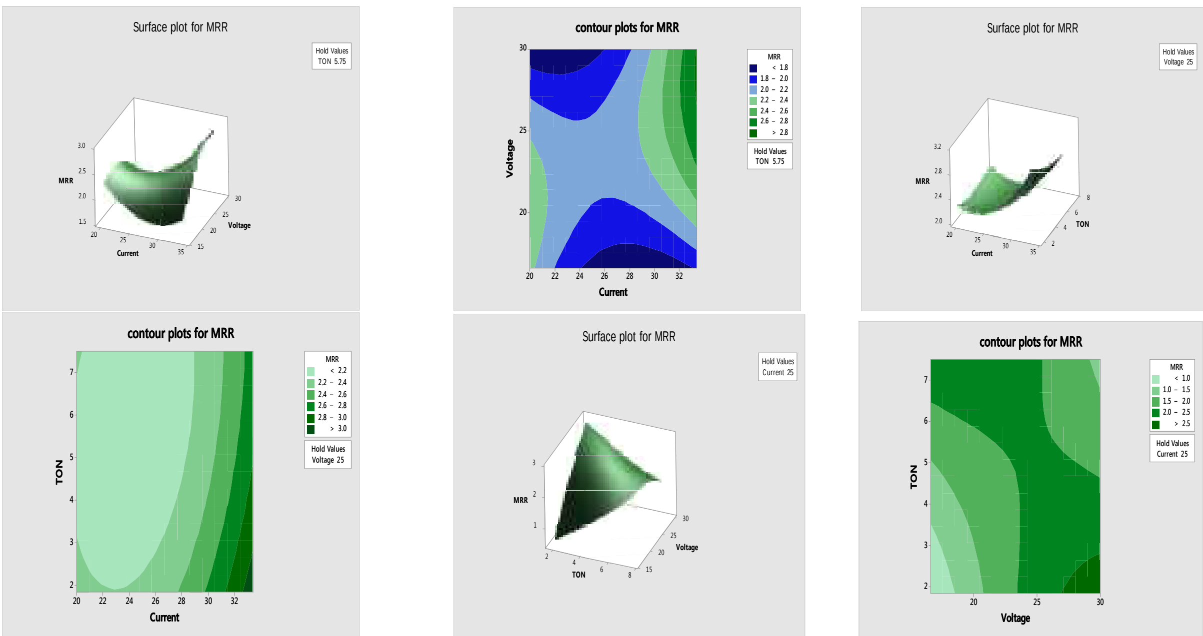
Table 5 ANOVA for MRR

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	9	2.47047	0.27450	11.01	0.000
Linear	3	0.22982	0.07661	3.07	0.078
Current	1	0.05644	0.05644	2.26	0.163
Voltage	1	0.15928	0.15928	6.39	0.030*
TON	1	0.00249	0.00249	0.10	0.759
Square	3	0.60603	0.20201	8.10	0.005 *Signi
Current*Current	1	0.36907	0.36907	14.80	0.003 * Signi
Voltage*Voltage	1	0.26508	0.26508	10.63	0.009 * Signi
TON*TON	1	0.02154	0.02154	0.86	0.375
2-Way Interaction	3	1.57270	0.52423	21.02	0.000 * Signi
Current*Voltage	1	0.39197	0.39197	15.72	0.003 * Signi
Current*TON	1	0.01700	0.01700	0.68	0.428
Voltage*TON	1	1.16373	1.16373	46.66	0.000 * Signi
Error	10	0.24941	0.02494		
Lack-of-Fit	6	0.14955	0.02492	1.00	0.525
Pure Error	4	0.09986	0.02496		
Total	19	2.71988			

S	R-sq	R-sq(adj)	R-sq(pred)
0.157927	90.83%	82.58%	66.18%

MRR =2.02- 0.593 Current+ 0.358 Voltage+ 1.080 TON
+ 0.00833 Current*Current 0.00706 Voltage*Voltage+ 0.0114 TON*TON+ 0.00885 Current*Voltage - 0.00527 Current*TON - 0.04359 Voltage*TON

Surface plots and contour plots for MRR



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B. Analysis for Tool wear rate (TWR)

The ANOVA table for the quadratic model for TWR is shown in Table VI. The model results indicate that the model is significant and the lack of fit is insignificant. The fit summary recommended that the quadratic model is statistically significant for analysis. The value of R2 is over 90% and the associated P-value for the model is lower than 0.05 (i.e. μ = 0.05, or 95% confidence),

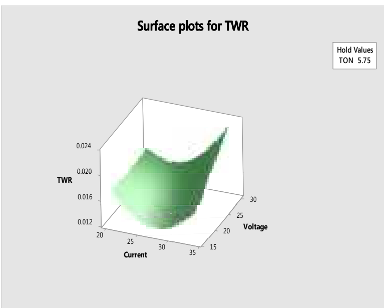
Table 6 ANOVA for TWR

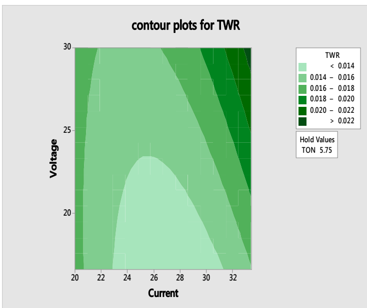
Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	9	0.000166	0.000018	12.24	0.000
Linear	3	0.000059	0.000020	13.09	0.001 Signi.
Current	1	0.000000	0.000000	0.27	0.613
Voltage	1	0.000013	0.000013	8.62	0.015 Signi.
TON	1	0.000042	0.000042	27.72	0.000 Signi.
Square	3	0.000073	0.000024	16.18	0.000 Signi.
Current*Current	1	0.000039	0.000039	25.86	0.000 Signi.
Voltage*Voltage	1	0.000000	0.000000	0.09	0.772
TON*TON	1	0.000028	0.000028	18.90	0.001 Signi.
2-Way Interaction	3	0.000040	0.000013	8.96	0.003 Signi.
Current*Voltage	1	0.000007	0.000007	4.77	0.054
Current*TON	1	0.000028	0.000028	18.72	0.001 Signi.
Voltage*TON	1	0.000005	0.000005	3.38	0.096
Error	10	0.000015	0.000002		
Lack-of-Fit	6	0.000011	0.000002	1.65	0.327
Pure Error	4	0.000004	0.000001		
Total	19	0.000181			

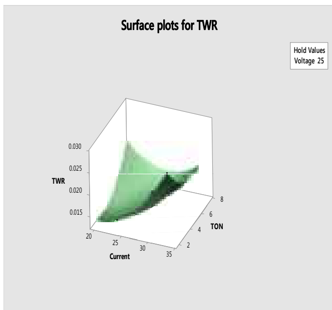
S	R-sq	R-sq(adj)	R-sq(pred)
0.0012272	91.67%	84.18%	50.35%

TWR=0.0789- 0.00403 Current- 0.001500 Voltage-
0.00044 TON+ 0.000086 Current*Current+ 0.000005 Voltage*Voltage+ 0.
000415 TON*TON+ 0.000038 Current*Voltage- 0.000215 Current*TON
+ 0.000091 Voltage*TON

Surface plots and contour plots for TWR







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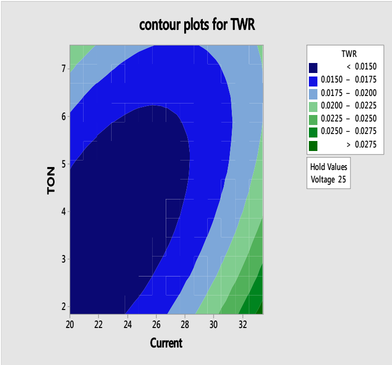

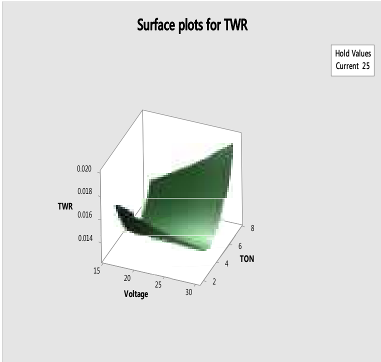

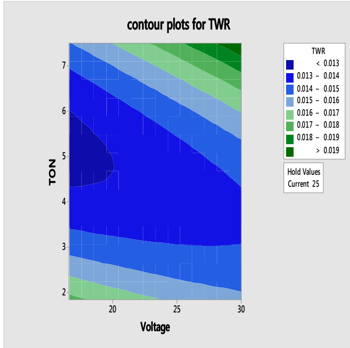

C. Analysis of variance for SR

TABLE 7 ANOVA FOR SR

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	9	0.490362	0.054485	13.30	0.000
Linear	3	0.206697	0.068899	16.82	0.000 Signi
Current	1	0.158612	0.158612	38.71	0.000 Signi.
Voltage	1	0.029010	0.029010	7.08	0.024 Signi.
TON	1	0.027381	0.027381	6.68	0.027 Signi.
Square	3	0.049685	0.016562	4.04	0.040 Signi.
Current*Current	1	0.023440	0.023440	5.72	0.038 Signi.
Voltage*Voltage	1	0.002227	0.002227	0.54	0.478
TON*TON	1	0.026249	0.026249	6.41	0.030 Signi.
2-Way Interaction	3	0.265467	0.088489	21.60	0.000 Signi.
Current*Voltage	1	0.077756	0.077756	18.98	0.001 Signi.
Current*TON	1	0.149249	0.149249	36.43	0.000 Signi.
Voltage*TON	1	0.038462	0.038462	9.39	0.012 Signi.
Error	10	0.040970	0.004097		
Lack-of-Fit	6	0.012313	0.002052	0.29	0.916
Pure Error	4	0.028657	0.007164		
Total	19	0.531331			

S	R-sq	R-sq(adj)	R-sq(pred)
0.0640075	92.29%	85.35%	75.85%

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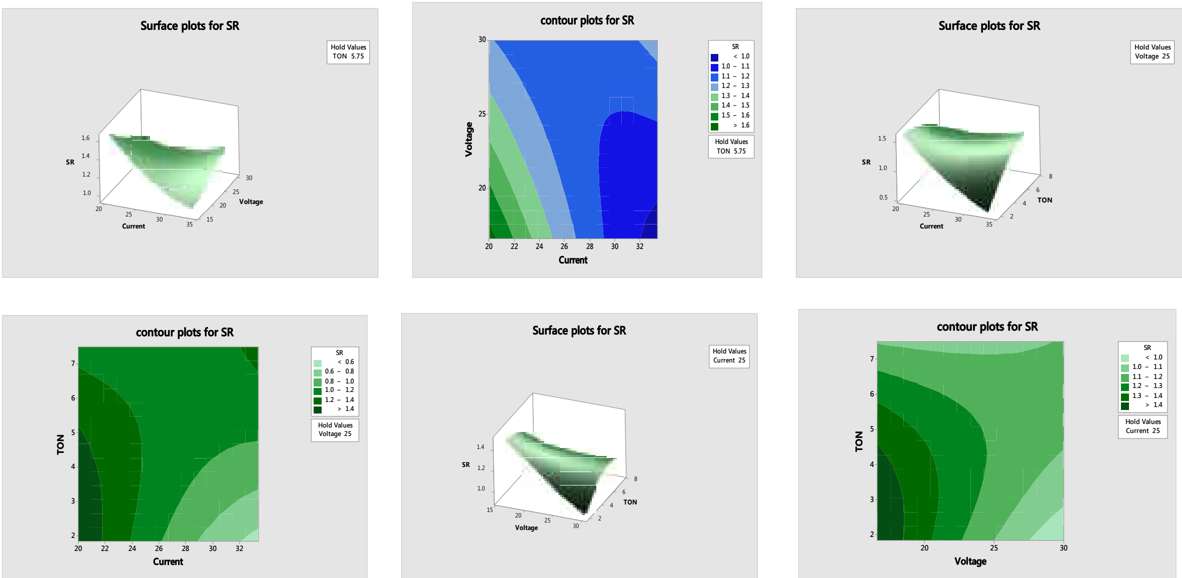
Surface plots and contour plots for SR



Parametric optimization using desirability function (df) approach

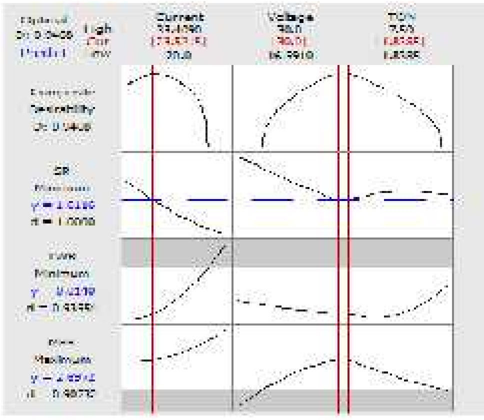


Fig 4.20 optimization plot

Table 8-Optimal setting

Responses	Current	Voltage	TON
Optimal value	23.5215	30	1.8385

Experimental validation
Table 9. Experimental validation of optimal setting

Response	Predicted	Experimental	Error (%)
MRR (mm3/min)	22.7033	2.8520	5.21
TWR (mm3/min)	0.01426	0.01340	6.41
Ra (μm)	1.0116	1.023	1.11

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VI. CONCLUSION

From the results of MRR we conclude that the Voltage is most significant or influencing factor then current and at last pulse on time on the given input. Maximum MRR obtained is 2.8321 mm3/min and is obtained at 33A Current, 25v Voltage and 5.75 µs Pulse on time. MRR increased linearly with some extent of current and Voltage and decreases slightly with pulse on time.
Tool wear rate is mostly influence by pulse on time followed by voltage and lastly by current. TWR is found to have an increasing trend with the increase of pulse on time and voltage and reduced with increasing current. Minimum tool wear rate obtained is 0.0133 g/m and is obtained at 25A Current, 25v Voltage and 5.75 µs pulse on time.
In case of surface roughness the current is the most effective parameter after that voltage and followed by Ton. Minimum Surface roughness obtained is 1.013µm and obtained at 30A current, 30v Voltage and 4µs pulse on time. TWR increased linearly with so current and Voltage and decreases slightly with pulse on time.
Predicted optimum setting obtained for maximizing MRR and minimizing TWR and SR is 23.52A current, 30v Voltage and 1.83µs pulse on time and predicted values of responses MRR, TWR and SR are 22.7033, 0.01426, 1.0116 and experimental values are 2.8520, 0.01340, 1.023 respectively.

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