Analysis of Material Removal Rate of AISI 304 SS in EDM Process

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Abstract— EDM has become an important and cost-effective method of machining extremely tough and brittle electrically conductive materials. It is widely used in the process of making moulds and dies and sections of complex geometry and intricate shapes. The work piece material selected in this experiment is AISI 304 Stainless steel taking into account its wide usage in industrial applications. In today's world 304 stainless steel contributes to almost half of the world's production and consumption for industrial purposes. The input variable parameters are current, pulse on time and duty cycle. Taguchi method is applied to create an L_{27} orthogonal array of input variables using the Design of Experiments (DOE). The effect of the variable parameters mentioned above upon machining characteristics such as Material Removal Rate (MRR), Surface Roughness (SR) and Overcut (OC) is studied and investigated. The tool material is copper. The results obtained showed that current was the most significant parameter followed by pulse on time and the least significant was the duty cycle for the entire three responses namely Material removal rate, Surface roughness and overcut. With the increase in current and duty cycle MRR increased but for pulse on time it increased only up to 100 µs and then started to decrease. SR increased significantly with the increase in current; for pulse on time it increased up to 100 µs and after that there was no significant increase; and in case of duty cycle SR increased up to 70% and then started to decrease. OC increased with the increase in current and pulse on time but in different fashion and in case of duty cycle, OC increased up to 70% and then started decreasing.

***Keywords**:* MRR-Material Removal Rate, EDM-Electric Discharge, Taguchi design in MINITAB

I. Introduction

Electrical discharge machining is a non-traditional machining method. It is a process for eroding and removing material from electrically conductive materials by use of consecutive electric sparks. The process is carried out in a dielectric liquid with a small gap between the work piece and electrode. Each electrical discharge generates heat energy in a narrow area that locally melts, evaporates and even ionizes work piece material. EDM does not make direct contact between the electrode and the work piece where it can eliminate mechanical stresses, chatter and vibration problems during machining. Some of the melted and all of the evaporated material is then quenched and flushed away by dielectric liquid and the remaining melt recast on the finished surface[1]. Important Parameters of EDM process are Spark on-time (Ton): The duration of time (µs) the current is allowed to flow per cycle.

Spark off-time (Toff): the duration of time in between the sparks generated. During this time the molten material gets removed from the gap between the electrode and the workpiece.

Voltage (V): It is the potential difference applied between the electrode and the workpiece.

Discharge Current (Ip): It is the current flowing through the electrode and is measured in amp.

Duty cycle: It is the ratio of Ton divided by total cycle time (Ton+Toff)[2].

The quality of an EDM product is usually evaluated in terms of its surface integrity, which is characterized by the surface roughness, existence of surface cracks and residual stresses. There are many process variables that affect the surface integrity such as pulse duration, peak current, open gap voltage, electrode polarity, material properties of the tool electrode, work piece and dielectric liquid, debris concentration and even size of the electrode [1].

II. Literature Review

In this paper, some selected research papers have been discussed related to Electrical Discharge Machining. The studies carried out in these papers are mainly concerned with the EDM parameters such as current, voltage, pulse on time, duty cycle, etc. and how these affect the machining characteristics like MRR, SR, OC, etc.B.S. Reddy et al. carried out a study on the effect EDM parameters over MRR, TWR, SR and hardness. Mixed factorial design of experiments and multiple regression analysis techniques had been employed to achieve the desired results. The parameters in the decreasing order of importance for; MRR: servo, duty cycle, current and voltage; TWR: current, servo and duty cycle; SR: current; HRB: servo only. M.M. Rahman et al. investigated the effect of the peak current and pulse duration on the performance characteristics of the EDM. The conclusions drawn were: the current and pulse on time greatly affected the MRR, TWR and SR, the MRR increases almost linearly with the increasing current, the SR increases linearly with current for different pulse on time, TWR increased with increasing peak current while decreased when the pulse on time was increased. Puertas et al. carried out results which showed that the intensity and pulse time factor were the most important in case of SR while the duty cycle factor was not significant at all. The intensity factor was again influential in case of TWR. The important factors in case of MRR were the intensity followed by duty cycle and the pulse time. S.H. Tomadi et al. investigated the machining of tungsten carbide with copper tungsten as electrode. The full factorial design of experiments was used for analyzing the parameters. In case of SR, the important factors were voltage and pulse off time while current and pulse on time were not significant. For MRR the most influential was pulse on time followed by voltage, current and pulse off time. Finally in case of TWR the important factor was pulse off time followed by peak current. Iqbal and Khan concluded that the voltage and rotational speed of the electrode are the two significant parameters for EDM milling. Optimization is concerned with maximizing the MRR and minimizing EWR along with an optimum R_a. Norliana Mohd Abbas et al. studied the research trends in dry wire EDM, EDM in water, EDM with powder additives, EDM on ultrasonic vibration and modeling techniques in predicting EDM performances. For every method that was introduced and employed in EDM process, the objectives were the same: to improve the capability of machining performances, to get improved output product and to create better technologies to machine new materials.Singh and Maheshwari found that the input parameters such as current, pulse on time, voltage applied and the workpiece material greatly influences overcut. It increases with the increase of current but only up to a certain limit. It also depends on the gap voltage. Kiyak and Cakir ound that SR of workpiece and electrode were influenced by current and pulse on time, higher values of these parameters increased the surface roughness. Lower current and pulse time and higher pulse off time produced a better surface finish. Bhattacharyya et al. observed that peak current and pulse on time significantly influenced different criteria of surface integrity such as surface crack density, surface roughness and white layer thickness. S Dhar et al. came to the following conclusions: with increase in peak current MRR, TWR and ROC increased significantly in a nonlinear fashion; MRR and ROC increased with the increase in pulse on time and gap voltage was found to have some effect on the three responses.

III. Experimental Details

In this paper we will discuss about the experimental work formulated prior to execution of work. It consists of an L-27 orthogonal array using Taguchi design, selection of workpiece, experimental set-up, tool design and calculation of Material Removal Rate, Surface Roughness and Overcut.

The experiments were conducted using the Electric Discharge Machine, model ELECTRONICA - ELECTRAPLUS PS 50ZNC (die sinking type) the polarity of the electrode was set as positive while that of workpiece was negative. The dielectric fluid used was EDM oil (specific gravity-0.763). The EDM consists of the following parts:

IV. Workipece Material

AISI 304 Stainless Steel is one of the most widely used materials in all industrial applications and accounts for approximately half of the world's stainless steel production and consumption. Because of its aesthetic view in architecture, superior physical and mechanical properties, resistance against corrosion and chemicals, weldability, it has become the most preferred material over others. Many conventional and non-conventional methods for machining AISI 304 stainless steel are available.

A. composition of AISI 304 stainless steel

Elements	**Weight Limit %**	**Actual Weight %**
C	0.04-0.08	0.08 max
Mn	0.06-1.00	1.00 max
Si	0.20-1.00	1 max
Cr	18-20	20
Ni	8 -10.5	10
Fe	66.345 – 74	74
P	0.045	0.045 max
S	0.03	0.03 max

Table 1

B. Properties of AISI 304 SS

Mechanical Properties	**Typical**	**Minimum**
Tensile Strength	600MPa	485MPa
Proof Strength, (off set 0.2%)	310MPa	170MPa
Elongation (Percent in 50mm)	60	40
Hardness(Brinell)	217	
Hardness (Rockwell)	95	
Endurance (fatigue Limit)	240MPa	

Table 2

V. Tool Material

The tools selected for this experiment is a Electrolytic Copper, which is a ductile metal with high thermal and electric conductivity. Pure copper is soft and mallable, freshly exposed copper surface has reddish-orange colour. It is used as conductor of heat and electricity and constituent of various metal alloys.

A. The properties of copper materials

Density	8.89g/cc
Tensile strength	220MPa
Tensile strength	69 MPa
Poisons ratio	0.333
Melting point	1065-1083^{o}c

Table 3

VI. Result And Discussion

Initially workpiece and copper tool materials are weighted each time before the machining process are carried out. The electrodes and workpiece after machining process are cleaned to remove the carbon deposition, and are weighted measuring using electronic weighing machine, which has a resolution of 0.0001 grams. Each experiment was repeated for three times and the averaged of MRR in term of (grams/min) and TWR in terms of (grams/min). The Materials Removal Rate and Tools Wear Rate are defined by a formula

$$MRR = \frac{wi - wf}{t}$$

A. Reading are tabulated

In this paper we will discuss the results obtained and along with that find out the influential parameters that affect each of the MRR.

Observation Table

Run No.	Ip (A)	T_{on} (µs)	τ (%)	MRR
				(mm^3/min)
1	3	60	80	1.5439
2	3	60	90	2.3064
3	3	60	100	1.3126
4	3	110	80	1.7939
5	3	110	90	2.0626
6	3	110	100	2.1501
7	3	160	80	1.9001
8	3	160	90	2.1189
9	3	160	100	2.1251
10	6	60	80	7.3501
11	6	60	90	8.3166
12	6	60	100	8.7967
13	6	110	80	8.1916
14	6	110	90	9.2249
15	6	110	100	9.4249
16	6	160	80	7.6581
17	6	160	90	9.1751
18	6	160	100	9.5079
19	9	60	80	14.2415
20	9	60	90	17.1001
21	9	60	100	17.5166
22	9	110	80	15.8416
23	9	110	90	18.8669
24	9	110	100	20.4671
25	9	160	80	14.5876
26	9	160	90	16.9876
27	9	160	100	19.3501

Table 4. 1

B. Analysis and Discussion of MRR

The MRR increases as the current increases throughout the entire range. In case of pulse on time, the MRR first slightly increases up to 100 µs and then decreases in a similar fashion till 150 µs. The MRR increases linearly along with the increase in duty cycle within the range but the magnitude of increase is not very large.

Analysis of Variance for Means of MRR

	Source	DF	Seq SS	Adj MS	F	P	% cont.
	Ip	2	1057.93	528.963	4893.21	0.000	96.231
	Ton	2	5.06	2.529	23.39	0.000	0.4602
	τ	2	18.45	9.227	85.36	0.000	1.6782
	I_p*T_{on}	4	3.10	0.774	7.16	0.009	0.282
	I_p*τ	4	13.16	3.291	30.44	0.000	1.1971
	T_{on}*τ	4	0.80	0.200	1.85	0.213	0.072
	Residual Error	8	0.86	0.108			0.078
	Total	26	1099.36				
	S = 0.3288		R-Sq = 99.9%			R-Sq(adj) = 99.7%	

Table 4.2

Response Table for Mean of MRR

	Level	I_p	Ton	τ
	1	1.924	8.720	8.123
	2	8.627	9.780	9.573
	3	17.218	9.268	10.072
	Delta	15.294	1.060	1.949
	Rank	1	2	3

Table 4.3

In table 4.1 1 column 1 represents variable sources such as current, pulse on time, duty cycle and the interactions between these three factors. Subsequently in the following columns degree of freedom (DF), Sum of squares (Seq SS), adjusted mean of square (Adj MS), F distribution and Probability are calculated respectively.

The standard deviation of errors in the modeling, S=0.3288. R^2=99.9% which indicates that the model is capable of predicting the response with a high accuracy.

From this table it can be concluded that all the factors except for the interaction between T_{on}*

τ are significant as the value of $p<0.05$. The value of p for T_{on}* τ is 0.213 and hence the interaction is not significant. From the response table it can be seen that the most significant factor is Ip followed by T_{on} and the least significant being Tau.

The interaction plot of MRR is shown in Fig. 4.3. This plot shows the interactions between the three input variables taken in this experiment. The significant interactions can be seen in the plot (* marked). It can also be confirmed from the ANOVA table.

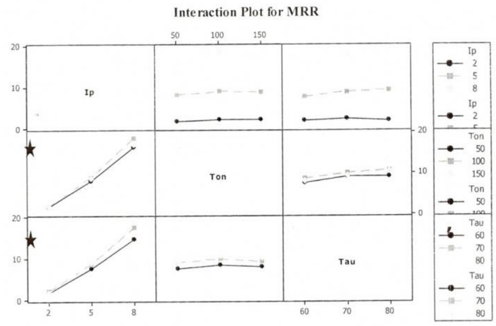

Fig 4. 4 Interaction Plot for MRR

VII. CONCLUSION

In this study the experiment was conducted by considering three variable parameters namely current, pulse on time and duty cycle. The objective was to find the Material Removal Rate, Surface Roughness and Overcut and to study the effects of the variable parameters on these characteristics. The tool material was taken as copper and the workpiece was chosen as AISI 304 stainless steel. Using the Taguchi method an L_{27} orthogonal array was created and the experiments were performed accordingly. The following conclusions were drawn for MRR the most significant factor was found to be peak current followed by pulse on time and the least significant was duty cycle. The MRR increased nonlinearly with the increase in current. For T_{on} the MRR first increased till 100 µs and then decreased. With increase in duty cycle, MRR increased insignificantly.

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