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Analysis of process parametersin electro-discharge machining of Tungsten carbideby using taguchi

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Abstract –
In this paper, tries have been made optimize process parameters in Electro-Discharge Machining (EDM) of tungsten carbide (WC/CO) using copper electrodes to development machining mode based on taguchi techniques. Four independent input parameters discharge current (Amp), pulse-on time (μs), duty cycle (%), and gap voltage (Volt) were selected to assess the EDM process performance in terms of material removal rate (MRR: g/min) has been used to design and examine the experiments. For each process response, a suitable second order decline equation was set up applying analysis of variance (ANOVA) and student t-test procedure to check modeling goodness of fit and select proper forms of influentially significant process variables (main, two-way interaction). The MRR increases by selecting higher discharge current and higher duty cycle which capitals providing greater amounts of discharge energy inside gap region. In this paper we conduct the experiment on maximum possible combination of process parameter (Discharge current, Pulse-on time, Duty cycle,Gap voltage) developed by taguchi method and find a set of optimal input parameters with maximum nearby MRR during ED Machining of WC/Co(tungsten carbide-cobalt composite) material.
Keywords: Electro-Discharge Machining (EDM); Design of Experiments (DOE); taguchi, Anova,

I. INTRODUCTION

The history of electro-discharge machining (EDM) dates back to the days of World Wars I and II when B. R. and N. I. Lazarenko invented the relaxation circuit (RC). Using a simple servo controller they maintained the gap width between the tool and the workpiece, reduced arcing, and made EDM more profitable.

Since 1940, die sinking by EDM has been refined using pulse generators, planetary and orbital motion techniques, computer numerical control (CNC), and the adaptive control systems.

During the 1960s the extensive research led the progress of EDM when numerous problems related to mathematical modeling were tackled. The evolution of wire EDM in the 1970s was due to the powerful generators,

new wire tool electrodes, improved machine intelligence, and better flushing. Recently, the machining speed has gone up by 20 times, which has decreased machining costs by at least 30 percent .

1.1 Need OF EDM

In recent years, materials with unique metallurgical properties – such as **tungsten carbide** and its composites, titanium based alloys, nickel based alloys, tool steels, stainless steels, hardened steels and other super alloys – have been developed to meet the demands of extreme applications. While these materials are harder, tougher, less heat sensitive and/or more resistant to corrosion and fatigue, they are more difficult to machine. Difficult-to-cut materials have been widely used these days not only in the aerospace industry but also in the public welfare industry. Therefore, the machining of difficult-to-cut materials is an important issue in the field of manufacturing. Since these difficult-to-cut materials possess excel- lent mechanical properties which can be useful in many important applications, machining of them can open up opportunities of utilizing them comprehensively

1.2 ELECTRICAL DISCHARGE MACHINING

Electrical discharge machining (EDM) is a thermal process with a complex metal-removal mechanism, involving the formation of a plasma channel between the tool and work piece. It has proved especially valuable in the machining of super-tough, electrically conductive materials such as the new space-age alloys that are difficult to machine by conventional methods [Kunieda et al.]. The word unconventional is used in sense that the metal like tungsten, hardened stainless steel tantalum, some high strength steel alloys etc. are such that they can‘t be machined by conventional method but require some special technique . The conventional methods in spite of recent advancements are inadequate to machine such materials from stand point of economic production. This technique has been developed in the late 1940s where the process is based on removing material from a part by means of a series of repeated electrical discharges between tool called the electrode and the work piece in the presence of a dielectric fluid. [Abbas et al.2007].

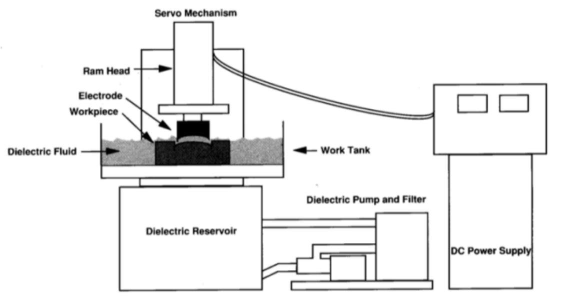


Figure – 1.1Line Diggram of Basic EDM System

1.3 Principle of EDM

Figure 1.1 shows the concept of EDM. Pulsed arc discharges occur in the ―gap filled with an insulating medium, preferably a dielectric liquid like hydrocarbon oil or de-ionized (de-mineralized) water between tool electrode and work piece[Kunieda et al.]. The dielectric medium is used in avoiding electrolysis effects on the electrodes during an EDM process. An offset equal to the gap-size is given to electrode,the liquid should be selected to minimize the gap (10-100μm) to obtain precise machining. On the other hand a certain gap width is needed to avoid short circuiting, especially when electrodes that arisensitive to vibration. The ignition of the discharge is initiated by a high voltage, overcoming the dielectric breakdown strength of the small gap. A channel of plasma is formed between the electrodes and develops further with discharge duration. As the metal removal per discharge is very small, discharges should occur at high frequencies (103 -106 Hz). For every pulse, discharge occurs at a single location where the electrode materials are evaporated and/or ejected in the molten phase. As a result, a small crater is generated both on the tool electrode and work piece surfaces. Removed materials are cooled and re-solidified in the dielectric liquid forming several hundreds of spherical debris particles, which are then flushed away from the gap by the dielectric flow.

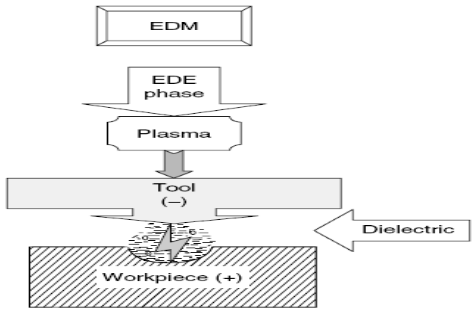


Figure –1.2 Working principal of EDM .

After the end of the discharge duration, the temperature of the plasma and the electrode surfacescontacting the plasma rapidly drops, resulting in a recombination of ions and electrons and a recoveryof the dielectric breakdown strength. The next pulse discharge occurs at a spot distanced sufficiently far from the previous discharge location where the gap is small or contaminated with debris particleswhich may weaken the dielectric breakdown strength of the liquid. The interval time between pulse discharges must be sufficiently long so that the plasma generated by the previous discharge can bedeionized and the dielectric breakdown strength around the previous discharge location can berecovered by the time the next pulse voltage is applied. Otherwise discharges occur at the samelocation for every pulse, resulting in thermal overheating and a non uniform erosion of the work piece

The popularity of EDM process is due to the following advantages:

1. The process can be readily applied to electrically conductive materials. Physical and metallurgical properties of the work material, such as strength, toughness, microstructure, etc., are no barrier to its application.
2. During machining, the workpiece is not subjected to mechanical deformation as there is no physical contact between the tool and work. This makes the process more versatile. As a result, slender and fragile jobs can be machined conveniently.
3. Although the metal removal in this case is due to thermal effects, yet there is no heating in the bulk of the material.
4. Complicated die contours in hard materials can be produced to a high degree of accuracy and surface finish.
5. The overall production rate compares well with the conventional processes because it can dispense with operations like grinding, etc.
6. The process can be automated easily thereby requiring very little attention from the machine operator

1.4 Process Parameters

1. Discharge Voltage
2. Peak Current
3. Pulse On-time & Off-time
4. Electrode Gap (Arc Gap)
5. Polarity
6. Frequency

Objective of the paper

1. To conduct experiments in Electro-discharge machining process using Taguchi method.
2. To perform statistical analysis using S/N and ANOVA technique.
3. To determine the optimum machining parameters using evolutionary algorithms.
4. To identify the best optimization method in finding the optimum machining parameters
5. Based on the maximum MRR.
6. Make use of other published work in the literature in order to prove the effectiveness of The proposed algorithms.

RESEARCH METHODOLOGY
Taguchi Technique

3.1 Introduction - This chapter introduces Taguchi's Method in which multiple variables can be changed simultaneously without losing control of the experiment. The complete methodology, design and analysis procedure is discussed.

3.2. Signal to Noise Ratios (S/N Ratios)

Taguchi recommends the use of the criterion he calls, "**Signal to noise ratio**" as performance statistic. The change in quality characteristic of a product under investigations in response to factor induced in the experimental design is the signal of the desired effect. The effect of external affairs (Uncontrollable factors) on the outcome of the quality characteristic under test is termed the noise. there are three possible categories of quality characteristic. They are:

1. Smaller the better.
2. Nominal is the best.
3. Larger is better.

The S/N ratio is computed from the mean square deviation (MSD) by the equations:

$$\mathbf{S/N = -10\log_{10}(MSD)} \qquad \text{……(i)}$$

For the S/N ratio to be large, MSC must have a value that is small.

If smaller is the best quality characteristic;

$$\mathbf{MSD = [(Y_1^2 + Y_2^2 + \text{----------------} + Y_n^2)] / N}$$

Where, Y_1, Y_2 --------- Y_n are the quality characteristic.

If nominal is the best quality characteristic;

$$\mathbf{MSD = [(Y_1 - Y_0)^2 + (Y_2 - Y_0)^2 + \text{-------} + (Y_n - Y_0)^2}$$

Where, Y_0 = target or nominal value

If larger is the best quality characteristic;

$$\mathbf{MSD = [(1/Y_1^2 + 1/Y_2^2 + \text{---------------} + 1/Yn^2)] /N}$$

The S/N ratio analysis is designed to measure quality characteristic. This is Taguchi's solution to Robust Product or Process Design.

3.2 Procedure and Steps of Taguchi parameterdesign

Step-1: Selection of the quality characteristic

Step-2: Selection of noise factors and control factors

Step-3: Selection of Orthogonal Array

Step-4: Conducting the experiments

Step-5: Analyzing the results and determining the optimum cutting conditions

Step-6: Predicting Optimum Performance

Step-7: Establishing the design by using a confirmation experiment

Step-8: Perform the Verification Experiment and Plan the Future Action

S.No.	Discharge current (A)	Pulse-on time (B)	Duty cycle (C)	Gap voltage (D)
1	L	L	L	L
2	L	L	H	H
3	L	H	L	H
4	L	H	H	L
5	H	L	L	H

6	H	L	H	L
7	H	H	L	L
8	H	H	H	H

Table 3.1- The Basic Taguchi L_8 Orthogonal Array **

EXPERIMENTAL SET UP

4.1 Components of Electric Discharge Machine

Its main components (Figure 1.5) are given as under:

1. Control Unit
2. Electrode holder
3. Electrode feed mechanism
4. Tank
5. Fixture

Photo -4.1EDM Machining **(Model No. T – 3822M)**

EDM Control

The control of EDM (Model T- 3822M) are listedbelow:

1. Rotary Switch (Mains)
2. IndicatorLamps(Three Phase)
3. Rotary Switch (Finish)
4. Rotary Switch (Pump)
5. Rotary Switch (Current Range)
6. Rotary Knob (CurrentAdjust)
7. Ammeter (Gap Current)
8. Rotary Switch (Base)
9. Rotary Switch (Duration)
10. Indicator (Gap)
11. Rotary Potentiometer (Gap Control)
12. Toggle Switch (Soft Pulse)
13. IndicatorLamp (Spark)
14. Push Button (Spark)
15. Toggle Switch (Auto-flushing)
16. Rotary Potentiometer (Sparking Time)
17. Rotary Potentiometer (Lifting Time)

18. IndicatorLamp (OV/SP)
19. Push ButtonRed (OFF)
20. Rotary Switch (AUT/MAN)
21. Push Button (UP/DN)
22. IndicatorLamp (Interlock)
23. Rotary Switch (Ignition)
24. IndicatorLamp (Pump ON)
25. Push Button (AUTOPOS)
26. IndicatorLamp (AUTOPOS)\

EXPERIMENTATION DATA ANALYSIS

5.1- EDM Process Parameter and Their Level Used In Experiment

Experiment process parameter for EDM

EDM process parameter	Parameter Designation	Level	
		Level 1	**Level 2**
Discharge current (A)	Amp	1	2
Pulse-on time (B)	**(□ s)**	30	60
Duty cycle (C)	-	45	65
Gap voltage (D)	Volte	60	70

Table: - 5.1 Experiment process parameter for EDM

5.2-Experimental Results for MRR

S. No	Discharge current	Pulse on-time	Duty Cycle	Gap voltage	Experimental Results
	Amp	**□ s**	**-**	**Volt**	**MRR(g/min)**
1	1	1	1	1	0.0007
2	1	1	2	2	0.000725
3	1	2	1	2	0.00065
4	1	2	2	1	0.000825
5	2	1	1	2	0.000925
6	2	1	2	1	0.00115
7	2	2	1	1	0.0007
8	2	2	2	2	0.00085

Table5.2 – L8 Orthogonal Array

5.3 Calculation

The S/N ratio is computed from the mean square deviation (MSD) by the equations:

$$S/N = -10 \log_{10} (MSD)$$

For the S/N ratio to be large, MSC must have a value that is small. If smaller is the best quality characteristic;

$$MSD = [(Y_1^2 + Y_2^2 + \text{------} + Y_n^2)] / N$$

5.4 - S/N Ratio for MRR

S.No.	S/N Ratio
1	-63.098
2	-62.7932
3	-63.7417
4	-61.6709
5	-60.6772
6	-58.786
7	-63.098
8	-61.4116

Table 5.3- S/N Ratio (minitab15)

5.5 -Average S/N ratio for MRR

Level	DC	POT	DC	GV
1	-62.83	-61.34	-62.65	-61.66
2	-60.99	-62.48	-61.17	-62.16
DELTA	1.83	1.14	1.49	0.49
Rank	**1**	**3**	**2**	**4**

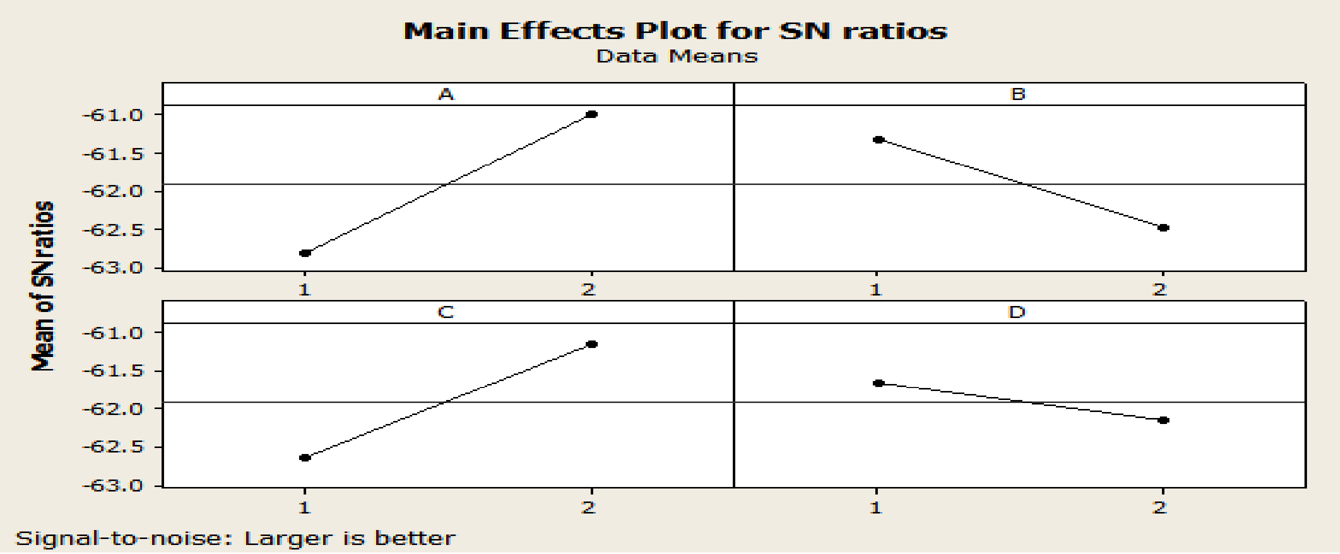
Table 5.4 –Average S/N Ratio

5.6 - Analysis of Variance for MRR (ANOVA)

Source	DF	Seq SS	Adj SS	Adj MS	F	P-Value
A	1	0.0000001	0.0000001	0.0000001	4.90	0.004
B	1	0.0000000	0.0000000	0.0000000	1.68	0.285
C	1	0.0000001	0.0000001	0.0000001	4.25	0.131
D	1	0.0000000	0.0000000	0.0000000	0.15	0.728
Error	3	0.0000000	0.0000000	0.0000000		
Total	7	0.0000002				

Table 5.5-The results of a ANOVA statistical test performed **(Result acquire byMINITAB)**

The results are analyzed by using ANOVA in MINITAB16 software. The analysis of variance at 99% confidence level is given by F test in table 5.3. The principle of F test is that larger the value of F of parameter more is the significance of parameter on the MRR. ANOVA table shows that "A" has the highest

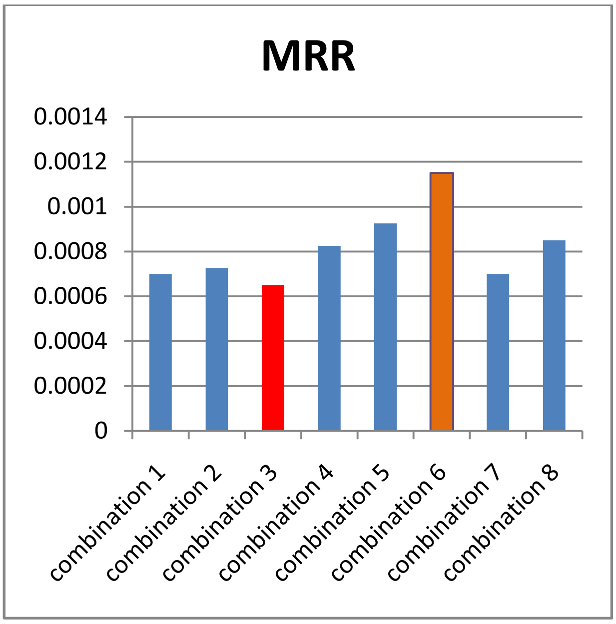


Graph 5.1 – Mean effects Plote of S/N ratio

RESULT& CONCLUSION

1 To conduct experiments in Electro-discharge machining process using Taguchi method.

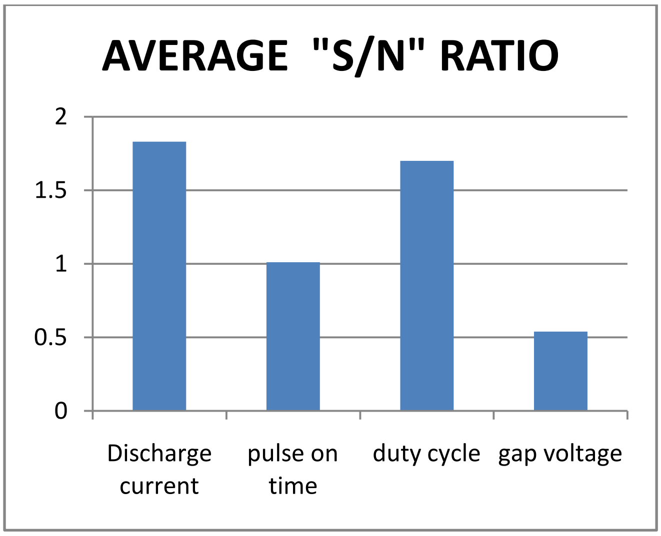
In this experiment we use the four factor two level tachugi experimental method in which with the help of minitab-15 we equate the eight combination of varies parameter (Discharge current Pulse on-time, Duty Cycle Gap voltage) and consist the machining process to find out the martial removing rate of tungsten carbide tool material.



Graph 6.1 – Experimental result of machining operation

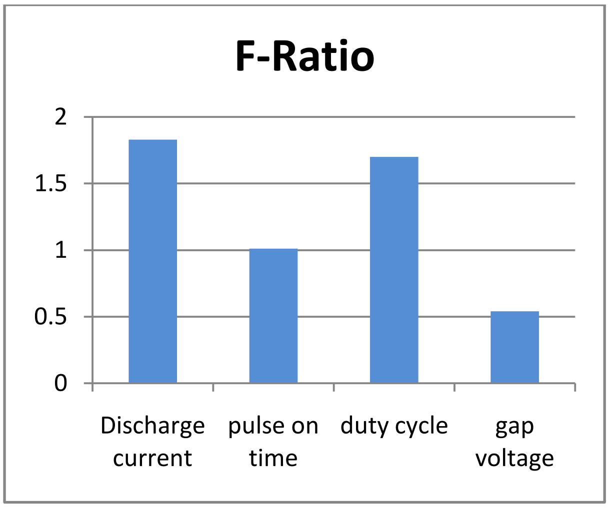
2- To perform statistical analysis using S/N and ANOVA technique.

Average S/N ratio shows that Discharge current" has the highest rank (rank= 1.83). It means Discharge current is the most significant factor for MRR and "Duty Cycle" with rank= 1.49 is second most important factor. From table it is clear that "Pulse on-time (rank-1.14)&Gap voltage (rank-0.49)" has least effect on MRR.



Graph 6.2- Average S/N ratio result

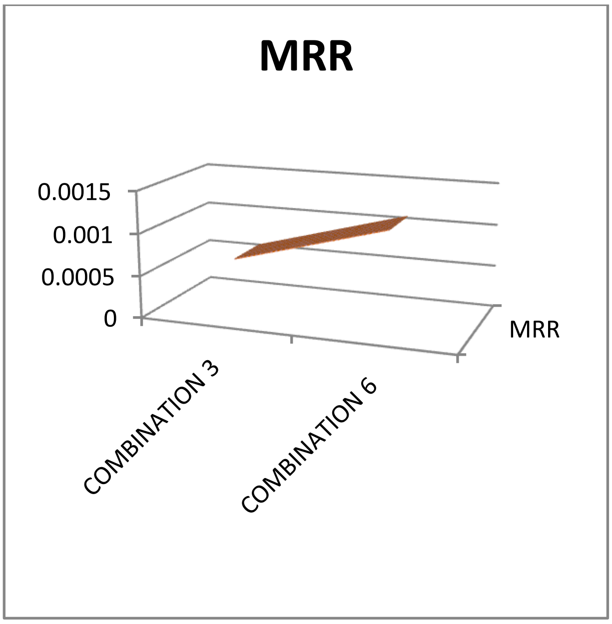
Similar ANOVA table shows that "Discharge current (A)" has the highest value (F= 4.90). It means Discharge current is the most significant factor for MRR and "Duty Cycle (C)" with F= 4.25 is second most important factor. From table it is clear that "Pulse on-time (B) &Gap voltage (D)" has least effect on MRR.



Graph -6.3 ANOVA Result

3 - To determine the optimum machining parameters using evolutionary algorithms.

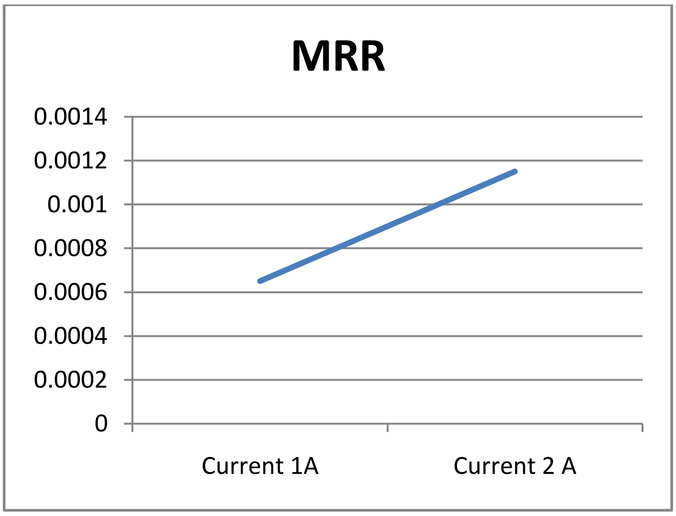
As seen in graph the combination number 6[Discharge current (2) Pulse on-time (1), Duty Cycle (2), Gap voltage (1)] have maximum material removing rate 0.00115 g/min. and combination number 3 have minimum MRR result 0.00065 g/min. its mean the MRR can be **increase up to 0.0005 g/min**by using best combination.



Graph 6.4 – Comparison of maximum and minimum MRR rate combination

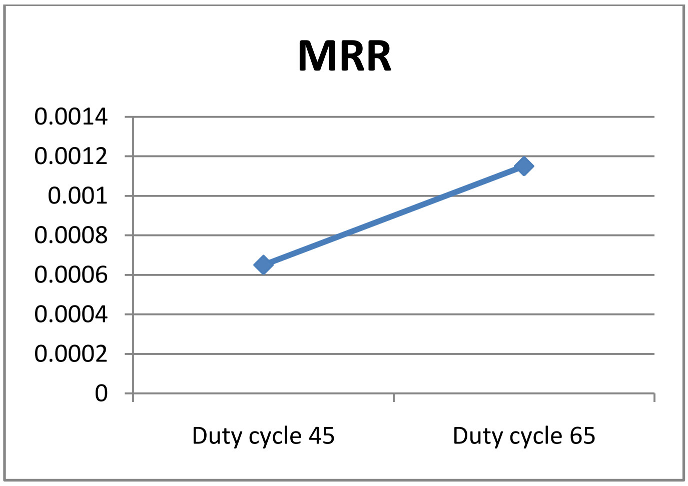
4-To determine the effect of machining parameters on electro - discharge machining result.

4.1– Effect of current on machining



Graph 6.5 – MRR versus CURRENT

4.2 Effect of Duty cycle on machining



Graph 6.6 — MRR versus Duty Cycle

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