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INFLUENCE OF CONTROL PARAMETERS ON MRR IN ELECTRICAL DISCHARGE MACHINING (EDM) USING S/N RATIO AND ANOVA ANALYSIS

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ABSTRACT- Electro Discharge Machining (EDM) is a non-traditional machining process, based on thermo electric energy between the work piece and electrode. In this process, the material removal is occurred electro thermally by a series of successive discrete discharges between electrode and the work piece. Electro Discharge Machine which has the ability to machine hard, difficult to machine material and parts with internal complex shape by using precisely controlled sparks that occurs between electrode and work piece in the presence of dielectric fluid. This spark removes material from both work piece and electrode. Material Removal Rate (MRR) is of crucial importance in this process. In this research experiment has been done along with Copper and Graphite tool material as well as Mild Steel and Aluminium material has been used as work piece. Three major Control Parameters named as Electrode Speed (V), Current (I) and Depth of Cut (h) are considered to determine their influence on MRR. In this experiment three levels of each parameter has been taken and an analysis has been made to find out the influence of control parameters on MRR using S/N Ratio and ANOVA Analysis.

Index Terms: Current, Depth of Cut, Electrode Speed, MRR, S/N Ratio, ANOVA etc.

I. INTRODUCTION

There has been rapid growth in the development of harder and difficult to machine metals and alloys during last two decades. Machining process that involves chip formation have number of inherent limitations which limit their application in industry. Large amount of energy are expended to produce unwanted chips which must be removed and discarded. Electro Discharge Machining Process is now become the most important accepted technologies in manufacturing industries since may many complex 3D shapes can be machined using simple shaped tool electrode. The basis of Electro Discharge Machining (EDM) was first traced far back in 1770's by English scientist Joseph Priesty who discovered the erosive effect of electrical discharges of sparks. The EDM technique was developed by two Russian scientists B.R Lazarenko and N.I Lazarenko in the year 1943. Electrical-discharge machining (EDM) is an unconventional, non-contact machining process where metal removal is based on thermo-electric principles. In this process, the material removal mechanism uses the electrical energy and turns it into thermal energy through a series of discrete electrical discharges occurring between the electrode and work piece immersed in an insulating dielectric fluid. Its unique feature of using thermal energy is to machine electrically conductive parts regardless of their hardness; its distinctive advantage is in the manufacture of mould, die, automotive, aerospace and other applications. Moreover, EDM does not make direct contact between the electrode and the work piece, eliminating mechanical stresses, chatter and vibration problems during machining. Hence, the tool material is generally softer than the work piece material. A dielectric fluid is required to maintain the sparking gap between the electrode and work piece. This dielectric fluid is normally a fluid. Dielectric fluid is used in EDM machine provides important functions in this process. These are: (i) Controlling the sparking gap spacing (ii) Cooling the heated material to form the chip and (iii) Removing chips from the sparking area. EDM is basically of two types: (i) Die sinking EDM (ii). Wire cut EDM. We have been performed this experiment by using Die-Sinking type Electro Discharge Machine.

Material Removal Rate (MRR) is an important performance measure in EDM process. MRR is mainly dependent on the different control parameters, electrode and work piece. Electrode Speed (**V**), Current (**I**) and Depth of Cut (**h**) are the three basic control parameters and three levels of each parameter are taken for this experimental study. In this paper an experimental study has been done to analyze the influence of control parameters on MRR for different material and different electrode in EDM using S/N Ratio and ANOVA Analysis. Signal to Noise ratio and Analysis of Variance (ANOVA) are applied to study Performance characteristics of control parameters [Electrode Speed (**V**), Current (**I**) and Depth of Cut (**h**)] with consideration of MRR.

II. EXPERIMENTAL SET-UP

We have done this experimental research work at MSME tool room, Kolkata with different Work piece and different electrode. The whole experiments have been done by Electro Discharge Machine, model AGITRON COMPACT-1 (Die-Sinking type) and positive polarity for electrode is used to conduct the experiments. The materials that are normally used as electrodes in this EDM are copper, graphite, tungsten and brass. Copper and Graphite are selected as tool/electrode in this experiment. Electrodes are prepared with the diameter of 8 mm. Mild Steel and Aluminium are selected as work piece. One piece Mild Steel and one piece Aluminum is prepared with dimension of (101*62*9.7) mm and (110*65.3*15) mm respectively for this experimental work. These two electrodes copper and graphite is expected to give better MRR and it is major commercially available EDM electrodes. The work piece material are used for this work are mild Steel and Aluminum which is having a wide applications in industrial field like manufacturing, cryogenic, space application etc. RUSTLICK E.D.M. 20 oil (specific gravity = 0.763, freezing point = 94^{0}C) is used as Dielectric Fluid in this experiment.

III. PARAMETERS AND RANGE SELECTION

In this study L_9 orthogonal array has been used which is attributed to its suitability for three level problems. On the basis of Taguchi method three factors with three levels of each are selected and L_9 array has been made for calculating MRR. We have been selected the following suitable level values of various factors.

Parameters	Symbol	Level		
		Low	Medium	High
Electrode Speed (mm/min)	V	500	600	700
Current (Amp)	I	4	6	8.5
Depth of Cut (mm)	h	2	3	4

IV. OBSERVATION TABLE

Table – 1. Work Piece Aluminium and Electrode Copper

Exp. No	Impulse	Spark Gap (mm)	Electrode Speed (mm/min)	Current (Amp)	Depth of Cut (mm)	Machining Time (min)	MRR (mm^3/min)
1	1060	0.20	500	4	2	7.167	14.730
2	1070	0.26	500	6	3	5.033	31.924
3	1080	0.31	500	8.5	4	4.50	48.186
4	1060	0.20	600	4	3	8.167	19.390
5	1070	0.26	600	6	4	6.10	35.120
6	1080	0.31	600	8.5	2	1.75	61.953
7	1060	0.20	700	4	4	10.233	20.633
8	1070	0.26	700	6	2	2.133	50.219
9	1080	0.31	700	8.5	3	2.367	68.706

Table – 2. Work Piece Aluminium and Electrode Graphite

Exp. No	Impulse	Spark Gap (mm)	Electrode Speed (mm/min)	Current (Amp)	Depth of Cut (mm)	Machining Time (min)	MRR (mm^3/min)
1	1060	0.20	500	4	2	7.50	14.076
2	1070	0.26	500	6	3	6.317	25.435
3	1080	0.31	500	8.5	4	4.467	38.950
4	1060	0.20	600	4	3	9.0	17.500
5	1070	0.26	600	6	4	7.317	29.279
6	1080	0.31	600	8.5	2	2.233	48.553
7	1060	0.20	700	4	4	10.333	20.433
8	1070	0.26	700	6	2	2.567	41.728
9	1080	0.31	700	8.5	3	2.75	59.137

Table – 3. Work Piece Mild Steel and Electrode Copper

Exp. No	Impulse	Spark Gap (mm)	Electrode Speed (mm/min)	Current (Amp)	Depth of Cut (mm)	Machining Time (min)	MRR (mm^3/min)
1	1060	0.20	500	4	2	13.75	7.678
2	1070	0.26	500	6	3	13.167	12.203
3	1080	0.31	500	8.5	4	9.5	22.825
4	1060	0.20	600	4	3	18.75	8.445
5	1070	0.26	600	6	4	15.533	13.792
6	1080	0.31	600	8.5	2	3.95	27.447
7	1060	0.20	700	4	4	23.667	9.315
8	1070	0.26	700	6	2	6.0	17.853
9	1080	0.31	700	8.5	3	4.417	36.818

Table – 4. Work Piece Mild Steel and Electrode Graphite

Exp. No	Impulse	Spark Gap (mm)	Electrode Speed (mm/min)	Current (Amp)	Depth of Cut (mm)	Machining Time (min)	MRR (mm^3/min)
1	1060	0.20	500	4	2	26.667	3.959
2	1070	0.26	500	6	3	31.20	5.150
3	1080	0.31	500	8.5	4	30.0	7.228
4	1060	0.20	600	4	3	38.333	4.130
5	1070	0.26	600	6	4	38.933	5.503
6	1080	0.31	600	8.5	2	14.0	7.749

7	1060	0.20	700	4	4	48.333	4.368
8	1070	0.26	700	6	2	17.367	6.168
9	1080	0.31	700	8.5	3	19.0	8.560

V. SIGNAL-TO-NOISE RATIO (S/N RATIO)

Taguchi uses the loss function to measure the performance characteristic deviating from the desired value. The value of loss function is then further transformed to S/N ratio. Usually, there are three categories of the performance characteristic in the analysis of the S/N ratio, i.e. the lower-the-better, the higher-the-better, and the nominal-the-better. The S/N ratio for each level of control parameters is computed based on the S/N analysis and the higher S/N ratio corresponds to the better Material Removal Rate (MRR). Therefore, the optimal level of the process parameter is the level with the highest S/N ratio. S/N ratio calculation has done to find out influence of the control parameters on MRR and also find the optimal setting of control parameter for maximum MRR. In this paper we used "Larger-the-Better" type performance characteristics in the analysis of S/N ratio.

$[SN_i] = -10 \log_{10}[\Sigma(1/ (X_i^2)/ n]$

Where, SN_i = S/N Ratio for Respective Result,

X_i = Material Removal Rate for each experiment, [i=1to9]

n = no. of results for each experiment.

[In this paper calculation has been shown only for experiment (Work piece Aluminium and Electrode Copper) and calculation for rest of three set experiment has done in the same method. After calculating all result is given to the table.]

S/N ratio Calculation for Work Piece Aluminium and Electrode Copper

$SN_1 = -10 \log_{10}[\Sigma(1/X_1^2)/ n] = -10 \log_{10}[\Sigma(1/14.730^2)/1] = 23.364$

$SN_2 = -10 \log_{10}[\Sigma(1/X_2^2)/ n] = -10 \log_{10}[\Sigma(1/31.924^2)/1] = 30.082$

$SN_3 = -10 \log_{10}[\Sigma(1/X_3^2)/ n] = -10 \log_{10}[\Sigma(1/48.186^2)/1] = 33.658$

$SN_4 = -10 \log_{10}[\Sigma(1/X_4^2)/ n] = -10 \log_{10}[\Sigma(1/19.390^2)/1] = 25.752$

$SN_5 = -10 \log_{10}[\Sigma(1/X_5^2)/ n] = -10 \log_{10}[\Sigma(1/35.120^2)/1] = 30.911$

$SN_6 = -10 \log_{10}[\Sigma(1/X_6^2)/ n] = -10 \log_{10}[\Sigma(1/61.953^2)/1] = 35.841$

$SN_7 = -10 \log_{10}[\Sigma(1/X_7^2)/ n] = -10 \log_{10}[\Sigma(1/20.633^2)/1] = 26.291$

$SN_8 = -10 \log_{10}[\Sigma(1/X_8^2)/ n] = -10 \log_{10}[\Sigma(1/50.219^2)/1] = 34.017$

$SN_9 = -10 \log_{10}[\Sigma(1/X_9^2)/ n] = -10 \log_{10}[\Sigma(1/68.706^2)/1] = 36.740$

S/N Ratio Table

Table – 1(A). Work piece Aluminium and Electrode Copper

Exp. No	Parameter						MRR (mm^3/min)	S/N Ratio for Larger the better
	Combination of Control Parameter			Control Parameter				
				Electrode Speed (mm/min)	Current (Amp)	Depth of Cut (mm)		
1	1	1	1	500	4	2	14.730	23.364
2	1	2	2	500	6	3	31.924	30.082
3	1	3	3	500	8.5	4	48.186	33.658
4	2	1	2	600	4	3	19.390	25.752
5	2	2	3	600	6	4	35.120	30.911
6	2	3	1	600	8.5	2	61.953	35.841
7	3	1	3	700	4	4	20.633	26.291
8	3	2	1	700	6	2	50.219	34.017
9	3	3	2	700	8.5	3	68.706	36.740

Table- 2(A). Work piece Aluminium and Electrode Graphite

Exp. No	Parameter						MRR (mm^3/min)	S/N Ratio for Larger the better
	Combination of Control Parameter			Control Parameter				
				Electrode Speed (mm/min)	Current (Amp)	Depth of Cut (mm)		
1	1	1	1	500	4	2	14.076	22.970
2	1	2	2	500	6	3	25.435	28.109
3	1	3	3	500	8.5	4	38.950	31.810
4	2	1	2	600	4	3	17.50	24.861
5	2	2	3	600	6	4	29.279	29.331
6	2	3	1	600	8.5	2	48.553	33.724
7	3	1	3	700	4	4	20.433	26.207
8	3	2	1	700	6	2	41.728	32.409
9	3	3	2	700	8.5	3	59.137	35.437

Table – 3(A). Work piece Mild Steel and Electrode Copper

Exp. No	Parameter						MRR (mm^3/min)	S/N Ratio for Larger the better
	Combination of Control Parameter			Control Parameter				
				Electrode Speed (mm/min)	Current (Amp)	Depth of Cut (mm)		
1	1	1	1	500	4	2	7.678	17.705
2	1	2	2	500	6	3	12.203	21.729
3	1	3	3	500	8.5	4	22.825	27.168
4	2	1	2	600	4	3	8.445	18.532
5	2	2	3	600	6	4	13.792	22.792
6	2	3	1	600	8.5	2	27.447	28.770
7	3	1	3	700	4	4	9.315	19.384
8	3	2	1	700	6	2	17.853	25.034
9	3	3	2	700	8.5	3	36.818	31.321

Table – 4(A). Work piece Mild Steel and Electrode Graphite

Exp. No	Parameter						MRR (mm^3/min)	S/N Ratio for Larger the better
	Combination of Control Parameter			Control Parameter				
				Electrode Speed (mm/min)	Current (Amp)	Depth of Cut (mm)		
1	1	1	1	500	4	2	3.959	11.952
2	1	2	2	500	6	3	5.150	14.236
3	1	3	3	500	8.5	4	7.228	17.180
4	2	1	2	600	4	3	4.130	12.319
5	2	2	3	600	6	4	5.503	14.812
6	2	3	1	600	8.5	2	7.749	17.785
7	3	1	3	700	4	4	4.368	12.806
8	3	2	1	700	6	2	6.168	15.803
9	3	3	2	700	8.5	3	8.560	18.649

VI. OVERALL MEAN OF S/N RATIO

The calculation of overall mean is done by the following process:-

V_{11} = Mean of low level values of Electrode Speed

$V_{11} = (SN_1+SN_2+SN_3) /3 = (23.364+30.082+33.658) /3 = 29.035$

V_{21} = Mean of medium level values of Electrode Speed

$V_{21} = (SN_4+SN_5+SN_6) /3 = (25.752+30.911+35.841) /3 = 30.835$

V_{31} = Mean of high level values of Electrode Speed

$V_{31} = (SN_7+SN_8+SN_9) /3 = (26.291+34.017+36.740) /3 = 32.349$

I_{12} = Mean of low level values of Current

$I_{12} = (SN_1 +SN_4+ SN_7) /3 = (23.364+25.752+26.291) = 25.136$

I_{22} = Mean of medium level values of Current

$I_{22} = (SN_2 +SN_5+ SN_8) /3 = (30.082+30.911+34.017) /3 = 31.67$

I_{32} = Mean of high level values of Current

$I_{32} = (SN_3 +SN_6+ SN_9) /3 = (33.658+35.841+36.740) /3 = 35.413$

h_{13} = Mean of low level values of Depth of Cut

$h_{13} = (SN_1 +SN_6+ SN_8) /3 = (23.364+35.841+34.017) /3 = 31.074$

h_{23} = Mean of medium level values of Depth of Cut

$h_{23} = (SN_2 +SN_4+ SN_9) /3 = (30.082+25.752+36.017) /3 = 30.617$

h_{33} = Mean of high level values of Depth of Cut

$h_{33} = (SN_3 +SN_5+ SN_7) /3 = (33.658+30.911+26.291) /3 =30.287$

Overall Mean of S/N Ratio Table

Table – 1(B). Work piece Aluminium and Electrode Copper

Level	Average S/N Ratio by Factor level			Overall Mean of S/N Ratio (SN_0)
	S/N Ratio associate with Electrode Speed	S/N Ratio associate with Current	S/N Ratio associate with Depth of Cut	
Low	29.035	25.136	31.074	30.713
Medium	30.835	31.167	30.617	
High	32.439	35.413	30.287	
Delta = Larger - Smaller	3.404	10.277	0.787	
Rank	2	1	3	

Table – 2(B). Work piece Aluminium and Electrode Graphite

Level	Average S/N Ratio by Factor level			Overall Mean of S/N Ratio (SN_0)
	S/N Ratio associate with Electrode Speed	S/N Ratio associate with Current	S/N Ratio associate with Depth of Cut	
Low	27.630	24.679	29.701	29.429
Medium	29.305	29.950	29.469	
High	31.351	33.657	29.116	
Delta = Larger - Smaller	3.721	8.978	0.585	
Rank	2	1	3	

Table – 3(B). Work piece Mild Steel and Electrode Copper

Low Medium	Average S/N Ratio by Factor level			Overall Mean of S/N Ratio (SN_0)
	S/N Ratio associate with Electrode Speed	S/N Ratio associate with Current	S/N Ratio associate with Depth of Cut	
Low	22.201	18.540	23.836	23.604
Medium	23.365	23.185	23.861	
High	25.246	29.086	23.115	
Delta = Larger - Smaller	3.045	10.546	0.746	
Rank	2	1	3	

Table – 4(B). Work piece Mild Steel and Electrode Graphite

Medium	Average S/N Ratio by Factor level			Overall Mean of S/N Ratio (SN_0)
	S/N Ratio associate with Electrode Speed	S/N Ratio associate with Current	S/N Ratio associate with Depth of Cut	
Low	14.450	12.359	15.180	15.060
Medium	14.972	14.950	15.068	
High	15.753	17.871	14.933	
Delta = Larger - Smaller	1.303	5.512	0.247	
Rank	2	1	3	

Graphical Representation of Mean S/N Ratio with Electrode Speed, Current and Depth of Cut

Work piece Aluminium and Electrode Copper

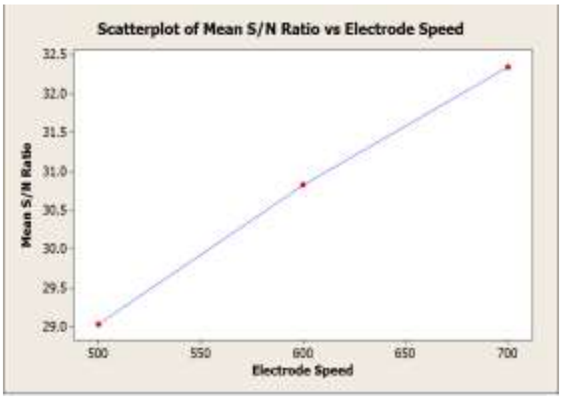

Fig.1:Variation of mean S/N ratio with Electrode Speed

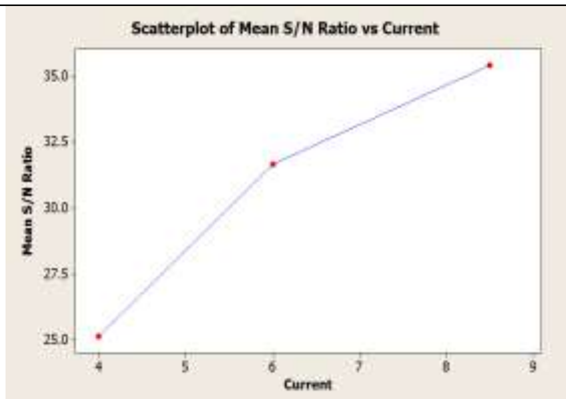

Fig.2: Variation of mean S/N ratio with Current

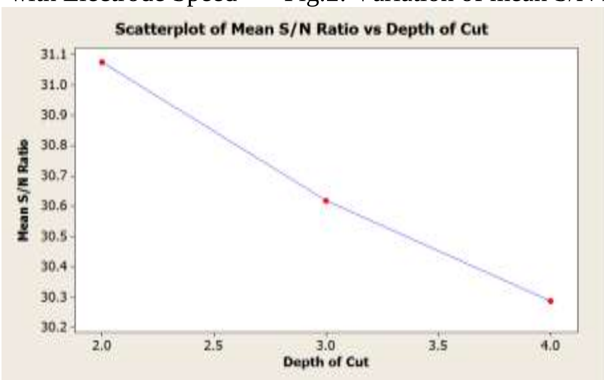

Fig.3: Variation of mean S/N ratio with Depth of Cut

Work piece Aluminium and Electrode Graphite

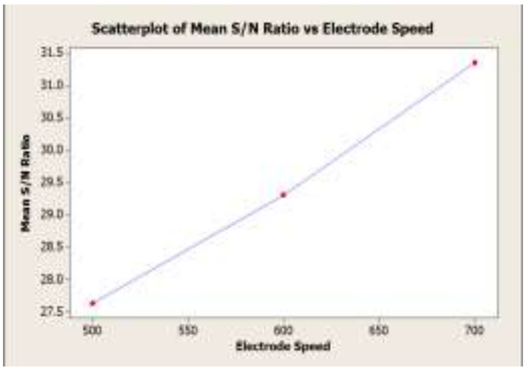

Fig.1(A): Variation of mean S/N ratio with Electrode Speed

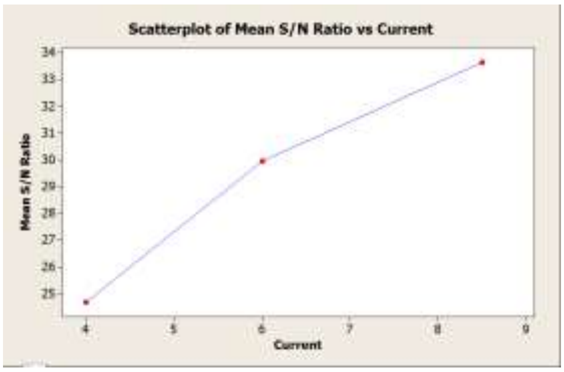

Fig.2(A): Variation of mean S/N ratio with Current

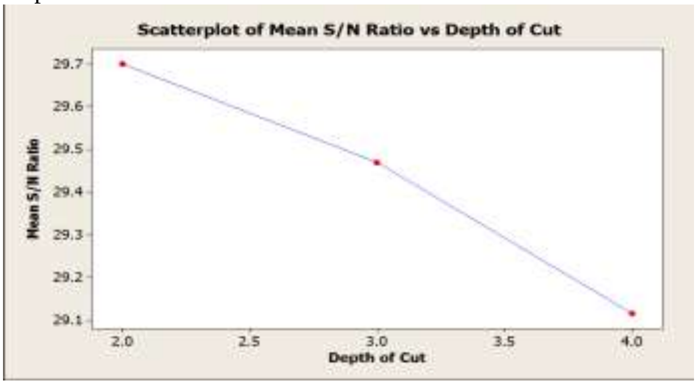

Fig.3(A): Variation of mean S/N ratio with Depth of Cut

Work piece Mild Steel and Electrode Copper

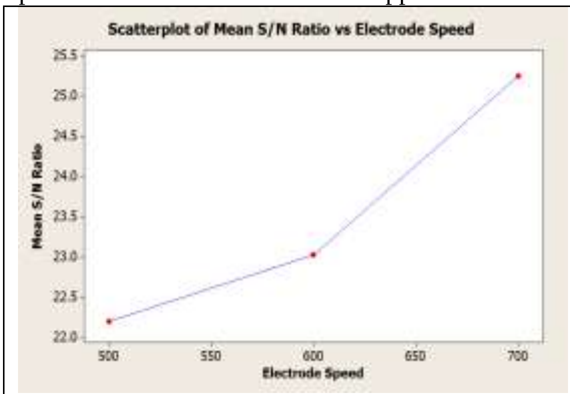

Fig.1(B): Variation of mean S/N ratio with Electrode Speed

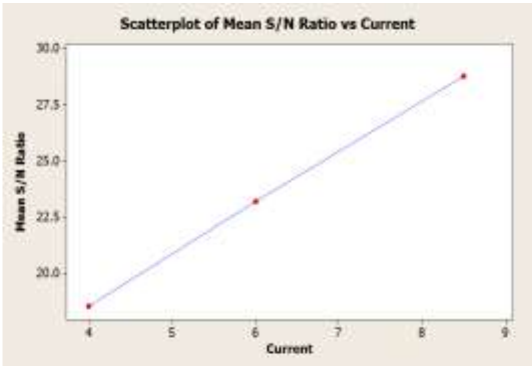

Fig.2(B): Variation of mean S/N ratio with Current

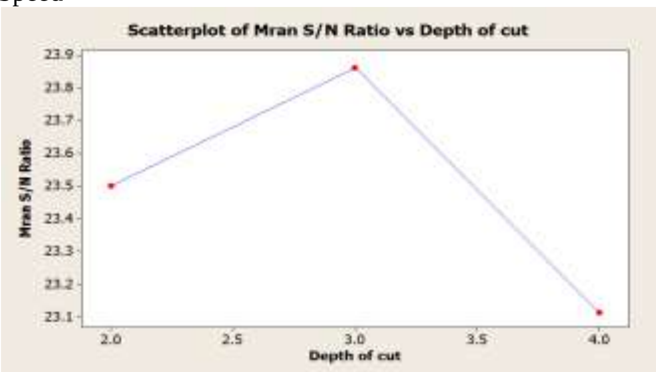

Fig.3(B): Variation of mean S/N ratio with Depth of Cut

Work piece Mild Steel and Electrode Graphite

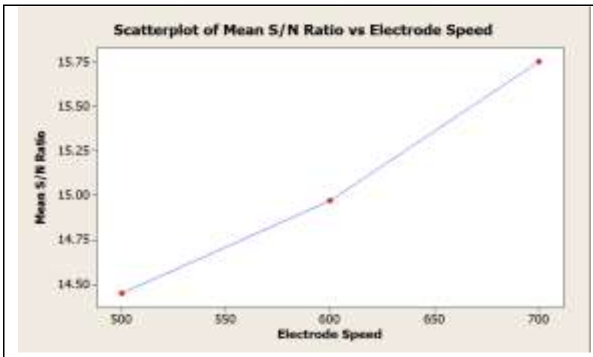

Fig.1(C):Variation of mean S/N ratio with Electrode Speed

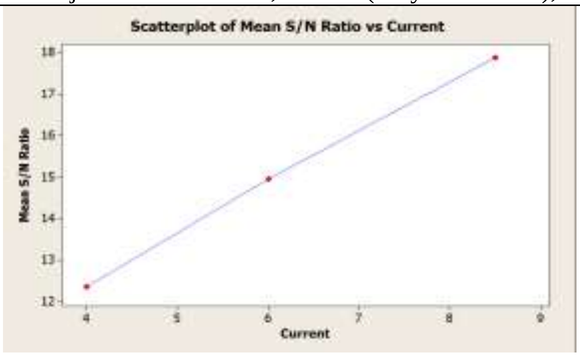

Fig.2(C): Variation of mean S/N ratio with Current

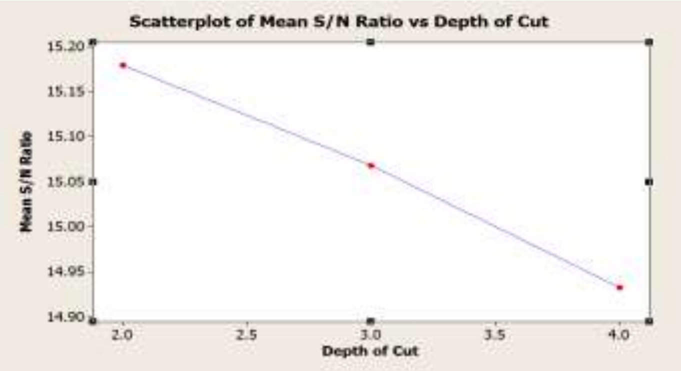

Fig.3(C): Variation of mean S/N ratio with Depth of Cut

VII. ANALYSIS OF VARIANCE (ANOVA) CALCULATION:

The test results analyzed using Computer Simulation and S/N Ratio were again analyzed by using ANOVA (Analysis of Variance) for identifying the significant factors and their relative contribution on the outcome or results. By using S/N Ratio it is not possible to judge and determine the effect of individual parameter where by using ANOVA percentage contribution of individual parameters can be determined. The analysis was carried out with a 95% confidence level. Effect of each parameter can be determined by subtraction of each value of table no.(1B, 2B, 3B & 4B) to the overall average of S/N ratio values (30.713, 29.429, 23.604 & 15.060).After subtraction, the effect of each control parameter obtained as follows.

Effect of Each Parameter

Table – 1(C). Work piece Aluminium and Electrode Copper

Level	S/N Ratio associate with Electrode Speed	S/N Ratio associate with Current	S/N Ratio associate with Depth of Cut
Low	-1.678	-5.577	0.361
Medium	0.122	0.957	-0.096
High	1.636	4.7	-0.426

Table – 2(C). Work piece Aluminium and Electrode Graphite

Level	S/N Ratio associate with Electrode Speed	S/N Ratio associate with Current	S/N Ratio associate with Depth of Cut
Low	-1.799	-4.75	0.272
Medium	-0.124	0.521	0.04
High	1.922	4.228	-0.313

Table – 3(C). Work piece Mild Steel and Electrode Copper

Level	S/N Ratio associate with Electrode Speed	S/N Ratio associate with Current	S/N Ratio associate with Depth of Cut
Low	-1.403	-5.064	0.232
Medium	-0.239	-0.419	0.257
High	1.642	5.482	-0.489

Table – 4(C). Work piece Mild Steel and Electrode Graphite

Level	S/N Ratio associate with Electrode Speed	S/N Ratio associate with Current	S/N Ratio associate with Depth of Cut
Low	-0.61	-2.701	0.12
Medium	-0.088	-0.11	-0.008
High	0.693	2.811	-0.127

ANOVA calculation has been shown for the experiment of Work piece Aluminium and Electrode Copper.

SS= Sum of square of each parameter air velocity = Σ (Vij – SN_o)^2 *n

Vij =Average S/N ratio values from table (1B, 2B, 3B & 4B) each parameter (low, medium and high level)

SN_o = Overall mean of S/N ratio, n= 3

SS Electrode Speed = $[(-1.678)^2*3 +(0.122)^2*3+(1.636)^2*3] = 16.521$

SS Current = $[(-5.577)^2*3 +(0.957)^2*3+(4.7)^2*3] = 162.326$

SS Depth of Cut = $[(-0.361)^2*3 +(-0.096)^2*3+(-0.426)^2*3 = 0.963$

Total sum of square(TSS)=[(SN i)^2] – [(Σ SN i)^2 / 9]

SN i=S/N ratio values for each experiment, [i= varies from 1……9]

TSS = $[(23.364)^2 + (30.082)^2 + (33.658)^2 + (25.752)^2 + (30.911)^2 + (35.841)^2 + (26.291)^2 + (34.017)^2 + (36.740)^2] – [(276.656)^2 /9] = 8685.097 – 8504.282 = 180.815$

Sum of Squared Error (SSE) = TSS - Σ(SS $_{Electrode\ Speed}$ + SS $_{Current}$ + SS $_{Depth\ of\ Cut}$)

= 180.815 – (16.521 + 162.326 + 0.963) = 1.012

Mean Square Error (MSE) = SS $_{each\ factor}$ / DOF $_{each\ factor}$

F value = MSE $_{each\ factor}$ / SSE

Percentage Contribution = $\left(\frac{Sum\ of\ square\ of\ factor}{Total\ sum\ of\ square}\right) * 100$

ANOVA Calculation for MRR at 95% Confidence Level

ANOVA table consists of sum of squares, Corresponding degree of freedom, the F ratio corresponding to the ratio of two mean square and the contribution properties from each of the control factors.

Table – 1(D). Work piece Aluminium and Electrode Copper

Source	Symbol	Degree of Freedom	Sum of Squares (SS)	Mean Squares (MS)	F Ratio	P	Contribution (%)
Electrode Speed (mm/min)	V	2	333.40	166.70	108.17	0.009	11.130
Current (Amp)	I	2	2566.52	1283.26	832.67	0.001	85.677
Depth of Cut (mm)	h	2	92.58	46.29	30.04	0.032	3.091
Error		2	3.08	1.54			0.103
Total		8	2995.59	1497.79			100

Table – 2(D). Work piece Aluminium and Electrode Graphite

Source	Symbol	Degree of Freedom	Sum of Squares (SS)	Mean Squares (MS)	F Ratio	P	Contribution (%)
Electrode Speed (mm/min)	V	2	339.50	169.75	4.95	0.168	13.098
Current (Amp)	I	2	2151.54	1075.77	31.39	0.031	83.010
Depth of Cut (mm)	h	2	32.31	16.16	0.47	0.680	1.247
Error		2	68.55	34.27			2.645
Total		8	2591.90				100

Table – 3(D). Work piece Mild Steel and Electrode Copper

Source	Symbol	Degree of Freedom	Sum of Squares (SS)	Mean Squares (MS)	F Ratio	P	Contribution (%)
Electrode Speed (mm/min)	V	2	78.45	39.23	4.13	0.195	9.959
Current (Amp)	I	2	667.75	333.88	35.16	0.028	84.769
Depth of Cut (mm)	h	2	22.54	11.27	1.19	0.457	2.861
Error		2	18.99	9.50			2.411
Total		8	787.73				100

Table – 4(D). Work piece Mild Steel and Electrode Graphite

Source	Symbol	Degree of Freedom	Sum of Squares (SS)	Mean Squares (MS)	F Ratio	P	Contribution (%)
Electrode Speed (mm/min)	V	2	1.2935	0.6468	13.18	0.071	5.803
Current (Amp)	I	2	20.7684	10.3842	211.65	0.005	93.181
Depth of Cut (mm)	h	2	0.1282	0.0641	1.31	0.433	0.575
Error		2	0.0981	0.0491			0.440
Total		8	22.2883				100

VIII. CONCLUSION

i) From the S/N Ratio calculation and graph analysis, the optimum set of combination of control parameter for Material Removal Rate (MRR) is Electrode Speed (V) 700 mm/min, Current (I) 8.5 amp and Depth of Cut (h) 3mm. This optimality has been proposed within the experimental working range of Electrode Speed (500 mm/min to 700 mm/min), Current (4 amp to 8.5 amp) and Depth of Cut (2 mm to 4 mm). S/N Ratio also indicates that current is the most influencing control parameter on MRR.

ii) From ANOVA analysis it can be concluded that current (I) is the most influencing control parameter on MRR at 95% confidence level.

iii) From ANOVA analysis the contribution of each control parameter on MRR are as follows: -

a) The Contribution of current are 85.677%, 83.01%, 84.769% & 93.181% on MRR of these four set of combination of experiments respectively.

b) The Contribution of Electrode Speed are 11.13%, 13.098%, 9.959% & 5.803% on MRR of these four set of combination of experiments respectively.

c) The Contribution of Depth of Cut are 3.091%, 1.247%, 2.861% & 0.575% on MRR of these four set of combination respectively.

iv) Results obtained from both S/N Ratio and polynomial regression analysis are also bearing same trend.

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