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Optimization of the EDM process based on the orthogonal array with Taguchi method

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Abstract **-** Electric discharge machining (EDM) is a widely used unconventional manufacturing process that uses thermal energy of the spark to machine electrically conductive as well as non-conductive parts regardless of the hardness of the work material. This technique has been widely used in modern metal working industry producing complex cavities in dies and moulds, which are otherwise difficult to create by conventional machining. Present research proposes an optimization methodology for the selection of best process parameters in multi-response situation. Regular cutting experiments are carried out on EDM machine under different conditions of process parameters Experiments have been conducted on a electric discharge machine under different conditions of process parameters.

This paper describes the selection of machining parameters, Discharge current (A), Pulse on time (µs) Pulse off time (µs), Dielectric fluid (g/l) in EDM for the machining of EN-353 Stainless steel material. The signal- to-Noise ratio applied to find optimum process parameter for EDM. Experiments were designed and conducted using Taguchi's L'9 orthogonal array and ANOVA are applied to study the performance characteristics of machining parameter with consideration of Material removal rate (MRR) & surface Roughness(SR).

***Keywords* -** EDM, Process Parameters, S/N Ratio, ANOVA

I. INTRODUCTION

Electrical Discharge Machining (EDM) is a unconventional machining process which is more efficient than Conventional Machining process due to ease of machining of difficult-to-machine materials with complex shapes. EDM is used for machining of toughened and high strength conductive materials which is hard enough to cut by traditional processes. It has many applications in manufacturing sectors especially industries like aerospace, ordinance, automobile and general engineering[1].This technique has been widely used in modern metal working industry producing complex cavities in dies and moulds, which are otherwise difficult to create by conventional machining [2]. EDM can be used to machine difficult geometries in small batches or even on job-shop basis. Work material to be machined by EDM has to be electrically conductive, the attainments of accurate and consistent. EDM performance are mainly dependent on eight main factors; polarity, open-circuit or no-load voltage, discharge current, pulse duration, electrode material, pulse interval, gap control and circulation rate. The first four of these are called planning parameters that are dependent on the type of

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machining operation and whether the cut is roughing or finishing operation .The last four are adjusted to give the best operating conditions for the machine used and the results required. The pulse interval, gap control and circulation rate are the operating parameters, which are automatically monitored and corrected in modern machines [3].Several researchers carried out various investigations for improving the process performance. The important output parameters of the process are the material removal rate (MRR) and surface roughness (*R*a). Optimisation of the EDM process is concerned with maximising MRR while minimising TWR, and also producing the optimum (Ra) usually, the finish should be as smooth as possible. Optimisation is concerned with maximising material removal rate, minimising the tool wear ratio and obtaining a good surface finish. There are many input parameters which can be varied in the EDM process which have different effects on the EDM performance characteristics [4].Taguchi proposes a procedure that applies orthogonal arrays from statistical design of experiments to efficiently obtain the best model with the least number of experiments[5].

Fig 1.1 - EDM Machine

In this work, the selected EN-353 stainless steel material for the present investigation is having a wide range of applications in the industrial field. The taguchi method was used early on in the process of this experiment, inspecting the effects of different parameters and levels in EDM on the various characteristics of EDM, including material (MRR), and Surface roughness (SR).The taguchi methodologies to optimize the finishing parameter in EDM use EN-353 and Electrode tool is Copper. Author analysed the data using ANOVA with the help of Commercial software packing MINITAB-15.A series of experiment based on the L'9 orthogonal array is utilized for experiment planning for EDM. In this paper the finishing of EN-353 with parameters of finishing at three levels and four factors each. The main and interaction effects are analyzed using the analysis of variance.

II. EXPERIMENTAL LAYOUT

The equipment used to perform the experiments was a EDM machine Elektra S-3822. The experimental setup is shown in Fig 1. It is energized by 128 A pulse generator. Also, a jet flushing system in order to ensure the adequate flushing of the EDM process debris from the gap zone is employed. Pressure of the dielectric fluid is adjusted manually at the beginning of the experiment. The dielectric fluid used for the EDM machine was I-POL EDM 30, which is commercially available dielectric fluid with a flash point of 93^0C. The materials normally used in EDM electrodes are various types of copper, graphite, tungsten, brass and silver. Copper is the most appropriate material with excellent electrical and thermal conductivity and one of the major commercial materials. The electrode having a diameter_(Ø17.5 mm and L=18 mm).The electrode material Composition are 99.9% copper.

Physical properties of copper electrode [16] shown in Table 2.1.

Physical properties	**Copper**
Thermal conductivity [W/m·K]	380.7
Melting point [°C]	1083
Boiling temperature [°C]	2595
Specific heat [cal/g·°C]	0.092
Specific gravity at 20°C [g/cm3]	8.9
Coefficient of thermal Expansion [×10-6 (1/°C)]	17

Table 2.1 - Physical properties of copper electrode

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MATERIAL

En 353 steel has carbon content of 0.17% and the most common form of steel as it's provides material properties that are acceptable for many automobile applications such as heavy duty gear, shaft, pinion, cam shafts, gudgeon pins etc [14,15] . It is neither externally brittle nor ductile due to its lower carbon content and lower hardness. As the carbon content increases, the metal becomes harder and stronger. The chemical analysis, carbon - 0.171 %, silicon - 0.3 %, manganese - 0.56 %, phosphorus - 0.012 %, sulphur - 0.13 %, Chromium – 0.953 %, Nickel - 0.989 %, molybdenum - 0.16 % and remaining percentage is iron respectively. In this study, EN-353 steel was applied as work material for experimentation. The chemical composition of the selected work material is shown in Table2.2.

Material	**Elements (%)**								
Elements	Carbon	Mn	Si	S	P	Cr	Ni	mo	Fe
En-353	0.171 %	0.56 %	0.3 %	0.13 %	0.012 %	0.953 %	0.989 %	0.16 %	Remaining

Table 2.2 - Composition of substrate material

The mechanical and physical properties of Stainless Steel En-353 are given in Table 2.3.

Property	**Description**
Mechanical	
Tensile Strength	600MPa to 800MPa
Proof Strength, (off set 0.2%)	834MPa
Elongation	18%
Hardness (Brinell)	260
Endurance (fatigue Limit)	400MPa
Physical	
Density	7.85g/cm^3
Elastic Modulus	190-210GPa
Thermal conductivity	51.9W/mK
Electrical Resistivity	1.74X10^{-05} Ohm-cm
Specific Heat	0.472 J/gm-K
Coefficient of Thermal Expansion	11.5
Melting Point	1510^{o}C

Table 2.3 - Mechanical and physical properties of Stainless Steel En-353.

SURFACE ROUGHNESS

Roughness is often a good predictor of the performance of a mechanical component, since irregularities in the surface may form nucleation sites for cracks or corrosion [13]. Roughness is a measure of the texture of a surface. It is quantified by the vertical deviations of a real surface from its ideal form. If these deviations are large, the surface is rough; if small, the surface is smooth. Roughness is typically considered to be the high frequency, short wavelength component of a measured surface. The parameter mostly used for general surface roughness is Ra. It measures average roughness by comparing all the peaks and valleys to the mean line, and then averaging them all over the entire cut-off length. The surface roughness (Ra) is measured with a mitutoyo surf test SJ-201 series 178 Portable surface roughness tester instrument.

III. METHODOLOGY OF STATISTICAL ANALYSES:

This section describes the methodology behind the work and is as follows. Initially experiments are designed and conducted as planned. Taguchi's approach is used to design the experiments. Analysis of variance is used to calculate the percentage contribution of each parameter and means analysis is used to optimize the parameters. Finally the confirmation experiments are conducted to make sure that the optimized levels of each parameters result in the optimum value of EDM characteristics (response).

IV. DESIGN OF EXPERIMENTS

Taguchi uses a special design of orthogonal arrays to study the entire process parameter space with

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only a small number of experiments. The taguchi design of experiments approach eliminates the need for repeated experiments and thus saves time, material, and cost[6].Taguchi technique is a powerful tool for the design of high quality systems[7,8].The taguchi approach to experimentation provides an orderly way to collect, analyze, and interpret data to satisfy the objectives of the study. In the design of experiments one can obtain the maximum amount of information for the amount of experimentation. Taguchi parameter design can optimize the performance characteristics through the setting of design parameter and reduce the sensitivity of the system performance to the source of variation [9, 10]. This is carried by the efficient use of experiment runs to the combinations of variables to be studied. This technique is a powerful tool for acquiring the data in a controlled way and to analyze the influence of process parameters over specific parameters which is unknown function of these process variables. The crucial stage in the plan of experiments is selection of factors. Which have effects on the process. Taguchi technique creates a standard orthogonal array to consider the effect of several factors on the target value and defines the plan of experiments [11].In this work experimental design L9 orthogonal array design matrix is used to set the control parameters to evaluate the process performance.

In an EDM process with the help of copper electrode on En-353 as work piece material for each combination of parameters considered according to the Orthogonal Array. The work piece and tool electrode were weighed before and after the machining by using the electronic weigh-balance. Metal removal rate and Electrode Wear rate is calculated (mm^3/min) for each cutting condition, by measuring the average amount of material removed and the machining time by using the following equation:

MRR or TWR (mm^3/min) = Reduction in weight of work piece or Electrode (g)/Density of Work piece or Electrode (g/mm3) **X** Machining time (min)

Where: MRR=Material removal rate (mm^3/min)
TWR=Tool wear rate (mm^3/min)
Wi =Initial weight of work piece or Electrode (gm)
W_f =Final weight of work piece or Electrode (gm)
$Á_w$ or $Á_e$ =Density of work piece or Electrode(gm/cm3)
T= Periods of trail (min)

Control Parameters	Level			Observed values
	1	2	3	
	Minimum	Intermediate	Maximum	
Discharge current (Ampere) **'A'**	9	23	25	1.Material removal rate (MRR)
Pulse on time,(μs) **'B'**	10	70	87	
Pulse off time (μs), **'C'**	4	9	11	2.Surface roughness (Ra)
Dielectric fluid (g/l) **'D'**	1	3	5	

Table 4 - Design scheme of experiment of Parameters and levels

Experiment No	Discharge Current	Pulse on Time	Pulse off Time	Di-electric fluid
1	9	10	4	1
2	9	70	9	3
3	9	87	11	5
4	23	10	9	5
5	23	70	11	1
6	23	87	4	3
7	25	10	11	3
8	25	70	4	5
9	25	87	9	1

Table 5 - Design matrix used in the work.

4.1Calculation of signal to noise (S/N) ratio:

Taguchi method is one of the simple and effective solutions for parameter design and experimental

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planning [5]. In this method, signal-to-noise (S/N) ratio is used to represent a performance characteristic and the largest value of S/N ratio is required. There are three types of S/N ratio the lower-the- better, the higher-the-better, and the nominal-the-better.

The S/N ratio with a lower-the-better characteristic that can be expressed as:

$$\eta_{ij} = -10\log\left(\frac{1}{n}\sum_{j=1}^{n} y_{ij}^2\right)$$

The S/N ratio with a higher-the-better characteristic can be expressed as:

$$\eta_{ij} = -10\log\left(\frac{1}{n}\sum_{j=1}^{n} \frac{1}{y_{ij}^2}\right)$$

The S/N ratio with a nominal-the-better characteristic can be expressed as:

$$\eta_{ij} = -10\log\left(\frac{1}{ns}\sum_{j=1}^{n} y_{ij}^2\right)$$

Where, *yij* is the *i*th experiment at the *j*th test, *n* is the total number of the tests, and *s* is the standard deviation.

Expt. No	MRR		SR	
	S/NRA	MEAN	S/NRA	MEAN
1	9.3374	2.93	-11.6617	3.829
2	15.9868	6.30	-20.8136	10.982
3	19.7712	9.74	-14.7756	5.480
4	24.7106	17.20	-7.6835	2.422
5	28.9648	28.07	-18.6302	8.541
6	25.3246	18.46	-17.1972	7.242
7	29.7229	30.63	-12.0129	3.987
8	26.9388	22.23	-21.7407	12.219
9	28.7898	27.51	-20.4188	10.494

Table 6- .S/N ratios of different experiments for MRR and SR.

4.2. ANALYSIS OF VARIANCE (ANOVA):

Statistical software with an analytical tool of ANOVA is used to determine which parameter significantly affects the performance characteristics [12].The results of the experiments were evaluated by the analysis of variance (ANOVA). The main objective of the analysis was to determine the influence of every parameter on the variance of the results, regarding the total variance of all the parameters. This is defined by the sum of squares. The calculation of ANOVA was made on the basis of the recommendations in [12].

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$$SS = \sum_{i=1}^{N}\left(y_i - \bar{y}\right)^2 \quad oz. \quad SS = \sum_{i=1}^{N} y_i^2 - CF$$

$$CF = \frac{T^2}{N}$$

$$SS_A = \frac{A_1^2}{N_{A1}} + \frac{A_2^2}{N_{A2}} + \ldots.. + \frac{A_n^2}{N_{An}} - \frac{T^2}{N}$$

$$V_A = \frac{SS_A}{f_A}$$

$$F_A = \frac{V_A}{V_e}$$

$$P_A = \frac{SS_A}{SS}$$

The degrees of freedom are an important part of the statistical analysis because they provide us with additional information about the process. The degrees of freedom for the Taguchi array are defined as follows:

DOF parameter = number of factor levels - 1
DOF experiment = number of results - 1
DOF Error = Number of all DOFs – Number of DOFs of all parameters
ANOVA analysis have been performed with the help of MINITAB software release 15, on selected significance factors, using data given in Table.9, 11 &14

V. RESULTS AND DISCUSSION

Experiments are conducted on electric discharge machine (EDM) with a copper electrode and a steel rectangular work piece of dimension 40mm X 53mm X 120mm. I-pol EDM oil is used as dielectric. Parameters like, Discharge current, pulse-on time and pulse-off time, dielectric fluid are varied alternatively.

Taguchi Analysis: Response versus Discharge Current (A), Pulse on time (B), Pulse off time (C), Di-electric fluid (D).

Expt. No	Discharge current	Pulse on time	Pulse off time	di elctric fluid	MRR	SR
1	9	10	4	1	2.93	3.829
2	9	70	9	3	6.30	10.982
3	9	87	11	5	9.74	5.480
4	23	10	9	5	17.20	2.422
5	23	70	11	1	28.07	8.541
6	23	87	4	3	18.46	7.242
7	25	10	11	3	30.63	3.987
8	25	70	4	5	22.23	12.219
9	25	87	9	1	27.51	10.494494

Table 7 - Experimental Results of different trails

As the first step of experiments, the samples with the factor level setting (L9 orthogonal arrays) suggested by Taguchi method were prepared in internal mixer.

Level	Discharge current	Pulse on time	Pulse off time	Dielectric fluid
1	15.0318	21.2570	20.5336	22.3640
2	26.3334	23.9635	23.1624	23.6781
3	28.4838	24.6285	26.1530	23.8068
Delta	13.4521	3.3716	5.6194	1.4428
Rank	1	3	2	4

Table 8 - Response Table for Signal to Noise Ratios (MRR) (Larger is better)

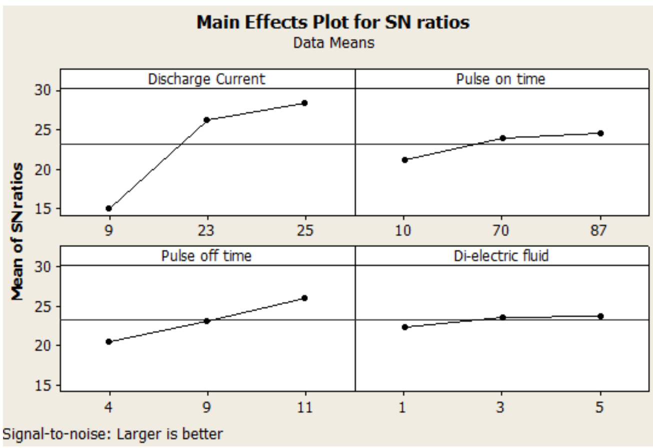

Fig. 2 - Main effect plot of S/N ratio for MRR

Parameter	DOF	Sum of Square	Mean Variance	F-ratio	P (% Contribution)	Rank
Discharge Current	2	313.308	156.654	**	0.81654	1
Pulse on	2	19.135	9.568	**	0.04987	3
Pulse of	2	47.432	23.716	**	0.12362	2
Di-elect	2	3.825	1.913	**	0.00997	4
Error	0	0	0	0	0	
Total	8	383.701	191.851		100	

Table 9-.Analysis of Variance for S/N Ratio, using for F-Tests (MRR)

Note: ** Significant Parameter, * Sub-significant Parameter

Level	Discharge current	Pulse on time	Pulse off time	Dielectric fluid
1	6.2333	16.9200	14.5400	19.5033
2	21.2433	18.8667	17.0033	18.4633
3	26.7900	18.5700	22.8133	16.3900
Delta	20.4667	1.9467	8.2733	3.1133
Rank	1	4	2	3

Table 10 - Response Table for Means (MRR)

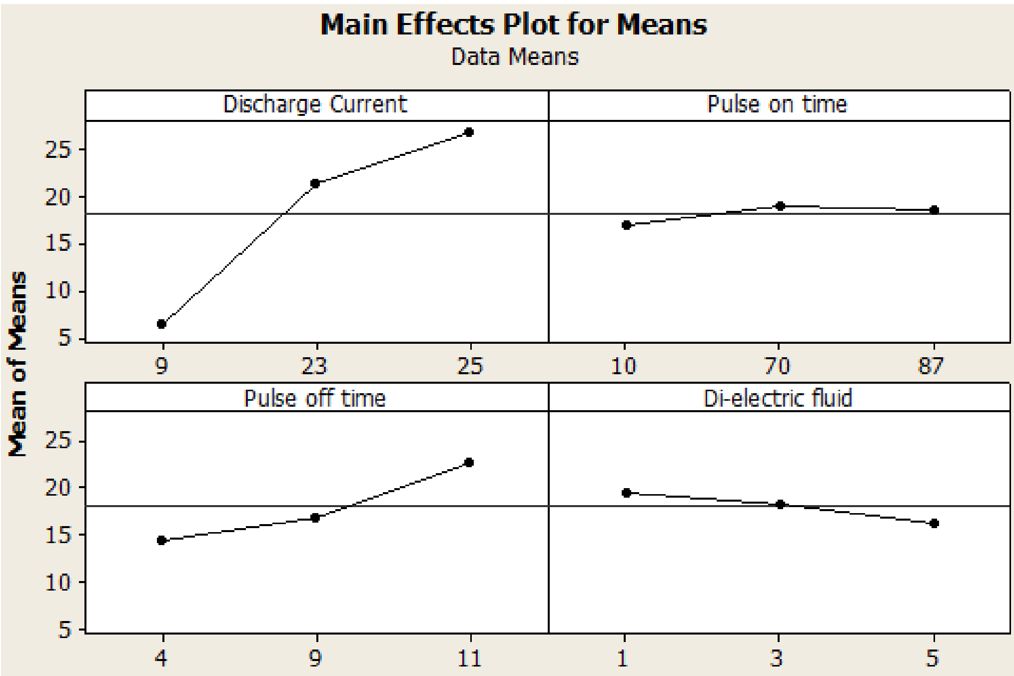

Fig 3 - Main effect plot of mean value for MRR

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Parameter	DOF	Sum of Square	Mean Variance	F-ratio	P	Rank
Discharge current	2	672.26	336.13	* *	83.81	1
Pulse on time	2	6.60	3.30	**	0.823	4
Pulse off time	2	108.27	54.14	**	13.497	2
Di-electric fluid	2	15.07	7.54	**	1.870	3
Error	0	0	0	0	0	
Total	8	802.20	401.11		100	

Table 11 - Analysis of Variance for mean, using for F-Tests (MRR)

As response parameter, MRR of the samples is given in Table 11. The relative contribution percentage (P) and F-value of each factor obtained by the ANOVA method are given in Table 10. It can be concluded from Tables 11 and 10, based on F-value, that the significance of factors prevails in the following order of importance: (1) Discharge current; (2) Pulse off time (3) Di-electric fluid (4) Pulse on time. The most significant factor is Discharge current; the percentage contribution of that parameter to MRR was 83.81%. The next significant factor is Pulse off time which contributed 13.497%, and the third significant factor is the Di-electric fluid with percentage contribution of 1.870%. and the forth significant factor is the Pulse on time with percentage contribution of 0.823%.

Level	Discharge current	Pulse on time	Pulse off time	Dielectric fluid
1	-15.7503	-10.4527	-16.8665	-16.9036
2	-14.5036	-20.3948	-16.3053	-16.6746
3	-18.0575	-17.4639	-15.1396	-14.7333
Delta	3.5539	9.9421	1.7270	2.1703
Rank	2	1	4	3

Table 12 - Response Table for Signal to Noise Ratios (SR) (Smaller is better)

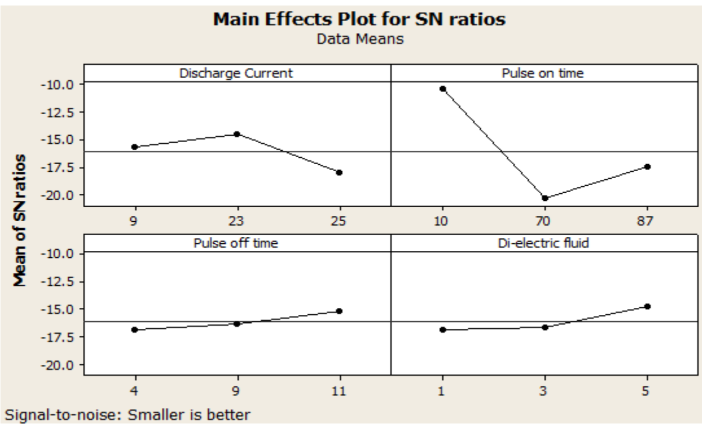

Fig 4 - Main effect plot of S/N ratio for SR

Parameter	DOF	Sum of Square	Mean Variance	F-ratio	P (% Contribution)	Rank
Discharge current	2	19.507	9.754	**	0.10305	2
Pulse on time	2	156.593	78.297	**	0.82727	1
Pulse off time	2	4.656	2.328	**	0.0246	4
Di-electric fluid	2	8.531	4.266	**	0.04507	3
Error	0	0	0	0	0	
Total	8	189.288	94.644		100	

Table 13- Analysis of Variance for S/N Ratio, using for F-Tests (SR)

Level	Discharge current	Pulse on time	Pulse off time	Dielectric fluid
1	6.76367	3.4127	7.76333	7.62133
2	6.06833	10.5807	7.96600	7.40367
3	8.90000	7.7387	6.00267	6.70700
Delta	2.83167	7.1680	1.96333	0.91433
Rank	2	1	3	4

Table 14 - Response Table for Means (SR)

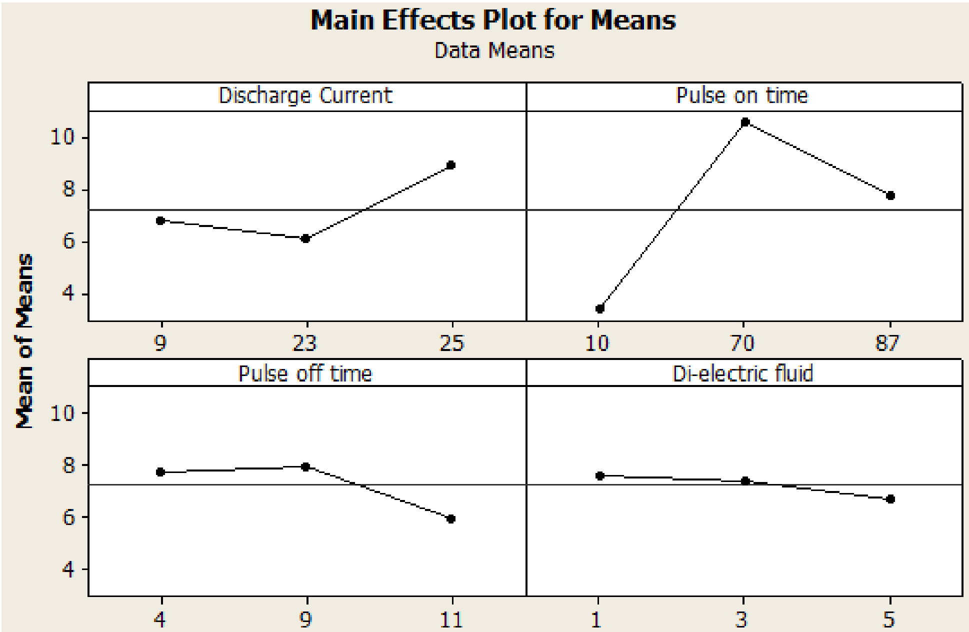

Fig 5 - Main effect plot of mean value for SR

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Parameter	DOF	Sum of Square	Mean Variance	F-ratio	P (% Contribution)	Rank
Discharge current	2	13.067	6.534	**	13.12	2
Pulse on time	2	78.172	39.086	**	78.49	1
Pulse off time	2	6.996	3.498	**	7.03	3
Di-electric fluid	2	1.369	0.685	**	1.360	4
Error	0	0	0	0	0	
Total	8	99.605	49.80		100	

Table 15 - Analysis of Variance for mean, using for F-Tests (SR)

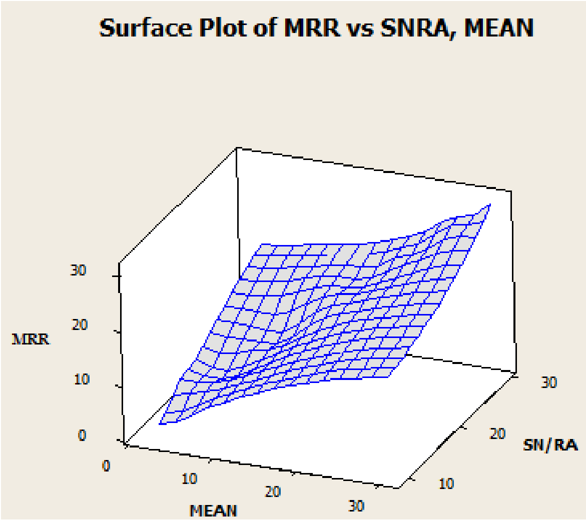

Fig. 6(a) - 3D surface plot for MRR

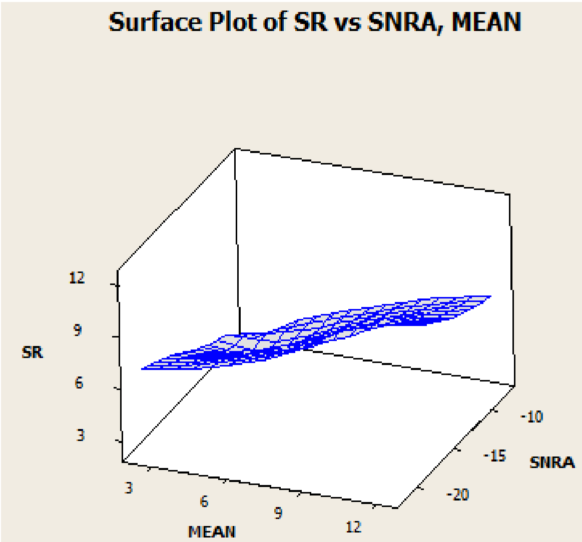

Fig. 6 (b) - 3D surface plot for Surface Roughness (SR)

3D surface graphs for the responses are shown in fig. 6(a) and 6(b). The figs. show the effects of Signal to Noise ratio (S/N) and Mean on Material Removal rate (MRR) and Surface roughness. It is clear that, for a particular S/N ratio Material removal rate (MRR) increases with decrease in Mean while SR decreases as Mean increases.

VI. CONCLUSION

Taguchi Method and Signal -to –Noise(S/N) ratio were applied in this work to improve the multi-response characteristics such as MRR (Material Removal Rate) and Surface Roughness of En-353 during EDM process. The conclusions of this work are summarized as follows:

- The optimal parameters combination MRR was determined as A3B3C3D3 i.e. Discharge current at 25A, pulse ON time at 87µs, pulse OFF time at 11µs and Di-electric fluid at 5l/g.
- The optimal parameters combination SR was determined as A2B1C3D3 i.e. Discharge current at 23A, pulse ON time at 10µs, pulse OFF time at 11µs and Di-electric fluid at 5l/g.
- This work demonstrates the method of using Taguchi methods for optimizing the EDM parameters for multiple response characteristics.

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VIII. REFRENCES

[1]. Ramakrishna, R. And Karunamoorthy, "Multi response optimization of wire EDM operations using robust design of experiments", International Journal of Advance Manufacturing Technology, 2006, 29, p. 105

[2]. Seung-Han Yang[a],J. Srinivas , Sekar Mohan, Dong-Mok Lee, Sree Balaji, "Optimization of electric discharge machining using simulated annealing**"** **,** Journal of Materials Processing Technology 209 (2009) 4471–4475 .

[3].T.M. Chenthil Jegan, M.Dev Anand,D.Ravindran, "Determination of EDM parameters in AISI202 Stainless steel using Grey relational analysis." Procedia Engineering 38 (2012) 4005-4012.

[4]. Jose Marafona, Catherine Wykes, "A new method of optimising material removal rate using EDM with copper–tungsten Electrodes", International Journal of Machine Tools & Manufacture 40 (2000) 153–164.

[5]. Ross P.J. Taguchi, "Techniques for quality Engineering ", USA: McGraw-Hill;1996.

[6]. Natarajan N,Arunachalam RM,"Optimization with micro EDM with multi performance characterstics using taguchi method and grey relational analysis.Journal of sci. Ind Research 2011;70:500-5.

[7]. Taguchi G, Introduction to quality engineering Tokyo, (Japan): Asian Productivity;1990.

[8]. Suresha B,Chandramohan G,Kishore,Sampath Kumaran P,Seetharamu S," Mechanical and three body abrasive wear behaviour of SiC filled glass-epoxy composites,Poly Compos 2008;29(9):1020-5.

[9]. Basavarajappa S, Chandramohan G,Paulo Davim J,"Application of taguchi techniques to study dry sliding wear behaviour of metal matrix composites.Mater Des 2007;28(4):1393-8.

[10]. Palani kumar K,Latha B, Senthi K VS,Davim JP,"Analysis of drilling of GRFP composites using grey relational analysis. Mater Manuf Process 2012;27(3):297-305.

[11]. Yang chao-Lieh. Optimizing the glass fiber cutting process using the taguchi methods and grey relational analysis,"New Journal glass ceram 2011;1:13-9.

[12]. R.K. Roy, Design of Experiments Using the Taguchi Approach; JohnWilley & Sons, Inc.: New York, 2001

[13]. Kadirgama, K., Noor. M.M., Zuki.N.M, Rahman, M.M., Rejab M.R.M, Daud, R., K. Abou-El-Hossein, A.,"Optimization of S urface Roughness inEnd Milling on Mould Aluminium Alloys (AA6061-T6) Using Response Surface Method and Radian Basis Function Network", Jordan Journal ofMechanical and Industrial Engineering, Vol 2, 2008.

[14] A. Bensely, S. Stephen Jayakumar, D. Mohan Lal, G. Nagarajan , and A. Rajadurai, "Failure investigation of crown wheel and pinion", Engineering Failure Analysis, 13, 2006, 1285–1292.

[15] H. Khorsand, S.M. Habibi, h.Yoozbashizadea, K. Janghorbon, S.M.S. Reihani, H. Rahmani Seraji, and M.ashtari "The role of heat treatment on wear behavior of powder metallurgy low alloy steels", Material and Design, 23, 2002, 667-670.

[16]. Fischer, U., Heinzle, M., Näher, F., Paetzold, H., Gomeringer, R., Kilgus, R., Oesterle, S.,Stephan, A. (2008). Tabellenbuch Metall. Verlag Europa-Lehrmittel, Nourney, Vollmer GmbH & Co. KG, Haan-Gruiten.

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