ISSN 2321-807X
Volume 12 Number24
Journal of Advances in chemistry

IMPROVING THE PERFORMANCES OF ELECTRO-DISCHARGE DRILLING PROCESS PARAMETERS

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ABSTRACT

The variation in a machining process is reduced by Taguchi method through robust design of experiments. The primary objective of this method is to produce the parts with high quality at lower cost. Taguchi method is commonly used for optimizing the process parameters of a single objective problem but it results the non-optimum values for remaining. So that multi-characteristics response optimization will be the solution for optimizing the multi-responses. In the present work, multi objective optimization model based on Taguchi which is used to optimize process parameters, such as Pulse on, Pulse off and Peak Current on multiple performance characteristics, namely, Material Removal Rate (MRR), Tool Wear Rate (TWR) and Surface Roughness (Ra) during Electrical Discharge Drilling (EDD) of Inconel 718 using Copper tool. Design of experiments is a Taguchi approach which involves using orthogonal arrays to arrange the parameters which affect the process and the levels at which they should be varied. In this present work Taguchi's L9 orthogonal array (OA) is selected for experimental planning and the experimental results showed that combination of higher levels of Pulse on, Pulse off and Peak Current are essential to achieve real-time maximization of MRR and minimization of TWR and SR and the results are analyzed by ANOVA.

Key words

Electrical-discharge machining, Electrical Discharge Drilling, Material Removal Rate, Tool Wear and Surface Roughness.

I INTRODUCTION

During Electrical Discharge Drilling on super alloys, surface finish quality, tool wear rate and material removal rate (MRR) are important and high MRR with low tool wear and better surface finish are always needed. Hence the optimization of the process parameters in a systematic way is needed to achieve the output characteristics or responses by using experimental methods and statistical models. Dr. Taguchi's design of experiments (DOE) is one of the most important and effective tools of Total Quality Management (TQM) for designing high quality systems at lower cost. Taguchi emphasizes on the fact that Quality provides robustness and resistant to the uncontrollable factors in the manufacturing filed. The aim objective of the robust design is to find the process parameter settings which are controllable with minimal effect of noise and variation on the product or process functional characteristics. When the number of process parameters increases this approach uses to reduce the experimental trial numbers. Most of the works have been focused on single response performance characteristic optimization but the Taguchi approach is mostly suitable for optimizing the single response problems but not for multi-response problems. Some of the researchers has been efficiently developed the Taguchi method for multi-response optimization for various machining processes. In the present work, a multi response optimization model based on Taguchi method to find out the best combination of the machining parameters such as Pulse on, Pulse off and Peak Current to attain the maximum MRR, minimum Tool Wear Rate and better Surface Roughness.

II WORKING PRINCIPLE OF EDM

In this thermo electrical process the metal is removed from the work piece due to erosion of the spark discharged between the tool and work piece. Fig.1 shows the mechanical and electrical set up and electrical circuit for electro discharge machining. The tool is connected with negative terminal and work piece is connected with positive terminal of the generator. A constant gap is maintained between the work piece and tool by a servo system. Both the work piece and tool are submerged in a dielectric fluid. Generally Kerosene, EDM oil, deionized water are used as liquid dielectric even if gaseous dielectrics are also used in some cases. When the voltage across the gap is high the tools emits the electrons as it is connected in negative terminal. The positive ions and electrons get accelerated and travels to the anode through dielectric medium. As there is no free path in dielectric medium, the electrons collide with dielectric molecules and ionization takes place. It results in generation of a plasma channel and magnetic field and produces more numbers of sparks. This spark is used to melt and vaporize the metal and the temperature leads to material removal. The molten material is removed by the pressurized circulation of dielectric medium.

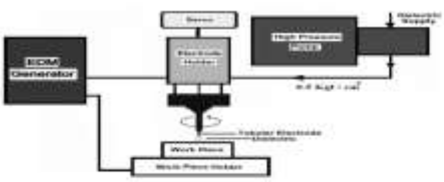

Fig. 1: Working of EDM

III LITERATURE SURVEY

Literature survey is one of the scope studies. It is used as guide to carry out this work. From the initial stage of work, the literature survey has been carried out through various Research Journals, books, printed or online conference articles. It gives the information about electrical discharge machine (EDM) and an idea to run the tests.

Kuppan [1] worked on the Inconel 718 by making deep hole drilling with EDM. The parameters peak current, pulse-on-time, duty factor and electrode speed were chosen to study behavior. The output responses were metal removal rate, depth of average surface roughness. The experiments were conducted using central composite design. The results revealed that metal removal rate is influenced by peak current, duty factor and electrode rotation, and MRR is increased with increase of peak current, duty factor and electrode speed, and concluded as depth of average surface roughness is increased with increase in peak current, electrode speed and pulse on time. Bozdana [2] presented a comparative experimental study on machining and surface characteristics of through and blind holes produced on aerospace alloys of Ti-6Al-4V and Inconel 718 by fast hole rotary EDM process using tubular hollow copper and brass electrodes. It was revealed that the achievement of desirable MRR and EW values and acceptable topography of machined surfaces were dependent upon the appropriate selection of tool electrode material and the choice of making through/blind hole. The brass electrode has provided a superior MRR for the production of through and blind holes on IN 718 and Ti 64 test pieces as compared with copper electrode. O. Yilmaz [3] performed an intelligent and automated approach for EDM hole drilling of super alloys. To accomplish the work, tests have been performed via drilling of micro and macro-scale holes on Inconel 718 and Ti-6Al-4V alloys. The experimental data was refined and analyzed using ANOVA to obtain parameter's relations and mathematical modeling for optimization. ANFIS has been adopted to associate the EDM hole drilling parameters like material removal rate, pulse current, pulse duration, surface roughness, capacitance, electrode wear for fulfilling reliable, cost, time effective and efficient hole making operations. Yilmaz [4] presented a comparative experimental investigation of fast hole drilling EDM on Inconel 718 and Ti-6Al-4V by using single and multi-channel tubular electrodes made of brass and copper materials. The experimental results revealed that the single-channel electrode provides higher material removal rates and lower electrode wear ratio and multi-channel electrodes produce better surface finish than single channel electrodes for these aerospace alloys. During the drilling operations, micro-structure was analyzed for both types of electrodes and the effects of annealing on Inconel 718 and a tempering on Ti-6Al-4V alloy and concluded that the multi-channel electrodes produce comparatively lower hardness values. Mihai Simon [5] studied for obtaining of an experimental rapid drilling machine, through EDM process for small holes. The parameters such as peak current, duty factor, pulse frequency and rotational speed of electrode were studied for obtaining the best machining characteristics. An electrolytic copper rod was selected as a tool electrode for getting maximum material removal rate with better surface roughness value. Dr. S. V. Deshmukh [6] conducted an experimental investigation for finding the effect of EDM drilling of holes on Inconel 718 using brass electrode. Response surface methodology was used for the better results in Material removal rate and electrode wear rate were investigated from the input process parameters like discharge current, pulse on and off times and capacitance. D. Sudhakara [7] performed an experimental investigation for EDM machining of Inconel-718. A rectangular copper block was used as a tool electrode. The output responses were measured and the results are revealed that how material removal rate, surface roughness and hardness are influenced by peak current, duty factor and pulse-on time. S. Rajesha [8] investigated an EDM process on Inconel 718 with hollow tubular copper electrode to machine the small holes. The mathematical models have been developed for MRR and SR using analysis of variance for the input parameters of pulse current, duty factor, sensitivity control, gap control and flushing pressure on material removal rate and surface quality and also tool wear and tool geometry have been presented by scanning electron microscope micrographs. S. Dhanabalan [9] carried out optimization of EDM machining parameters while machining of Inconel 718. A Grey relational coefficient is used to analyze the multiple responses like MRR, TWR, form and orientation tolerances through the levels of Peak current, Pulse on, Pulse off by using hexagonal and square profile copper electrodes.

Lot of research is going on various materials for machining metals, alloys, composites, super alloys for high MRR, good surface Finish. But in case of Inconel 718 very less research is done. And Inconel-718 is a High Strength and high temperature Resistant (HSTR) Nickel alloy. It is generally used in aerospace applications such as gas turbines, spacecrafts, pumps and tooling. Inconel-718 is difficult to machine, because of its high hardness, high toughness, poor thermal characteristics. Because of this wide area of applications in various fields, it is better to know the behavioral properties of Inconel-718 with EDM.

IV EXPERIMENTAL SETUP

The performance and cost-effective manufacturing is difficult to present researchers. Electrical discharge drilling (EDD) process is one of the processes and is shown in Fig. 2. The Sparknoix electro-discharge drilling process has been done for the present experimental work. The EDD set up is used for, continuous accurate drilling and high energy spark is generated. Drilling head is attached with servo system of negative terminal and Inconel 718 is selected as work material and is connected with positive terminal. Copper is used as a tool material and kerosene is used as a dielectric medium with a pressure of 0.5 kg/cm2 and side flushing was used to perform all the experiments.

Fig 2: Experimental Setup

V DESIGN OF EXPERIMENT APPROACH

Experimental design is a statistical technique which enables the researchers to conduct, analyze data and conclude the results from the experiment. The aim of this research is to identify the optimum settings for the different factors that affect the manufacturing process and also to obtain maximum information from minimum amount of resources being employed.

The design of an experiment involves the following steps:-

5.1 Identification of main function, side effects and failure mode

To optimize the EDM process the performance characteristics are identified as (i) Material Removal Rate (MRR) (ii) Tool Wear Rate (TWR) and (iii) Surface Roughness (SR). Control factors are selected so that there will not be any failure during experimentation leading to aborting an experiment.

5.2 Identification of noise factors, testing conditions and quality characteristics

The spark time is maintained as constant for all trials with random noise factor. Four work pieces are made for each experiment under random noise condition and the quality characteristics are chosen as (i) MRR (ii) TWR and (iii) SR.

5.3 Identification of objective function to be optimized

Taguchi recommends that the response values at each internal array design point be summarized by a performance criterion called a signal to noise ratio. S/N ratio is expressed in decibels (dB). Theoretically, the S/N ratio (η) is the ratio of signal to noise in terms of power. The method of calculating the S/N ratio depends on whether the quality characteristics are smaller the better, larger the better or nominal is the best. The S/N ratio for this type of response was used and given below:

MRR --- Higher is better,

$$S/N = - 10 \log [1/n \sum_{i=1}^{n} 1/yi^2] \qquad (1)$$

TWR and SR ---- Lower is better,

$$S/N = - 10 \log [1/n \sum_{i=1}^{n} yi^2] \qquad (2)$$

Where; n is the number of experiments in the orthogonal array and $y_i$is the i^{th} measured value.

5.4 Identification of control factors and levels

Pulse on, Pulse off and Peak Current are identified and selected as control factors which are shown in table 1. After determining the control factors, the levels of each factor should be determined. As a result, each of the control factors was evaluated with three levels.

Table 1. Control Factors and Levels

CONTROL FACTORS	LEVELS		
	1	2	3
A. PEAK CURRENT (Amps)	4	8	12
B. PULSE ON TME (µSec.)	200	400	600
C. PULSE OFF TME (µSec.)	20	40	60

5.5 Degrees of Freedom

Degrees of freedom is defined as the number of evaluations between process parameters that is needed to determine which level is better and specifically how much better it is.

Degrees of freedom = 1 for mean

DF for each Control Factor A, B, C etc. = (no. of levels–1) = 2 each for 3 factors = 1+6 = 7

Orthogonal arrays with 3 - level factors:

No. of factors 2-4 5-7 8-13

Orthogonal Array L9 L18 L27

Degrees of freedom for the current problem are

- DF for μ = number of rows of OA = 9 (OA is L9)
- DF for μ or m = 1 (always 1 for the overall mean)
- DF for each Control Factor A, B, C etc. = (no. of levels–1) = (3 -1) = 2
- DF for 3 Control Factors = 3 * 2 = 6
- This leaves DF for error = (no. of rows) – (1) – (no. of CF)*(No. of CF Levels-1)

= 9 – 1 – (3 * 2) = 2

5.6 Selection of orthogonal array

The selection of suitable orthogonal array (OA) depends on the total degrees of freedom of process parameters. In this work, since each parameter has three levels therefore, the total degrees of freedom (DOF) are equal to 7. The number of trials should be equal or greater than the degrees of freedom. The standard L9 orthogonal array has four 3 level columns with 7 DOF. Therefore, an L9 orthogonal array with four columns and nine rows was derived and used in this experimental work which is shown in Table II. The experimental layout for the EDM Drilling parameters using the L9 OA is shown in Table 2. Each row of this table stands for an experiment with different set of parameters and their levels. For deriving the orthogonal array and optimized results we are using MINITAB 17 software.

Table 2. L9 orthogonal array

SL. NO	PEAK CURRENT (Amps)	PULSE ON TME (μsec.)	PULSE OFF TME (μsec.)
1	4	200	20
2	4	400	40
3	4	600	60
4	8	200	40
5	8	400	60
6	8	600	20
7	12	200	60
8	12	400	20
9	12	600	40

5.7 Conducting the experiments

Here three parameters are considered: A, B, and C and each at three levels. This is called an "L9" design, the 9 represents the nine rows, experiments to be tested. Thus, L9 means that nine experiments have to be carried out for the parameters. The column numbers of an array represents the maximum number three variables at three levels of that can be done using the L9 array.

5.7.1 Data for Quality Characteristics

The data quality characteristics of EDM performance measures through the process parameters are shown in Table 3, 4 and 5

Table 3.Data for Quality Characteristics of MRR

Sl. No	Peak Current	To n	Toff	MATERIAL REMOVAL VALUES		
				MRR1 (g/min)	MRR2 (g/min)	MRR3 (g/min)
1	4	200	20	50	48	61
2	4	400	40	71	65	74

3	4	600	60	116	107	122
4	8	200	40	150	154	143
5	8	400	60	176	174	168
6	8	600	20	252	249	258
7	12	200	60	284	280	293
8	12	400	20	360	354	354
9	12	600	40	323	327	298

Table 4.Data for Quality Characteristics of TWR

Sl. No.	Peak Current	T on	T off	TOOL WEAR VALUES		
				TWR1 (g/min)	TWR2 (g/min)	TWR3 (g/min)
1	4	200	20	0.010	0.022	0.018
2	4	400	40	0.013	0.022	0.017
3	4	600	60	0.020	0.027	0.026
4	8	200	40	0.042	0.046	0.035
5	8	400	60	0.037	0.035	0.029
6	8	600	20	0.041	0.038	0.047
7	12	200	60	0.045	0.041	0.054
8	12	400	20	0.055	0.049	0.051
9	12	600	40	0.064	0.068	0.071

Table 5.Data for Quality Characteristics of SR

Sl. No.	Peak Current	T on	T off	SURFACE ROUGHNESS VALUES		
				Ra1 (µm)	Ra 2 (µm)	Ra 3 (µm)
1	4	200	20	0.023	0.020	0.026
2	4	400	40	0.060	0.055	0.065
3	4	600	60	2.980	2.973	2.987
4	8	200	40	0.843	0.834	0.852
5	8	400	60	1.543	1.532	1.554
6	8	600	20	0.057	0.055	0.059
7	12	200	60	0.077	0.073	0.081
8	12	400	20	0.777	0.771	0.783
9	12	600	40	1.937	1.929	1.945

5.7.2 Calculating S/N Ratio

Calc 1: Find the sum of squares of reciprocals of all measured values

SSQ = Y1^-2 + Y2^-2 + Y3^-2 + Y4^-2

Calc 2: Find the 'mean sum of squares of reciprocals'

MSSQ = (SSQ) / (number of measurements)

Calc 3: Take 10 Log10 of MSSQ to get S/N Ratio

$$\eta = -10 * \text{Log10 of (MSSQ)}$$

$$\eta = -10 \text{ Log10 } [1/n \sum (1/Y12+1/Y22+\ldots+1/Yn2] \qquad (3)$$

The Signal to Noise ratio values are tabulated below,

Table 6. S/N ratio values for MRR (“LARGER-THE-BETTER”)

Sl. No.	MRR1 (g/min)	MRR2 (g/min)	MRR3 (g/min)	SNRA for LARGER is BETTER
1	50	48	61	34.35
2	71	65	74	36.86
3	116	107	122	41.18
4	150	154	143	43.45
5	176	174	168	44.74
6	252	249	258	48.06
7	284	280	293	49.11
8	360	354	354	51.03
9	323	327	298	49.97

Table 7. S/N ratio values for TWR (“SMALLER-THE-BETTER”)

Sl. No.	TWR1 (g/min)	TWR2 (g/min)	TWR3 (g/min)	SNRA for SMALLER is BETTER
1	0.01	0.022	0.018	35.19
2	0.013	0.022	0.017	35.03
3	0.02	0.027	0.026	32.21
4	0.042	0.046	0.035	27.69
5	0.037	0.035	0.029	29.41
6	0.041	0.038	0.047	27.50
7	0.045	0.041	0.054	26.56
8	0.055	0.049	0.051	25.73
9	0.064	0.068	0.071	23.38

Table 8. S/N ratio values for SR (“SMALLER-THE-BETTER”)

Sl. No.	Ra 1 (μm)	Ra 2 (μm)	Ra 3 (μm)	SNRA for SMALLER is BETTER
1	0.023	0.020	0.026	32.59
2	0.060	0.055	0.065	24.42
3	2.980	2.973	2.987	-9.48
4	0.843	0.834	0.852	1.48
5	1.543	1.532	1.554	-3.77
6	0.057	0.055	0.059	24.93
7	0.077	0.073	0.081	22.30

8	0.777	0.771	0.783	2.20
9	1.937	1.929	1.945	-5.74

Table 9. Experiment log with S/N ratios for MRR, TWR and SR

Sl. No.	Peak Current	T on	T off	S/N RATIO		
				MRR	TWR	SR
1	4	200	20	34.35	32.59	35.19
2	4	400	40	36.86	24.42	35.03
3	4	600	60	41.18	-9.48	32.21
4	8	200	40	43.45	1.48	27.69
5	8	400	60	44.74	-3.77	29.41
6	8	600	20	48.06	24.93	27.50
7	12	200	60	49.11	22.30	26.56
8	12	400	20	51.03	2.20	25.73
9	12	600	40	49.97	-5.74	23.38

5.8 Analyzing the data to predict the optimum levels and performance

Effect of a Factor Level is defined as "The deviation it causes from overall mean, m"

Table 10. Factor effects for MRR

EXP. NO.	A	B	C	S/N RATIO η	
	1	2	3		
1	A1	B1	C1	**η1**	34.35
2	A1	B2	C2	**η2**	36.86
3	A1	B3	C3	**η3**	41.18
4	A2	B1	C2	**η4**	43.45
5	A2	B2	C3	**η5**	44.74
6	A2	B3	C1	**η6**	48.06
7	A3	B1	C3	**η7**	49.11
8	A3	B2	C1	**η8**	51.03
9	A3	B3	C2	**η9**	49.97

Factor effect of A, Peak Current, Level 1, 2 and 3:

A1 occurs in experiments 1, 2, 3, A2 in 4, 5, 6 and A3 in 7, 8 and 9

mA1 = 1/3 * (η1 + η2 + η3) = 1/3 * (34.35 + 36.86 + 41.18) = **37.46**

mA2 = 1/3 * (η**4**+ η5 + η6) = 1/3 * (45.57 + 47.45 + 49.82) = **45.42**

mA3 = 1/3 * (η7 + η8 + η9) = 1/3 * (45.80 + 45.10 + 50.13) = **50.04**

Factor effect of A3, 'A3' = mA3 - m and so on

Factor effect of B, Pulse on Time, Level 1, 2 and 3:

mB1 = 1/3 * (η1 + η4 + η**7**) = 1/3 * (34.35+43.45+49.11) = **42.30**

mB2 = 1/3 * (η**2** + η**5** + η**8**) = 1/3 * (36.86+44.74+51.03) = **44.21**

MB3 = 1/3 * (η3 + **η6** + η9) = 1/3 * (41.18+48.06+49.97) = **46.40**

Factor effect of C, Pulse off Time, Level 1, 2 and 3:

mC1 = 1/3 * (η1 + η6 + **η8**) = 1/3 * (34.35+48.05+51.03) = **44.48**

mC2 = 1/3 * (**η2** + **η4** + **η9**) = 1/3 * (36.86+43.45+49.97) = **43.43**

MC3 = 1/3 * (η3 + **η5** + η7) = 1/3 * (41.18+44.74+49.11) = **45.01**

Overall Mean, m = 1/9 **(η1+η2+η3η+η4+…..+η9)** = **44.31**

Response Table for Signal to Noise Ratios Larger is better

Level	PEAK CURRENT (Amps)	PULSE ON TME (µSec.)	PULSE OFF TME (µSec.)
1	37.46	42.30	44.48
2	45.42	44.21	43.43
3	50.04	46.40	45.01
Delta	12.58	4.10	1.58
Rank	**1**	**2**	**3**

Similarly,

Table 11. Factor effects for TWR

EXP. NO.	A	B	C	S/N RATIO η	
	1	2	3		
1	A1	B1	C1	**η1**	32.59
2	A1	B2	C2	**η2**	24.42
3	A1	B3	C3	**η3**	-9.48
4	A2	B1	C2	**η4**	1.48
5	A2	B2	C3	**η5**	-3.77
6	A2	B3	C1	**η6**	24.93
7	A3	B1	C3	**η7**	22.30
8	A3	B2	C1	**η8**	2.20
9	A3	B3	C2	**η9**	-5.74

Taguchi Analysis: TWR 1 (g/mi, TWR 2 (g/min, versus PEAK CURRENT, PULSE ON TME,

Response Table for Signal to Noise Ratios

Smaller is better

Level	PEAK CURRENT (Amps)	PULSE ON TME (µSec.)	PULSE OFF TME (µSec.)
1	34.14	29.81	29.47
2	28.20	30.06	28.70
3	25.22	27.70	29.39
Delta	8.92	2.36	0.77
Rank	**1**	**2**	**3**

mA1 = 34.14

mA2 = 28.20

mA1 = 25.22

mB1 = 29.81

mB2 = 30.06

mB3 = 27.70

mC1 = 29.47

mC2 = 28.70

mC3 = 29.39

Overall Mean, m = 1/9 (η1+η2+η3η+η4+…..+η9) = **29.18**

Table 12. Factor Effects for SR

EXP. NO.	A	B	C	S/N RATIO η	
	1	2	3		
1	A1	B1	C1	**η1**	35.19
2	A1	B2	C2	**η2**	35.03
3	A1	B3	C3	**η3**	32.21
4	A2	B1	C2	**η4**	27.69
5	A2	B2	C3	**η5**	29.41
6	A2	B3	C1	**η6**	27.50
7	A3	B1	C3	**η7**	26.56
8	A3	B2	C1	**η8**	25.73
9	A3	B3	C2	**η9**	23.38

Taguchi Analysis: Ra1, Ra2, Ra3 versus PEAK CURRENT (Am, PULSE ON TME (μs, PULSE OFF TME (μs)

Response Table for Signal to Noise Ratios

Smaller is better

Level	**PEAK CURRENT** (Amps)	**PULSE ON TME** (μSec.)	**PULSE OFF TME** (μSec.)
1	15.883	18.821	19.929
2	7.532	7.614	6.719
3	6.237	3.217	3.004
Delta	9.646	15.603	16.925
Rank	**3**	**2**	**1**

mA1 = 15.83

mA2 = 7.53

mA3 = 6.24

mB1 = 18.8

mB2 = 7.61

mB3 = 3.22

mC1 = 19.93

mC2 = 6.72

mC3 = 3.00

Overall Mean, m = 1/9 (η1+η2+η3η+η4+…..+η9) = **9.0**

5.8.1 Plots of factor effects

The main effect plots for S/N ratios are shown below,

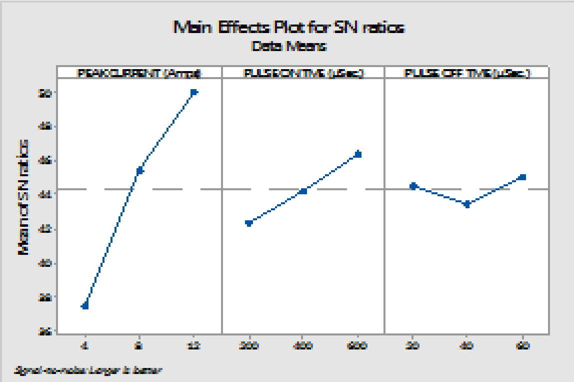

Fig 3: Main effects Plot for S/N Larger is better

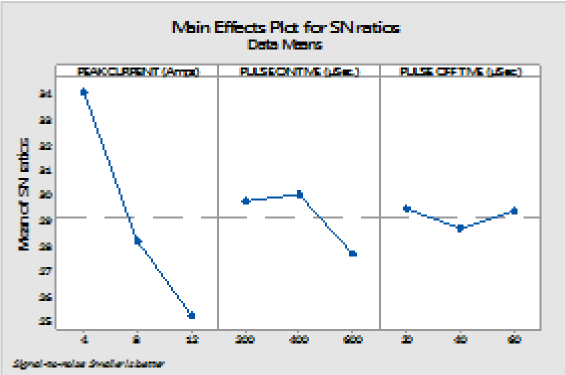

Fig 4: Main effects Plot for S/N Smaller is better

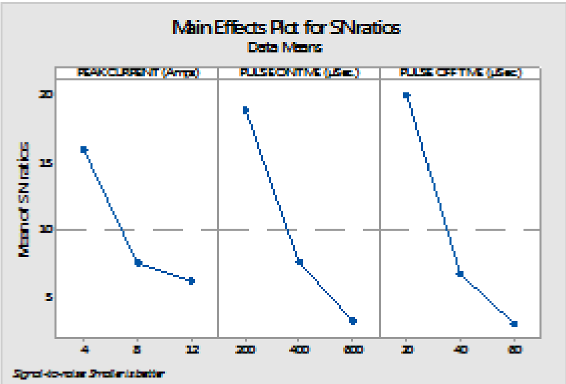

Fig 5: Main effects Plot for S/N Smaller is better

5.9 Performing the verification experiment

The final step of the design of experiment is verification. The purpose of verification is to confirm that the optimal conditions recommended by the matrix experiment do in reality give the improvement projected. The verification experiment is done by conducting a test with optimal settings of the factors and levels previously evaluated. The predicted value of the multiple Signal to Noise ratio is calculated by formula at the optimum level (η0).

$$\eta = \eta_m + \sum_{i=1}^{j} (\eta_i - \eta_m) \qquad (4)$$

For all experimental runs 'j' is the number of factors, η_m the mean value of multiple S/N ratios and η_i are the multiple S/N ratios consequent to optimum factor levels.

VI RESULTS AND DISCUSION

1). For obtaining **Higher Material Removal Rate**, the S/N ratio calculated for the optimum level is as follows:

The Optimized parameter settings for MRR are **A3B3C3**,

$$\eta_0 = \eta_m + (\eta A3 - \eta_m) + (\eta B3 - \eta_m) + (\eta C3 - \eta_m) \qquad (5)$$

where, η_0 is the optimum S/N ratio, η_m the overall mean of S/N values, ηA3 the average value of S/N at the third level of Peak Current, ηB3 the average value of S/N at the third level of the Pulse On Time and ηC3 is the average value of S/N at the third level of Pulse Off Time. Substituting the values of various terms in equation,

$$\boldsymbol{\eta_0 = 44.31 + (50.04 - 44.31) + (46.40 - 44.31) + (45.01 - 44.31) = 52.8}$$

2). For obtaining **Lower Tool Wear**, the S/N ratio calculated for the optimum level is as follows:

The Optimized parameter settings for TWR are **A3B3C2**,

$$\eta_0 = \eta_m + (\eta A3 - \eta_m) + (\eta B3 - \eta_m) + (\eta C3 - \eta_m) \qquad (6)$$

$$\boldsymbol{\eta_0 = 29.18 + (25.22 - 29.18) + (27.7 - 29.18) + (28.7 - 29.18) = 35.1}$$

where, η_0 is the optimum S/N ratio, η_m the overall mean of S/N values, ηA3 the average value of S/N at the third level of Peak Current, ηB3 the average value of S/N at the third level of the Pulse On Time and ηC3 is the average value of S/N at the Second level of Pulse Off Time. Substituting the values of various terms in equation,

3). For obtaining **Lower Surface Roughness**, the S/N ratio calculated for the optimum level is as follows:

The Optimized parameter settings for SR are **A3B3C3**,

$$\eta_0 = \eta_m + (\eta A3 - \eta_m) + (\eta B3 - \eta_m) + (\eta C3 - \eta_m) \qquad (7)$$

$$\boldsymbol{\eta_0 = 9 + (6.24 - 9) + (3.22 - 9) + (3.0 - 9) = 23.54}$$

where, η_0 is the optimum S/N ratio, η_m the overall mean of S/N values, ηA3 the average value of S/N at the third level of Peak Current, ηB3 the average value of S/N at the third level of the Pulse On Time and ηC3 is the average value of S/N at the third level of Pulse Off Time. Substituting the values of various terms in equation,

If the S/N is known and we want to learn about the result expected that will make the S/N, the procedure is to back-transform S/N to find the performance value expected.When the value 52.8 dB is placed into formula (1), the value obtained is 354 kPa. Values of the MRR, TWR and SR can be derived using the same formula. This result is very close to that estimated by Taguchi design.

Table 13. Optimized parameters

Design		**Parameters Values**			**Average**	**S/N, dB**
MRR	A3B3C3	355	349	358	354	52.8
TW	A3B3C2	0.012	0.018	0.02	0.02	36.5
SR	A3B3C3	1.85	1.95	1.92	1.91	38.2

The initial parameter design is accepted as A1B1C1, then the S/N ratio is attained according to the initial and optimum design and how much advantage is gained using the Taguchi design.

Table 14. Verification of results

Design	**Parameters**	**Prediction**			**Verification**		
		S/N			**S/N**		
		MRR	**TWR**	**SR**	**MRR**	**TWR**	**SR**

Initial Design	**A1B1C1**	34.35	35.59	35.2	33.57	37.3	38.5
Optimum Design	**A3B3C3**	52.8	36.5	38.2	56.71	38.4	39.7
Gain		**65%**	**97%**	**92%**	**59%**	**97%**	**97%**

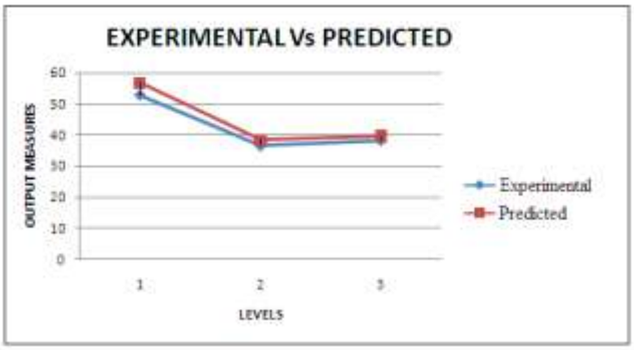

Fig 6: Comparative Results

VII CONCLUSIONS

1) In this work, we intended to create a process for optimizing the parameters in EDM process using Taguchi design to maximize the Material Removal Rate, Tool Wear and Surface Roughness. We can conclude from this project work that by using the Taguchi design to maximize the MRR, TW and SR, we can determine the optimal variables based on the S/N ratio and ANOVA analyses. They are: Moreover, the S/N ratio has been considerably improved as compared to the initial parameter settings of the experiment.
2) The results of predictions based on S/N ratios calculations and experimental values show that the Taguchi's experimental design technique is used successfully for both optimization and prediction. The probability plots of the residuals are shown in **Figure 6.** The scrutiny of the plots in the figure revealed that the residuals generally drop in a straight line, concerning that the errors are distributed normally.
3) As a result, the basic principle of the Taguchi method is to get better the quality of a product by minimizing the effect of the variations without eliminating them. In this methodology, the design is confirmed by selecting the best performance under conditions that produce a reliable performance.
4) The Taguchi approach gives simple, systematic and efficient methodology for the optimization of near optimum design parameters.

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