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Optimization of Machining Parametric Study on Electrical Discharge Machining

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***Abstract*—**Productivity and quality are two important aspects that have become great concerns in today's competitive global market. Every production/manufacturing unit mainly focuses on these areas in relation to the process, as well as the product developed. The electrical discharge machining (EDM) process, even now it is an experience process, wherein the selected parameters are still often far from the maximum, and at the same time selecting optimization parameters is costly and time consuming. Material Removal Rate (MRR) during the process has been considered as a productivity estimate with the aim to maximize it, with an intention of minimizing surface roughness taken as most important output parameter. These two opposites in nature requirements have been simultaneously satisfied by selecting an optimal process environment (optimal parameter setting). Objective function is obtained by Regression Analysis and Analysis of Variance. Then objective function is optimized using Genetic Algorithm technique. The model is shown to be effective; MRR and Surface Roughness improved using optimized machining parameters.

***Keywords*—**Material removal rate, TWR, OC, DOE, ANOVA, MINITAB.

I. INTRODUCTION

NON-TRADITIONAL machining has been improved out of the need to machine these material. The machining processes are non-conventional in the sense that they do not employ traditional tools for metal removal, but they directly use other forms of energy. The problems of high complexity in size, shape and higher demand for product accuracy and surface finish can be solved through non-traditional methods. EDM has been replacing grinding, milling, drilling and other traditional machining.

EDM has also made its presence felt in new fields such as medical, sports and surgical, optical, instruments, including automotive R&D areas. Since EDM was developed, much theoretical and experimental work has been done to identify the basic processes involved. It is now one of the main methods used in die production and has good accuracy and precision with no direct physical contact between the electrodes so that no mechanical stress is exerted on the work piece. The important output parameters of the process are the MRR, tool wear ratio (TWR) and surface roughness (roughness average). Optimization of the EDM process is concerned with maximizing MRR while minimizing TWR [1].

The EDM process optimization using tungsten–copper electrodes, and outlines a new two-stage processing method, which gives a significant improvement in overall performance. In the new two-stage method, a black layer modified surface is produced on the tool in the first stage which tool wear, thus giving better tool wear for a given material removal rate in the second stage [2]. During the EDM process, both the tool and work piece undergo surface modification. Many researchers have looked at modification of the work piece, but few have examined modification of the tool. The migration of elements from the work piece to the tool electrode occurs using both high and low current intensities. Some researchers, using tungsten-copper (80/20) electrodes and an IS-T215 Cr12 steel work piece, also showed that iron and chromium migrated from the work piece to the tool electrode. Some authors have claimed that most of the electrode wear is due to evaporation and fusion; however, they pointed out that the EDM material removal is caused by violent expulsion of the super heated electrode melts from the melt cavities at the end of the machine pulse.

Optimization is concerned with maximizing the material removal rate, minimizing 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. An adaptive control system that optimizes settings on line, for example, servo reference voltage, pulse duration, pulse interval and dielectric flow rate.

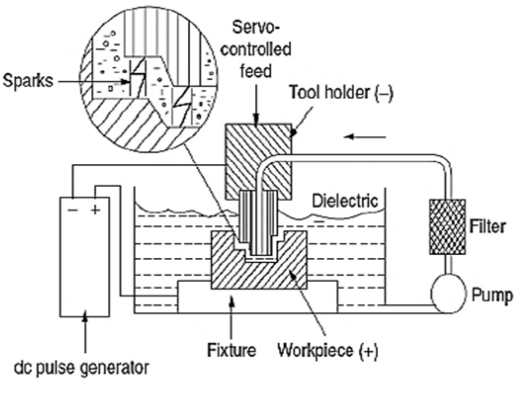

Fig. 1 Electric Discharge Machining Set up

II. EDM PRINCIPLE

Due to erosion caused by rapidly recurring spark discharge,

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which is taking place between the tool and work piece, metal is removed in this process. A thin gap of about 0.025mm is maintained between the work pieces and the tool by a servo system, as shown in Fig. 1. Both the work piece and tool are merged in a dielectric fluid like EDM oil/kerosene/de-ionized water. The work piece is anode and tool is cathode. In an interval of about 10 micro seconds voltage across the gap becomes sufficiently large to discharge a spark. Electrons and positive ions accelerate creating a discharge channel that becomes conductive. It is at this point when the spark causing collisions between the electrons and ions are creating a channel of plasma. Electrical resistance suddenly drops off and the previous channel allows that current density to reach very high values producing an increase of ionization and the creation of a powerful magnetic field. The moment the spark occurs sufficiently, the pressure developed between the tool and work piece, due to the high temperature, is reached and the metal is eroded at that high temperature and pressure.

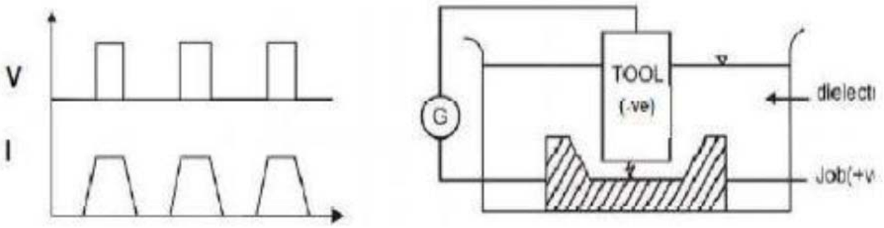

Fig. 2 Working Principle of EDM Process

Material removal occurs due to such extreme localized temperature, due to the instant vaporization of the material, as well as due to melting material removal that occurs. Molten metal is not completely removed but only partially.

The plasma channel is no longer sustained, as the potential difference is withdrawn, as shown in Fig. 2. It generates shock or pressure waves, which evacuates the molten material forming a crater of removed material all around the region of the spark, as the plasma channel collapses.

III. EDM PARAMETERS

A. Spark On-time (Pulse Time or T_{on})

Spark on-time is the duration of time (μs) that current is allowed to flow per cycle. MRR (Material Removal Rate) varies directly proportional to the amount of energy applied during this on-time. This energy is really controlled by the peak current and length of the on-time.

B. Spark Off Time (Pulse Time or T_{off})

This time allows the molten material to solidify and to be washed out of the arc gap. This parameter affects the speed and the stability of the cut. If the off-time is too short, it creates an unstable spark.

C. Arc Gap (or Gap)

It is the distance between the electrode and the work piece during the process of EDM. It may be called as the spark gap. The spark gap can be handled by the servo system.

D. Discharge Current (Current I_P)

The current is measured in ampere allowed per cycle. Discharge current directly proportional to the Material removal rate (MRR).

E. Duty Cycle (τ)

It is a percentage of the on-time relative to the total cycle time. This Parameter is measured by dividing the on-time by the total cycle time (on-time pulse off time).

$$\tau = \frac{T_{on}}{T_{on}+T_{off}} \qquad (1)$$

F. Voltage (V)

It is a potential that can be measured as volt, it is also effects the MMR and allowed per cycle. Voltage is given as 50 V in this experiment.

G. Diameter of Electrode (D)

There are two different sizes of 4mm and 6mm diameter in this experiment. This tool is used as an electrode and also for internal flushing.

H. Dielectric Fluid

In EDM, as has been discussed earlier, material removal occurs mainly due to melting and thermal evaporation. Thermal processing is required to be carried out in the absence of oxygen so that the process can be controlled and its oxidation is avoided. Frequently oxidation prompts poor surface conductivity (electrical) of the work piece further machining. Hence, dielectric fluid should provide an oxygen free machining environment and at the same time it should have enough strong dielectric resistance so that electrically it does not breakdown too easily, while at the same time ionize when electrons collide with its molecule. Moreover, it should be thermally resistant during sparking as well.

The metal removal rate, electrode wear rate and other operation characteristics are also influenced by the dielectric fluid. The general dielectric fluids used are transformer on silicon oil, kerosene (paraffin oil), EDM oil and de-ionized water are used as dielectric fluid in EDM. The dielectric medium is generally passed forcing around the spark zone and also applied through the tool to achieve efficient removal of molten material.

I. Flushing Method

Flushing is an important function in any electrical discharge machining operation. It is the process of introducing clean filtered dielectric fluid into the spark gap.

J. Tool Material

High electrical conductivity – electrons are cold emitted more easily and there is less bulk electrical heating. High thermal conductivity – for the same heat load, the local temperature rise would be less due to faster heat conducted to the bulk of the tool and thus less tool wear. Higher density – for the same heat load and same tool wear by weight, there would be less tool wear or volume removal and thus less dimensional loss or inaccuracy. High melting point – Since EDM is a thermal process, it would be logical to assume that the higher the melting point of the electrode material, the better the wear ratio will be between electrode and work piece material.

Different types of tool material are being used in the EDM method and the tool steel contains alloy and carbon steels that are particularly well-suited to be made into tools. The edge temperature under expected use is an important determinant of both the required heat treatment and composition. The higher carbon grades are typically used for such applications as stamping dies, metal cutting tools, etc.

In this experiment, we have used Ni-Cr-Co as a work piece material.

K. Work Piece Specification

TABLE I
WORKPIECE MATERIAL

Sr. No	Ni-Cr-Co Steel	Heat Analysis	Product Analysis
1	Ni	35.00-39.00	34.70-39.30
2	Co	18.00-22.00	17.75-22.25
3	Cr	16.00-22.00	15.75-20.25
4	Ti	2.50-3.00	2.43-3.07
5	Mo	2.50-3.50	2.40-3.60
6	B	0.001-0.01	0.001-0.012
7	Si	1.50(Max)	1.6
8	Mn	1.00(Max)	1.03
9	Al	0.25(Max)	0.3
10	C	0.08(Max)	0.09
11	P	0.030(Max)	0.035
12	S	0.030(Max)	0.035

IV. EXPERIMENTS

The experimental work which is consisting of L9 orthogonal array based on Taguchi design. The orthogonal array reduces the total number of experiments. In this experimental work total numbers of runs are 9. Experimental setup, selection of work piece and tool, experimental procedure and taking all the value and calculation of MRR are explained below.

Experiments were conducted by using the machining set up. The control parameters like Voltage (V), discharge current (Ip) and pulse duration (Ton) were varied to conduct 9 different experiments and the weights of the work piece before machining and after machining by using digital weighing machine were taken for calculation of MRR.

Fig. 3 The Experimental Setup

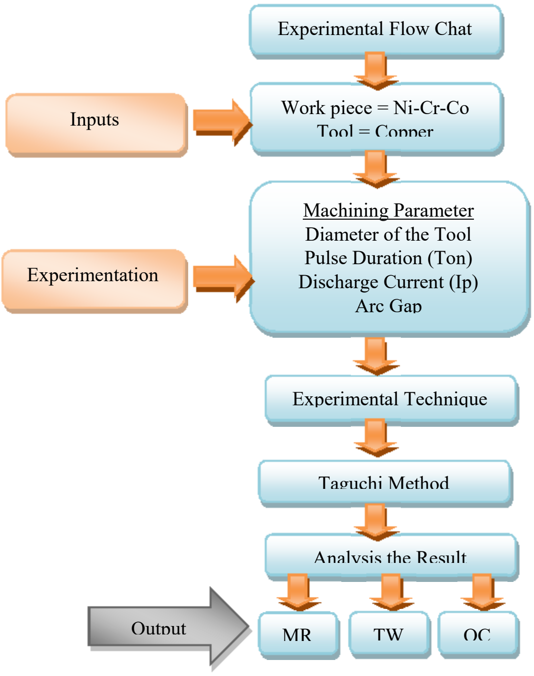

Fig. 4 Flow Chart of Experiment

V. TAGUCHI METHOD

The Taguchi methods are statistical methods developed by Genichi Taguchi to improve the quality of manufactured goods, and more recently is also applied to engineering, biotechnology, marketing and advertising. However, Taguchi realized methods of identifying those noise sources that have the greatest effects on product variability. His ideas have been adopted by successful manufacturers around the globe because of their results in creating superior production processes at much lower costs.

A. Quality of Taguchi Method

Quality has been defined by many as; "zero defects" or “customer satisfaction." Taguchi proposes a holistic view of quality which relates quality to cost, not just to the manufacturer at the time of production [11]. Taguchi defines quality as:

> "The quality of a product is the (minimum) loss imparted by the product to society from the time product is shipped” [8].

B. Taguchi's Approach to Parameter Design

Taguchi's approach to parameter design provides the design engineer with a systematic and efficient method for determining near optimum design parameters for performance and cost [9]. The objective is to select the best combination of control parameters so that the product or process is most robust with respect to noise factors.

The Taguchi method utilizes orthogonal arrays from design of experiments theory to study a large number of variables with a small number of experiments. Using orthogonal arrays significantly reduces the number of experimental configurations to be studied. Moreover, the conclusions drawn from small scale experiments are valid over the entire experimental region spanned by the control factors and their settings, orthogonal arrays are not unique to Taguchi [10]. In this array, the columns are mutually orthogonal. That is, for any pair of columns, all combinations of factor levels occur, and an equal number of times. Here there are four parameters A, B, C, and D, each at three levels. This is called an "L 9" design, with the 9 indicating the nine rows, configurations, or prototypes to be tested. Specific test characteristics for each experimental evaluation are identified in the associated row of the table. Thus, L 9 means that nine experiments are to be carried out to study four variables at three levels.

TABLE II
L9 (3^4) ORTHOGONAL ARRAY

Sr. No.	A	B	C	D
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

The number of columns of an array represents the maximum number of parameters that can be studied using that array. Note that this design reduces 81(3^4) configurations to nine experimental evaluations. There are greater savings in testing for the larger arrays. For example, using an L27 array, 13 parameters can be studied at three levels by running only 27 experiments instead of 1,594,323(3^{13}). The Taguchi method can reduce research and development costs by improving the efficiency of generating information needed to design systems that are insensitive to usage conditions, manufacturing variation, and deterioration of parts. As a result, development time can be shortened significantly, and important design parameters affecting operation, performance, and cost can be identified. Furthermore, thus manufacturing and operations costs can also be greatly reduced.

C. Design the Matrix Experiment and Define the Data Analysis

The next step is to design the matrix experiment and define the data analysis procedure. First, the appropriate orthogonal arrays for the noise and control parameters to fit a specific study are selected. Taguchi provides many standard orthogonal arrays and corresponding linear graphs for this purpose. A common approach is the use of Monte Carlo simulation [9]. However, for an accurate estimation of the mean and variance, Monte Carlo simulation requires a large number of testing conditions which can be expensive and time consuming. As an alternative, Taguchi proposes orthogonal array based simulation to evaluate the mean and the variance of a product's response resulting from variations in noise factors [9]. With this approach, orthogonal arrays are used to sample the domain of noise factors. The diversity of noise factors are studied by crossing the orthogonal array of control factors by an orthogonal array of noise factors [7].

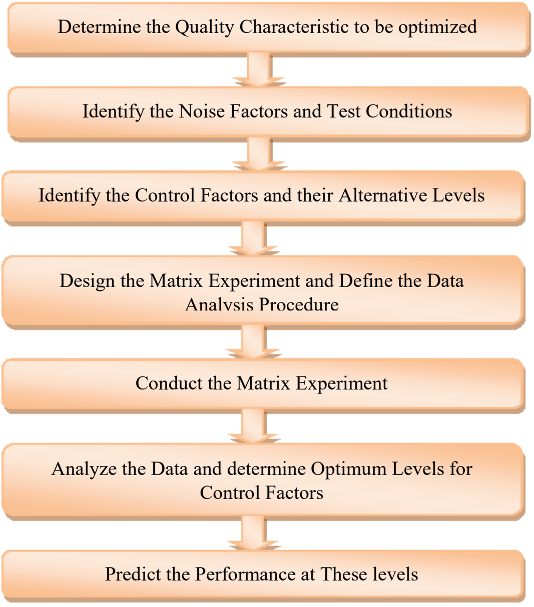

Fig. 5 Flow chart of Taguchi Method

TABLE III
CONTROL ORTHOGONAL ARRAY

Sr. No.	A	B	C	D
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

TABLE IV
NOISE ORTHOGONAL ARRAY

Sr. No.	1	2	3	4
N_1	1	1	2	2
N_2	1	2	1	2
N_3	1	2	2	1

D. Matrix Experiment

The next step is to conduct the matrix experiment and record the results. The Taguchi method can be used in any situation where there is a controllable process [11].

E. Analyze the Data and Determine the Optimum Levels

After the experiments have been conducted, the optimal test parameter configuration within the experiment design must be determined. To analyze the results, the Taguchi method uses a statistical measure of performance called the signal to noise (S/N) ratio borrowed from the electrical control theory [9]. The S/N ratio developed by Dr. Taguchi is a performance measure to choose control levels that best cope with noise [7]. The S/N ratio takes both the mean and the variability into account. In its simplest form, the S/N ratio is the ratio of the mean (signal) to the standard deviation (noise). The S/N equation depends on the criterion for the quality characteristic to be optimized. While there are many different possible S/N ratios, three of them are considered standard and are generally applicable in the situations below [5].

- Biggest-is-better quality characteristic (strength, yield);
- Smallest-is-better quality characteristic (contamination);
- Nominal-is-best quality characteristic (dimension).

$$\text{Nominal is Best:} \mathrm{SN_N} = 10\log\left(\frac{\mathrm{y}^{-2}}{\mathrm{s}^2}\right) \tag{2}$$

$$\text{Larger is better:} \mathrm{SN_L} = -10\log\left(\frac{\sum_{i=1}^{n} 1/\mathrm{y}_i^2}{\mathrm{n}}\right) \tag{3}$$

$$\text{Smaller is better: } \mathrm{SN_S} = -10\log\left(\frac{\sum_{i=1}^{n} \mathrm{y}_i^2}{\mathrm{n}}\right) \tag{4}$$

where y is the mean of observed data, s is the variance of y, n is the number of observations and y is the observed data.

VI. ANALYSIS OF VARIANCE (ANOVA) & MINITAB

A. Analysis of Variance (ANOVA)

ANOVA is a statistically based, objective decision-making tool for detecting any differences in the average performance of groups of items tested. ANOVA helps in formally testing the significance of all main factors and their interactions by comparing the mean square against an estimate of the experimental errors at specific confidence levels. First, the total sum of squared deviations SST from the total mean S/N ratio nm can be calculated as:

$$SS_T = \sum_{i=1}^{N}(n_i - m)^2 \tag{5}$$

where n is the number of experiments in the orthogonal array and m is the mean S/N ratio for the i^{th} experiment. The percentage contribution P can be calculated as:

$$\mathrm{P} = \frac{\mathrm{SS_d}}{\mathrm{SS_T}} \tag{6}$$

where $\mathrm{SS_d}$ is the sum of the squared deviations.

B. Minitab

MINITAB provides both static and dynamic response experiments in a static response experiment; the quality characteristic of interest has a fixed level. The goal of robust experimentation is to find an optimal combination of control factor settings that achieve robustness against (insensitivity to) noise factors [4]. MINITAB calculates response tables and generates the main effects and interaction plots for:

- Signal-to-noise ratios (S/N ratios) vs. the control factors.
- Means (static design) vs. the control factors.

DOE (design of experiments) helps to investigate the effects of the input variables (factors) on an output variable (response) at the same time. These experiments consist of a series of runs, or tests, in which purposeful changes are made to the input variables. Data are collected at each run. DOE is used to identify the process conditions and product components that affect quality, and then determine the factor settings that optimize results.

C. Taguchi Design Experiments in MINITAB

A Taguchi design is a designed experiment that lets you choose a product or process that functions more consistently in the operating environment. Taguchi designs recognize that not all factors that cause variability can be controlled. These uncontrollable factors are called noise factors. Taguchi designs try to identify controllable factors (control factors) that minimize the effect of the noise factors. During experimentation, you manipulate noise factors to force variability to occur and then determine optimal control factor settings that make the process or product robust, or resistant to variation from the noise factors. A process designed with this goal will produce more consistent output. A product designed with this goal will deliver more consistent performance regardless of the environment in which it is used.

Taguchi designs use orthogonal arrays, which estimate the effects of factors on the response mean and variation. An orthogonal array means the design is balanced so that factor levels are weighted equally. Because of this, each factor can be assessed independently of all the other factors, so the effect of one factor does not affect the estimation of a different factor. This can reduce the time and cost associated with the experiment when fractionated designs are used.

TABLE V
DESIGN MATRIX

Sr. No.	Machining Parameter	Symbol	Unit	Level		
				Level 1	Level 2	Level 3
1	Electrode C/S Area	A	mm^2	9.5	*9.5	*12.40
2	Spark on Time	Ton	µs	100	250	400
3	Discharge Current	Ip	A	10	20	30

In this study, a three factor mixed level setup is chosen with a total of 18 experiments to be conducted, and hence, the OA L_{18} was chosen [6]. This design would enable the two factor interactions to be evaluated. As a few more factors are to be added for further study with the same type of material, it was decided to utilize the L_{18} setup, which in turn would reduce the number of experiments at the later stage. In addition, a comparison of the results would be simpler [8]. The levels of experiment parameters electrode cross section area (A), spark on time (T_{on}), and discharge current (I_p), are shown in Table V and the design matrix is depicted in Table VI.

TABLE VI
OBSERVATION TABLE

Sr. No.	Area (mm^2)	Ip (A)	Ton (µs)	Wt of Work piece (gm) Wjb	Wt of Tool (gm) Djt	Wtb	Cavity C/S (mm) Wta
1	9.50*9.50	10	100	150.13	9.94*9.94	5.42	5.39
2	9.50*9.50	10	250	150.10	9.99*9.99	5.39	5.38
3	9.50*9.50	10	400	147.84	9.76*9.76	5.38	5.37
4	9.50*9.50	20	100	145.61	9.58*9.58	5.37	5.33
5	9.50*9.50	20	250	143.44	9.61*9.61	5.33	5.32
6	9.50*9.50	20	400	141.26	9.86*9.86	5.32	5.30
7	9.50*9.50	30	100	138.39	9.77*9.77	5.30	5.22
8	9.50*9.50	30	250	136.29	9.80*9.80	5.22	5.19
9	9.50*9.50	30	400	134.09	9.68*9.68	5.19	5.18
10	12.40*12.40	10	100	223.18	12.89*12.89	12.90	12.88
11	12.40*12.40	10	250	219.28	12.96*12.96	12.88	12.87
12	12.40*12.40	10	400	215.35	13.00*13.00	12.87	12.86
13	12.40*12.40	20	100	211.39	12.95*12.95	12.86	12.82
14	12.40*12.40	20	250	207.59	12.92*12.92	12.82	12.81
15	12.40*12.40	20	400	203.98	12.99*12.99	12.81	12.76
16	12.40*12.40	30	100	226.58	13.00*13.00	12.76	12.70
17	12.40*12.40	30	250	222.82	13.01*13.01	12.70	12.67
18	12.40*12.40	30	400	219.00	13.04*13.04	12.67	12.65

D. Design Matrix and Observation Table

Ni-Cr-Co steel material particulate used a square shape of Copper tube tool with the dimensions of 9.5*9.5 mm^2 and 12.40*12.40 mm^2. Commercial grade EDM oil (specific gravity= 0.763, freezing point= 94 °C) was used as the dielectric fluid. In this experiment, voltage and duty cycle are kept constant at 100 v and six, respectively. For the study, three factors are tackled with a total number of 18 experiments performed on die sinking EDM. The calculation of the material removal rate and tool wear rate was carried out using a digital weight machine. This machine capacity is 300 gram.

VII. RESULT AND DISCUSSION

A. Influence on MRR, TWR & OC

The S/N ratios for MRR are calculated, as below mention formula. The Taguchi method is used to analyze the results of the response of the machining parameter for the larger is better criteria.

$$\text{Larger is Better:} \mathrm{SN_L} = -10\log\left(\frac{\sum_{i=1}^{n} 1/y_i^2}{n}\right) \qquad (7)$$

The S/N ratios for TWR & OC are calculated, as shown in the formula below. The Taguchi method is used to analyze the results of the response of the machining parameter for the smaller is better criteria.

$$\text{Smaller is Better: } \mathrm{SN_S} = -10\log\left(\frac{\sum_{i=1}^{n} y_i^2}{n}\right) \qquad (8)$$

VIII. ANALYSIS OF VARIANCE FOR MRR

The analysis of variances for the factors are shown in Table VIII, which clearly indicates that the T_{on} of the tool is not important for influencing MRR and the Ip and Area are the most influencing factors for MRR. The delta values are Area of tool, Ton and Ip are 1.22, 0.73, 10.02, respectively, depicted in Table X.

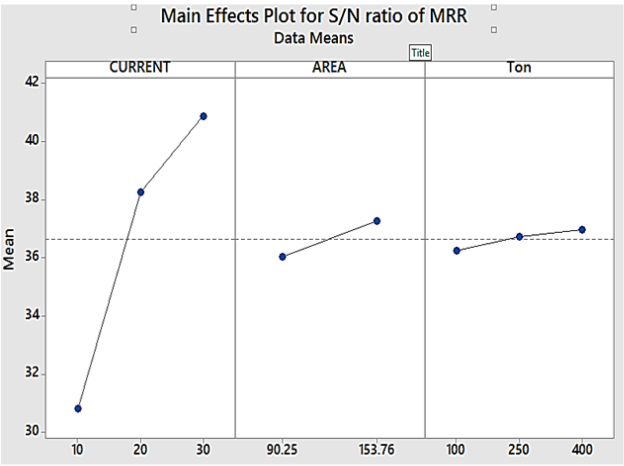

Fig. 6 Main effects plot for S/N ratio of MRR

During the process of electrical discharge machining, the influence of various machining parameters like Ip, Ton and Area of tool has significant effect on MRR, as shown in the main effect plot for the S/N ratio of MRR in Fig. 6 The discharge current (Ip) is directly proportional to MRR in the range of 10A to 20A. This is expected because an increase in pulse current produces a strong spark, which produces the higher temperature, causing more material to melt and erode from the work piece. Besides, it is clearly evident that the other factor does not influence as much compared to Ip. But, with the increase in discharge current from 20A to 30A, MRR increases slightly. However, MRR decreases monotonically with the increase in pulse on time [3].

The response table for MRR, TWR is shown along with the input factors.

IX. ANALYSIS OF VARIANCE FOR TWR

The analysis of the variances for the factors are Area, Ip Ton, as shown in Table X, clearly indicates that the Area of the tool is not important in influencing TWR and the value of Ip and Ton most effected the TWR. The delta values for Area of tool, Ip and Ton are 0.27, 3.45 and 1.30, respectively, as shown in Table XI.

TABLE VII
RESPONSE TABLE

Run	Area (mm^2)	Ip (A)	Ton (μs)	MRR (mm^3/min)	MRR (gm/min)	OC (mm)
1	9.50*9.50	10	100	43.85	0.003508	0.223
2	9.50*9.50	10	250	34.62	0.001225	0.255
3	9.50*9.50	10	400	30.46	0.001092	0.145
4	9.50*9.50	20	100	65.57	0.009661	0.062
5	9.50*9.50	20	250	67.61	0.002481	0.085
6	9.50*9.50	20	400	79.06	0.006024	0.221
7	9.50*9.50	30	100	82.84	0.020962	0.190
8	9.50*9.50	30	250	109.56	0.011673	0.450
9	9.50*9.50	30	400	111.55	0.003891	0.165
10	12.40*12.40	10	100	29.68	0.001218	0.245
11	12.40*12.40	10	250	34.66	0.000705	0.284
12	12.40*12.40	10	400	37.21	0.007577	0.315
13	12.40*12.40	20	100	89.96	0.002207	0.295
14	12.40*12.40	20	250	99.61	0.009615	0.290
15	12.40*12.40	20	400	95.19	0.014962	0.335
16	12.40*12.40	30	100	117.20	0.007334	0.345
17	12.40*12.40	30	250	116.74	0.004987	0.360
18	12.40*12.40	30	400	129.68	0.001169	0.390

TABLE VIII
THE S/N RATIO FOR MRR, TWR & OC

Sr. No.	Current	Area	Ton	MRR	TWR	OC	S/N TWR	S/N TWR	S/N OC
1	*10*	9.50*9.50	100	43.85	0.003508	0.223	58.64371	32.83939	13.0339
2	*10*	9.50*9.50	250	34.62	0.001225	0.255	58.23728	30.78654	11.8692
3	*10*	9.50*9.50	400	30.46	0.001092	0.145	59.23555	29.6746	16.77264
4	*20*	9.50*9.50	100	65.57	0.009661	0.062	40.29497	36.3341	24.15217
5	*20*	9.50*9.50	250	67.61	0.002481	0.085	52.10746	36.60022	21.41162
6	*20*	9.50*9.50	400	79.06	0.006024	0.221	44.4023	37.95914	13.11215
7	*30*	9.50*9.50	100	82.84	0.020962	0.190	32.05511	38.3648	14.42493
8	*30*	9.50*9.50	250	109.56	0.011673	0.450	38.65628	40.79304	6.93575
9	*30*	9.50*9.50	400	111.55	0.003891	0.165	48.19878	40.94939	15.65032
10	*10*	12.40*12.40	100	29.68	0.001218	0.245	58.28705	29.44928	12.21668
11	*10*	12.40*12.40	250	34.66	0.000705	0.284	63.03622	30.79657	10.93363
12	*10*	12.40*12.40	400	37.21	0.007577	0.315	62.47795	31.41319	10.03379
13	*20*	12.40*12.40	100	89.96	0.002207	0.295	42.41005	39.08099	10.60356
14	*20*	12.40*12.40	250	99.61	0.009615	0.290	53.12395	39.96606	10.75204
15	*20*	12.40*12.40	400	95.19	0.014962	0.335	40.34101	39.57183	9.499104
16	*30*	12.40*12.40	100	117.20	0.007334	0.345	36.50021	41.37855	9.370422
17	*30*	12.40*12.40	250	116.74	0.004987	0.360	42.67544	41.34439	8.87395
18	*30*	12.40*12.40	400	129.68	0.001169	0.390	46.04321	42.25746	8.178708

TABLE IX
ANALYSIS OF VARIANCE FOR S/N RATIO OF MRR

	Source	DF	Adj SS	Adj MS	F-Value	P-Value
1	Current	2	301.282	301.283	97.56	0.000
2	*Area*	2	6.670	6.670	2.16	0.164
3	*Ton*	2	1.598	1.598	0.52	0.484
4	*Error*	2	43.233	3.088	97.56	0.000
5	*Total*	8	352.783	312.639	197.8	

During the process of EDM, the influence of various machining parameters like Ip, To and Area of tool have significant effect on TWR, as shown in the main effect plot for the S/N ratio of TWR, as shown in Fig. 8. Increasing in the discharge current from 10A to 30A, the tool wear rate is decreasing. One can interpret that Ip has a significant direct impact on TWR. Pulse on time is directly proportional to the tool wear rate. And Area of the tool has no significant effect on TWR. The interaction plot of TWR is shown in Fig. 9, where each plot exhibits the interaction between three different machining parameters like Ip Ton and Area of tool. This implies that the effect of one factor is dependent upon another factor. It is also confirmed by the ANOVA table (Table XIII).

TABLE X
SIGNAL TO NOISE RATIOS FOR MRR OF RESPONSE

Sr. No.	Level	Current	Area	Ton
1	1	30.83	36.03	36.24
2	*2*	38.25	37.25	36.71
3	*3*	40.85		36.97
4	*DALTA*	10.02	1.22	0.73
5	*RANK*	1	2	3

TABLE XI
ANALYSIS OF VARIANCE FOR S/N RATIO OF TWR

Sr.No.	Source	DF	Adj SS	Adj MS	F-Value	P-Value
1	Current	2	1117.25	1117.25	41.89	0.000
2	*Area*	2	9.48	9.48	0.36	0.561
3	*Ton*	2	88.06	88.06	3.30	0.091
4	*Error*	2	373.41	26.67		0.000
5	***Total***	8	1588.21	1117.25		

TABLE XII
RESPONSE TABLE FOR SIGNAL TO NOISE RATIOS SMALLER IS BETTER

Sr. No.	Level	Current	Area	Ton
1	1	-35.56	-33.45	-32.78
2	*2*	-33.09	-33.72	-34.08
3	*3*	-32.11		-33.89
4	*DALTA*	3.45	0.27	1.30
5	*RANK*	1	3	2

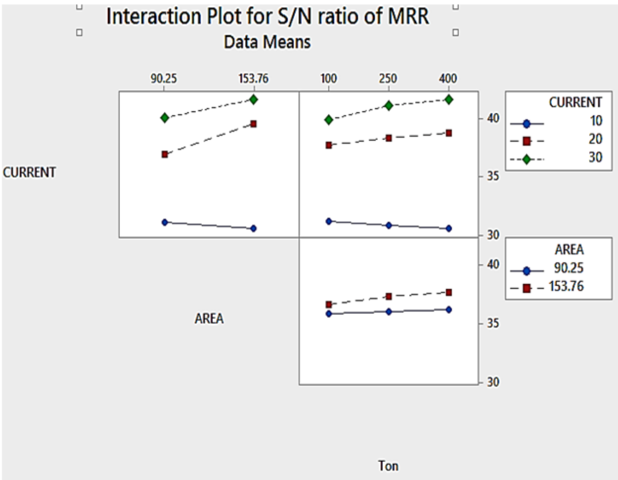

Fig. 7 Interaction Plot for S/N ratio of MRR

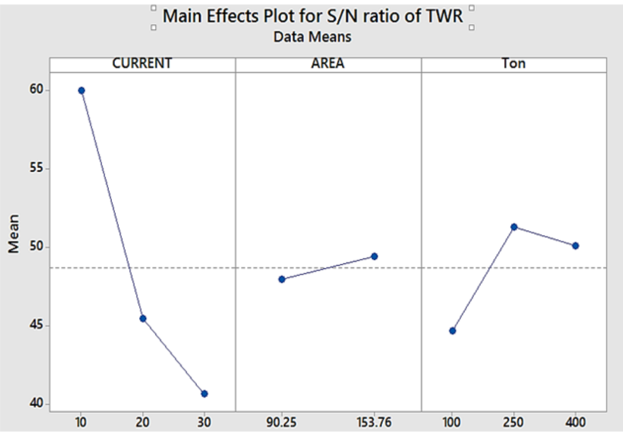

Fig. 8 Main effects plot for S/N ratio of TWR

X. ANALYSIS OF VARIANCE FOR OC

The analysis of variances for the factors are Area, Ip, Ton, as shown in Table V, clearly indicates that the value of Ip is most influencing on OC and also Area of tool is significant. The delta values for Area of tool, Ip and Ton are 3.21, 2.80, 1.59, respectively, as shown in Table VI.

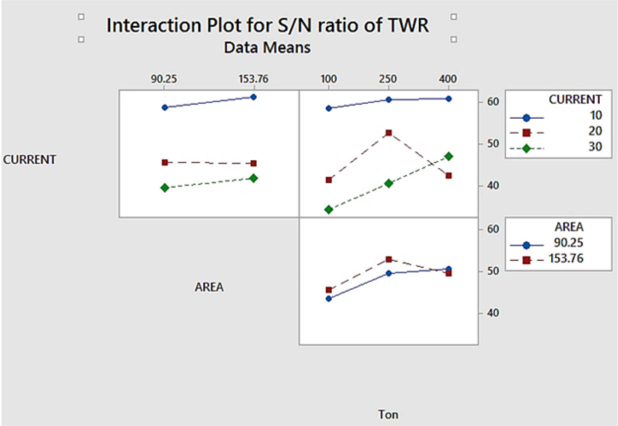

Fig. 9 Interaction Plot for S/N ratio of TWR

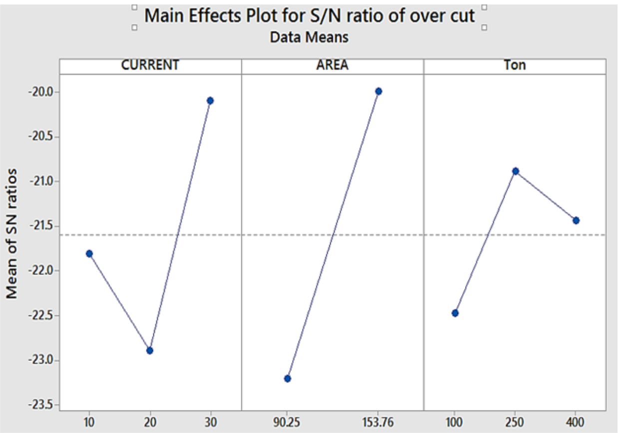

Fig. 10 Main effects plot for S/N ratio of OC

The over cut between the dimension of the electrode and the size of the cavity it is inherent to the EDM process which is unavoidable though adequate compensation are provided at the tool design. To achieve the accuracy, minimization of over cut is essential. Therefore factors affecting of over cut is essential to recognize. The over cut are effect to each parameter such as Area of tool, discharge current and pulse on time, the main effect plot for S/N ratios shown by Fig. 10 for over cut. This graphs are represent the Area of tool is directly proportional to the over cut. Increasing in the discharge current from 10 to 20 A the OC is decreasing, with increase in discharge current from 20A to 30A the OC increasing slightly. Whereas, OC increases monotonically with the increase in pulse on time because which is responsible for production of spark of tool and work piece interface. The interaction plot of OC is shown in Fig. 11 where each plot exhibits the interaction between three different machining parameters like Ip, Ton and Area of the tool. This implies that the effect of one factor is dependent upon another factor. It is also confirmed by ANOVA in Table XIII.

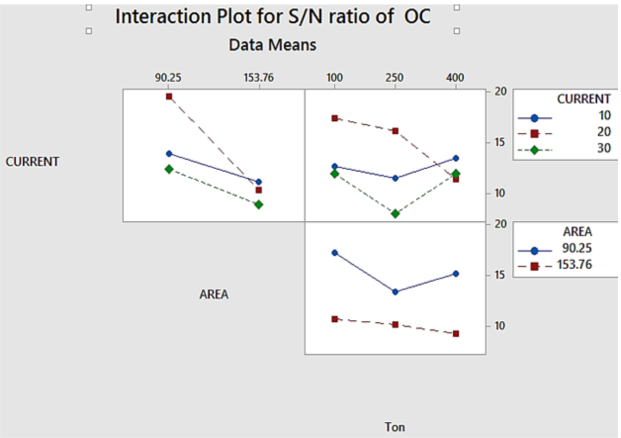

Fig. 11 Interaction Plot for S/N ratio of OC

TABLE XIII
ANALYSIS OF VARIANCE FOR S/N RATIO OF OC

Sr. No.	Source	DF	Adj SS	Adj MS	F-Value	P-Value
1	Current	2	10.879	10.879	0.75	0.400
2	*Area*	2	122.205	122.205	8.46	0.011
3	*Ton*	2	9.284	9.284	0.64	0.436
4	*Error*	2	202.172	14.441		
5	***Total***	8	344.540			

TABLE XIV
RESPONSE TABLE FOR SIGNAL TO NOISE RATIOS SMALLER IS BETTER

Sr. No.	Level	Current	Area	Ton
1	*1*	*-21.80*	-23.20	-22.47
2	*2*	*-22.89*	-19.99	-20.88
3	*3*	-20.09		-21.43
4	*DALTA*	2.80	3.21	1.59
5	*RANK*	2	1	3

XI. CONCLUSION

The effect of machining responses are MRR, TWR and OC of Ni-Cr-CO steel components using the cu tool with an internal flushing system tool have been investigated for the EDM process. The experiments were conducted under various parameters setting of Discharge Current (Ip), Pulse On-Time (Ton), and Area of the tool. L18 OA based on the Taguchi design was performed for Minitab software was used to analyze the results and these responses were partially validated experimentally. The findings of the results show that the MRR discharge current is the most influencing factor, and then pulse duration time, and lastly, the diameter of the tool. The MRR increased with the discharge current (Ip). As pulse duration is extended, MRR decreases monotonically. In the case of the tool wear rate, the most important factor is the discharge current, then pulse on time, followed by diameter of tool. In the case of over cut, the most important factor is the Area of the tool, then the discharge current and then pulse on time.

REFERENCES

[1] Cao, F.G., and Yang, D.Y., 2004, “The study of high efficiency and intelligent optimization system in EDM sinking process,” Journal of Materials Processing Technology, 149(1-3), pp. 83-87.

[2] Lee H.T, Hsu F.C., and Tai T.Y., 2004, “Study of surface integrity using the small area EDM process with a Copper-Tungsten electrode,” Material Science and Engineering, A364, pp. 346-356.

[3] Dew-angan, S., Datta, S., Patel, S.K., and Mahapatra S.S., 2011, “A case study on quality and productivity optimization in electric discharge machining,” 14th International Conference in Advanced Materials and Processing Technologies AMPT201113-16 July, Istanbul, Turkey.

[4] Joshi, S, N., and Pande, S.S., 2011, “Intelligent process modeling and optimization of die-sinking electric discharge machining,” Elsevier, 11(2), pp. 2743–2755.

[5] Mendel, D., Pal, S.K., and Saha, P., 2007, “Modeling of electrical discharge machining process using back propagation neural network and multi-objective optimization using non-dominating sorting genetic algorithm-II,” Journal of Materials Processing Technology, 186(1-3), pp. 154-162.

[6] American Supplier Institute Inc (ASI), 1989, "Taguchi Methods: Implementation Manual", ASI, Dearborn, MI.

[7] Bendell, A., 1988, "Introduction to Taguchi Methodology", Taguchi Methods: Proceedings of the 1988 European Conference, Elsevier Applied Science, London, England, pp. 1-14.

[8] Bryn, D., M. and Taguchi, S., 1986, "The Taguchi Approach to Parameter Design", ASQC Quality Congress Transactions, Anaheim, CA, p 168.

[9] Kackar, Raghu, 1985, "Off-Line Quality Control, Parameter Design, and the Taguchi Method", Journal of Quality Technology, Vol. 17, No.4, pp. 176-188.

[10] Sullivan, L. P., 1987. "The Power of Taguchi Methods", Quality Progress, June, pp 76-79.

[11] Phadke, S. M., 1989. Quality Engineering Using Robust Design, Prentice Hall, Englewood Cliffs, N.J.