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Optimization of MRR and TWR on EDM by Using Taguchi's Method and ANOVA

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Abstract*—Electrical Discharge Machining (EDM) is a non-traditional machining process where intricate and complex shapes can be machined. Only electrically conductive materials can be machined by this process and is one of the important machining processes for machining high strength, temperature-resistant (HSTR) alloys. It is capable of machining geometrically complex or hard materials, that are precise and difficult-to-machine such as heat treated tool steels, composites, super alloys, ceramics, carbides, heat resistant steels etc. These materials are being widely used in die and mould making industries, aerospace, aeronautics and nuclear industries. In this work OHNS EN-31 is the material used for the machining purpose. For achieving the best performance of the EDM process, it is crucial to carry out parametric design responses such as Material Removal Rate and Tool Wear Rate. It is essential to consider most number of input parameters to get the better result. A well-designed experimental scheme was used to reduce the total number of experiments. Parts of the experiment were conducted with the L9 orthogonal array based on the Taguchi method. Moreover, the signal-to-noise ratios associated with the observed values in the experiments were determined by which factor is most affected by the Responses of Material Removal Rate (MRR) and Tool Wear Rate (TWR). In the present work, Optimization of MRR and TWR on EDM conducted by using Taguchi and ANOVA.

***Keywords*— EDM, optimization of MRR & tool wear rate, Taguchi's method, ANOVA.**

I. INTRODUCTION

Electrical Discharge Machining (EDM) is a modern machining process, where electrically conductive material is removed by controlled erosion through a series of electric sparks of short duration and high current density between the electrode and the work piece, both is submerged in a dielectric bath, containing kerosene or distilled water. During this process thousands of sparks per second are generated, and each spark produces a tiny crater in the material along the cutting path by melting and vaporization. Generally the material is removed by erosion process. The top surface of the work piece subsequently resolidifies and cools at a very high rate. The application of this process is mostly found in press tools and dies, plastic moulds, forging dies, die castings, aerospace, automotive, surgical components manufacturing industries etc. This process is not restricted by the physical and metallurgical properties of the work material as there is no physical contact due to high energy electro thermal erosion between the tool and the work piece.

The objective of the present work is an attempt for finding feasibility of machining OHNS EN-31 work piece using circular copper electrode and dielectric flushing. The machining parameter selected are discharge current, pulse on time and feed of the tool using Taguchi design approach analysing the responses MRR and TWR. The Taguchi's method is used to formulate the experimental layout, ANOVA method is used to analysis the effect of process parameters on the machining characteristics and find the optimal process parameters of Electric Discharge Machining. Optimization helps for finding an alternative with the most cost effective or highest achievable performance under the given constraints, by maximizing desired factors and minimizing undesired ones.

II. LITERATURE REVIEW

S.Nizam Sadiq [11] conducted Optimization of milling parameters of OHNS steel using TiAlN coated cutter by deign of experiment technique. The experiment is about investigation of face milling operation of OHNS steel plates with different process parameters like spindle speed, feed rate and depth of cut and to find optimal machining conditions of minimum surface roughness (Ra). The experiments are designed and conducted based on Taguchi's design of experiments using L9 orthogonal array and analysed by ANOVA. Feed rate is a dominating and influencing parameter and optimum milling process parameters for achieving lower surface roughness are 1000 rpm of spindle speed, 0.08 mm of feed rate and 0.8 mm depth of cut. The OHNS steel plates are probable for manufacturing tools and having good machinability property by using TiAlN coated milling cutter with optimum cutting parameters.

M.M. Rahman et al. [7] investigated the effect of the peak current and pulse duration on the performance characteristics of the EDM. The conclusions drawn were: the current and pulse on time greatly affected the MRR, TWR and SR, the MRR increases almost linearly with the increasing current, the SR increases linearly with current for different pulse on time, TWR increased with increasing peak current while decreased when the pulse on time was increased.

Velusamy Senthilkumar [3] evaluates effect of Titanium Carbide particle addition in the aluminium composite on EDM process parameters. The Machining of hard materials such as metal matrix composites (Al/TiC) to a high degree of accuracy and surface finish is difficult. Electrical discharge machining (EDM) is an important process for machining difficult-to-machine materials like metal matrix composites. EDM is an effective tool in shaping such difficult-to-machine materials. The objective of this work is to investigate the effect of current (C), Pulse On-Time (POT) and flushing pressure (P) on Metal Removal Rate (MRR), Tool Wear Rate (TWR) during electrical discharge machining.A copper tool of diameter 7mm was used to drill the specimen. An L18 orthogonal array (OA), for the three machining parameters at three levels each, was opted to conduct the experiments. Analysis of variance (ANOVA) was performed to find the validity of the experimental plan followed in the present work. An attempt was also made in the present work to study the effect of TiC particle addition on the Electrode Wear Ratio (EWR), a new parameter taking into consideration both MRR and TWR.

Ajeet Bergaley [5], investigates about the optimization of Electrical and Non Electrical Factors in EDM for Machining Die Steel Using Copper Electrode by Adopting Taguchi Technique. In this paper both the electrical factors and non electrical factors has been focused which governs MRR, EWR and there optimization. Paper is based on Design of experiment and optimization of EDM process parameters .The technique used is Taguchi technique which is a statistical decision making tool helps in minimizing the number of experiments and the error associated with it. The research showed that the peak current has significant effect on material removal rate. A series of experiments have been conducted by varying parameters current, pulse on time, pulse off time, copper powder mixed concentration in dielectric to analyse the effects on MRR as per the Taguchi orthogonal L9 array. The data collected in MRR and EWR form is optimized and analysed by Taguchi technique and there after confirmation test ANOVA is performed.

I.Puertas and C.J. Luis [10] conducted analysis of the influence of EDM parameters on surface quality, MRR and EW of WC–Co. In this work, a study was carried out on the influence of the factors of intensity (I), pulse time (ti) and duty cycle (η) over the listed technological characteristics. The ceramic used in this study was a cemented carbide or hard metal. The adequate selection of manufacturing conditions is one of the most important aspects to take into consideration in the die-sinking electrical discharge machining (EDM) of conductive ceramics, as these conditions are the ones that are to determine such important characteristics as: surface roughness, electrode wear (EW) and material removal rate.

Velusamy Senthilkumar [3] suggested that Electrical discharge machining (EDM) is an important process for machining difficult-to-machine materials like metal matrix composites. EDM is an effective tool in shaping such difficult-to-machine materials.

Rajmohan T. [1] evaluates the optimization of Machining Parameters in Electrical Discharge Machining (EDM) of 304 Stainless Steel In this investigation, the effect of electrical discharge machining parameters such as pulse-on time, pulse-off time, voltage and current on material removal rate in 304 stainless steel was studied. The experiments are carried out as per design of experiment approach using L9 orthogonal array. The results are analyzed using ANOVA and response graphs. From this study, it is found that different combinations of EDM process parameters are required to achieve higher MRR for 304SS. S/N ratio and ANOVA is used to analyze the effect of parameters on MRR and also to identify the optimum cutting parameters. The contribution of each cutting parameters towards the MRR is also identified. The result from this study is useful for manufacturing engineers to select appropriate EDM process parameters to machine SS304.

From journal references and publications, OHNS steel is an important tool and die material, mainly because of its high strength, high hardness and high wear resistance. OHNS have wide applications in industries for the production of Lathe tools, Planer tools, Milling cutter, Cutter blades, Boring tools, Twist drills, Milling knives, etc. EDM is used for manufacturing geometrically complex or hard material parts that are extremely difficult-to-machine by conventional machining process.

From the literature survey it is found that the parameters voltage, current, pulse time and duty cycle has significance importance regarding the MRR and surface roughness.The input parameters selected such as pulse-on time, pulse-off time, current and feed rate. So there is a scope for the optimization process of output parameters in EDM machining. The objective of the research study is to investigate the optimal output parameters of Electric Discharge Machining on OHNS steel. The Taguchi method is used to formulate the experimental layout, ANOVA method is used to analysis the effect of process parameters on the machining characteristics and find the optimal process parameters of Electric Discharge Machining.

III. METHODOLOGY

Taguchi's method is a powerful technique for the design of a high quality system. It provides not only, an efficient, but also a systematic approach to optimize designs for performance and quality. Furthermore, Taguchi parameter design can reduce the fluctuation of system performance and quality to the source of variation.

A. *The basic steps for the methodology are:*

- Identify the quality characteristics and select process parameters to be evaluated.
- Select the appropriate orthogonal array and assign these parameters to the orthogonal array.
- Conduct the experiments based on the arrangement of the orthogonal array.
- Analyze the experimental results using the signal to noise(S/N) ratio and analysis of variance (ANOVA).

B. *Experimental design*

1) *Step1- Selection of process parameters:* Process parameters and their ranges were determined by the trial tests. The parameters are identified for the test such as current, pulse-on and feed rate. Which are reported to be the main parameters in the process of EDM machining.

2) *Step 2- Selection of orthogonal array:* To select an appropriate orthogonal array for the experiments, on the basis of parameter selection and its levels. Here we have three parameters and three levels are selected.
3) *Step 3- Recording of responses:* Nine experimental runs were conducted as per the Taguchi's L9 orthogonal array. The test runs were carried out at random to avoid a systematic error creeping into the experimental procedure.
4) *Step 4- Calculation of signal-to-noise ratio:* In the Taguchi's method, the signal-to-noise ratio is used to measure the quality characteristics and also to evaluate the influence of each selected factor on the responses. The signals indicate the effect of selected factors on the average responses. The noises are measured by the deviations from the average responses, which would reveal the sensitiveness of the experiment output to the noise factors. Therefore, the S/N ratio is the ratio of the mean to the square of the deviation.
5) *Step 5- ANOVA analysis:* The analysis of variance (ANOVA) is used to discuss the relative importance of all control factors on the machined material quality and also to determine which control factor has the most significant effect. Analysis of variance (ANOVA) is employed to find the optimal process parameter levels and to analyze the effect of these parameters on metal removal rate values and electrode wear rate.

IV. EXPERIMENTATION

Orthogonal Arrays (often referred to Taguchi Methods) are often employed in industrial experiments to study the effect of several control factors. In this experimental work which consists of L-9 orthogonal array based on Taguchi design. Orthogonal array will reduce the total number of experiments.

A. Experimental setup

The experiments were conducted using a ram EDM machine, model 150 Minor EDM manufactured by MMT (Modern Machine Tool), India. The electrode is fed downwards into the OHNS EN-31 work piece under servo control in this EDM machine. Before experimentation, the work piece top and bottom faces were ground to a good surface finish using a surface grinding machine. The bottom of the tube electrode is polished using a very fine grade emery sheet before every experiment. The initial weight of the work piece was weighed using a 1mg accuracy digital weighing machine Electronic Balance of model UN 620H manufactured by Shimodzu Corporation. The work piece was held on the machine table using a specially designed fixture as shown in fig 1. The work piece and tool were connected to the negative and positive terminals of the power supply, respectively. The dielectric fluid used here is kerosene. The time taken for machining was recorded. The machining was signalled by the emergence of the dielectric jet through the bottom of the work piece. The experiments were conducted in the order of L9 orthogonal array. At the end of each experiment, the work piece was removed from the machine, washed, dried and weighed on an electronic balance.

Fig.1. Tool holder with work piece

B. Selection of work piece

OHNS steel is an important tool and dies material, mainly because of its high strength, high hardness, and high wear resistance. It has a high strength due to that it cannot be easily machinable by conventional machining techniques. EDM is a non-conventional machining process that removes material by thermal erosion, such as melting and vaporization of material. To understand the machining characteristics of OHNS EN-31 grade steel by EDM is explored in this experimental study.

OHNS material is used for blanking and stamping dies, Punches, Rotary shear blades, Thread cutting tools, Milling cutters, Reamers, Measuring tools, Gauging tools, Wood working tools, Broaches, Chasers. Ideal type oil-hardened steel which is economical and dependable for gauging, cutting and blanking tools as well as can be relied for hardness and good cutting performance. OHNS Tool Steel is an electric-furnace melted, oil-hardened, non-shrinking, general-purpose tool steel. It is chemically composed of approximately 0.95 percent carbon, 1.1 percent manganese, 0.6 percent chromium, 0.6 percent tungsten and 0.1 percent vanadium. The hardening temperature of OHNS tool steel is between 790 degrees Celsius and 820 degrees Celsius. OHNS EN31 is a high carbon Alloy steel which achieves a high degree of hardness with compressive strength and abrasion resistance.

V. TAGUCHI'S DESIGN OF EXPERIMENT

MINITAB 16 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. Which calculates response tables and generates main effects and interaction plots for:-

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

A Taguchi design is to design the experimental procedure using different types of design like, two, three, four, five, and mixed level. In the study, three factors mixed level setup is chosen with a total of nine numbers of experiments to be conducted and hence the OA L9 was chosen. 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 L9 setup, which in turn would reduce the number of experiments at the later stage. In addition, the comparison of the results would be simpler. The levels of experiment parameters discharge current (I), Pulse on time (T on) and feed are shown in Table 1 and the design matrix is depicted in Table 2.

Table 1 Machining parameters and their levels.

	Machining Factors	Symbol	Unit	Levels		
				1	2	3
1	Current	I	Amp	10	15	20
2	Pulse-on	Ton	µs	25	50	75
3	Feed	f	mm/rev	0.15	0.20	0.25

VI. DESIGN MATRIX AND OBSERVATION TABLE

In the study, three factors mixed level setup is chosen. This experiment has 3 variables at 3 different settings. A full factorial experiment would require 34 = 81 experiments. We conducted a Taguchi experiment with a L9 (34) orthogonal array (9 tests, 3 variables, 3 levels). The experiment design is shown in table 2.

A. Design of Experiments and Observation table

DOE (design of experiments) helps to investigate the effects of input variables (factors) on an output variable (response) at the same time. Here the input variables are current, pulse on and feed as shown in table 1.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 and the output variables are MRR and TWR. The average results of MRR and TWR from OA L9 replication is calculated is shown in Table 2.

Table 2 Design of Experiments

Run	I(Amp)	Pulse on (µsec)	Feed (mm/rev)	MRR	TWR
1	10	25	0.15	2.242	0.146
2	10	50	0.20	2.610	0.084
3	10	75	0.25	4.113	0.098
4	15	25	0.20	1.983	0.022
5	15	50	0.25	2.881	0.022
6	15	75	0.15	0.832	0.038
7	20	25	0.25	1.616	0.053
8	20	50	0.15	2.633	0.053
9	20	75	0.20	2.854	0.069

VII. RESULT AND DISCUSSION

A. Response Table

The Response Table contains a row for the average signal to noise ratio for each factor level. The response table for MRR and TWR are shown in table 5 and table 9 respectively along with the input factors. In Taguchi designs, a measure of robustness used to identify control factors that reduce variability in a product or process by minimizing the effects of uncontrollable factors (noise factors). Control factors are those design and process parameters that can be controlled. Noise factors cannot be controlled during production or product use, but can be controlled during experimentation. In a Taguchi designed experiment, the results that identify optimal control factor settings that make the process or product robust, or resistant to variation from the noise factors. Higher values of the signal-to-noise ratio (S/N) identify control factor settings that minimize the effects of the noise factors. The signal-to-noise ratio measures how the response varies relative to the nominal or target value under different noise conditions.

Table 3. Response table

Run	I(Amp)	Pulse on (µsec)	Feed (mm/rev)	MRR	TWR	Ra (surface roughness)	S/N (MRR)	S/N (TWR)
1	10	25	0.15	2.242	0.146	3.47	7.0127	16.7129
2	10	50	0.20	2.610	0.084	3.99	8.3328	21.5144
3	10	75	0.25	4.113	0.098	4.56	12.2832	20.1755
4	15	25	0.20	1.983	0.022	2.41	5.9465	33.1515

5	15	50	0.25	2.881	0.022	2.67	9.1909	33.1515
6	15	75	0.15	0.832	0.038	2.64	-1.5975	28.4043
7	20	25	0.25	1.616	0.053	3.27	4.1688	25.5143
8	20	50	0.15	2.633	0.053	4.16	8.4090	25.5145
9	20	75	0.20	2.854	0.069	3.45	9.1091	23.223

B .Influences on MRR

The S/N ratios for MRR are calculated as given in Equation.1. Taguchi method is used to analysis the result of response of machining parameter for larger is better criteria.

Larger is better: S/N ratio = -10log $(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{yi^2})$. . . . . (1)

Where the S/N ratios calculated from observed values, y_i represents the experimentally observed value of the ith experiment and n=1 is the repeated number of each experiment in L-9 OA is conducted.

The analysis of variances for the factors is shown in table 4, is clearly indicates that the current is important for influencing MRR comparing with pulse on and feed parameters. The delta values are current, pulse on and feed are 4.696, 2.935 and 3.94 respectively, depicted in table 5. The case of MRR, it is “Larger is better”, so from this table it is clearly definite that current is the most important factor then pulse on and feed of the tool.

Table.4. Analysis of Variance for S/N ratios for MRR

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% contribution
CURRENT	2	33.35	33.35	16.677	0.66	0.604	26.9 %
PULSE ON	2	13.59	13.59	6.795	0.27	0.789	10.96 %
FEED	2	26.25	26.25	13.124	0.52	0.659	21.18 %
Residual Error	2	50.77	50.77	25.386			40.96 %
Total	8	123.96					

Table.5. Response for S/N Rations Larger is better (MRR)

Level	CURRENT	PULSE ON	FEED
1	9.21	5.709	4.608
2	4.513	8.644	7.796
3	7.229	6.598	8.548
Delta	4.696	2.935	3.94
Rank	1	3	2

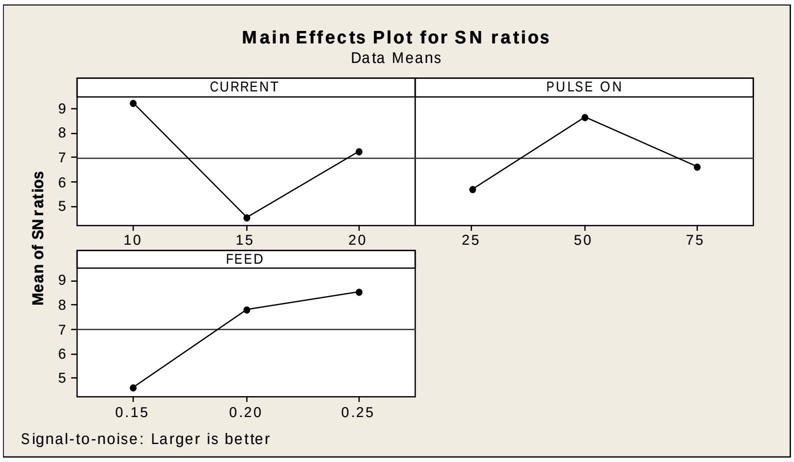

Fig.2. Main effects plot for S/N ratios (MRR)

C .Influences on TWR

The S/N ratios for TWR are calculated as given in Equation 2. Taguchi method is used to analysis the result of response of machining parameter for smaller is better (SB) criteria

Smaller is better: S/N ratio =-10log $(\frac{1}{n}\sum_{i=1}^{n} yi^2)$. . . . . (2)

The analysis of variances for the factors are current, pulse on , and feed as shown in table 6. The delta values of current, pulse on and feed are 12.1, 2.79 and 2.74 respectively, in Table 9. The case of TWR Smaller is better, so from this table it is clearly definite that current (I) is the most important factor then pulse on (Ton) and feed.

Table.6. Analysis of Variance for S/N ratios for TWR

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% contribution
CURRENT	2	220.849	220.849	110.425	39.57	0.025	87.76 %
PULSE ON	2	11.781	11.781	5.89	2.11	0.321	4.68 %
FEED	2	13.442	13.442	6.721	2.41	0.293	5.34 %
Residual Error	2	5.581	5.581	2.79			2.22 %
Total	8	251.653					

Table.7. Response for S/N Rations Larger is better (TWR)

Level	CURRENT	PULSE ON	FEED
1	19.47	25.13	23.54
2	31.57	26.73	25.96
3	24.75	23.93	26.28
Delta	12.1	2.79	2.74
Rank	1	2	3

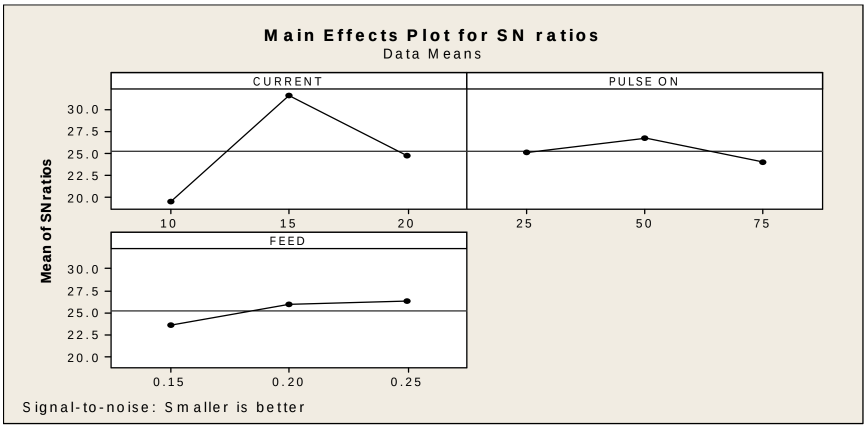

Fig.3. Main effects plot for S/N ratios (TWR)

VIII. CONCLUSION

From the calculations of main effects for each level of factors, the main effects values are presented in table 5 for MRR and in Table 7 for TWR. The main effect values and interactions are plotted in Figure 2 and Figure 3 for factors current, pulse on and feed respectively. The main effects plot shows the influence of each level of factors on the machining performance. The levels having the major contribution are selected from the plot and are the optimized levels for the particular factor. The relative importance of the machining parameters with respect to the MRR and TWR is investigated by analysis of variance (ANOVA). Table 4 and table 6 give the ANOVA results for MRR and TWR respectively. From the analysis of table 4, it is observed that residual error is about 40.96%, the current is 26.9%, feed is 21.18% and pulse on is 10.96% for MRR. So current have the statistical significance on MRR. And from the analysis of table 6, it is observed that the current (87.76%) and feed (5.34%) have statistical significance on the TWR. Thus, by utilizing experiment results and computed values of the S/N ratios, average effect response value and average S/N response ratios are calculated for MRR and TWR. The S/N ratio response graph for MRR and TWR is shown in Fig 2 and Fig 3.

On the basis of experimental results, calculated S/N ratio, analysis of variance (ANOVA) and 'F' test values, the following conclusions are drawn for EDM of OHNS EN-31.

- Current is the most significant machining parameter for MRR and TWR in EDM of OHNS EN-31.
- Based on the analysis of S/N ratio of MRR, the optimal machining performance for MRR is obtained at current of 10amps (level 1), pulse ON time of 50µs (level 2) and feed of 0.25mm/rev (level 3).
- Based on the analysis of S/N ratio of TWR, the optimal machining performance for TWR is obtained at current of 15amps (level 2), pulse ON time of 50µs (level 2) and feed of 0.25mm/rev (level 3).
- Regardless of category of the performance characteristics, a greater S/N ratio value corresponds to a better performance.
- The optimal value of machining parameters is the level with the greatest S/N ratio value.
- Based on minimum number of trials conducted to arrive at the optimum cutting parameters, Taguchi's method seems to be an efficient methodology to find the optimum machining parameters.

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