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Experimental Investigation of Process Parameters of EDM on 17-4 PH Steel using Taguchi Method

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Abstract

Electric discharge machining is one of the most suitable non conventional material removal processes. EDM is a thermo electric process in which material is removed from the work piece by erosion effect of series of electric discharges (sparks) between tool and work piece immersed in a die- electric fluid. In the present study the input machining parameters like discharge current, pulse ontime (Ton), pulse off time (Toff) and tool lift time (TL) are optimized with considerations of multiple performance characteristics including the material removal rate (MRR) and Tool wear rate (TWR). Taguchi's standard orthogonal array is used for experimental design. Optimal process parameters are selected with respect to S/N ratios. This also investigates the optimization of EDM machining parameters for hardened steel. Analysis of variance (ANOVA) and F-test should be used to check the validity of the regression model and to determine the significant parameter affecting the output parameters.

Keywords: *— EDM, TWR, MRR, TAGUCHI*

I. Introduction

Electrical Discharge Machining (EDM) is a modern manufacturing process 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 were both are submerged in a dielectric bath, containing EDM oil, 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 re-solidifies 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.

1.1 Principle of EDM

In this process the metal is removing from the work piece due to erosion case by rapidly recurring spark discharge taking place between the tool and work piece. Show the mechanical setup and electrical set up and electrical circuit for electro discharge machining. A thin gap about 0.025 mm is maintained between the tool and work piece by a servo system shown in figure 1. Both tool and work piece are submerged in a dielectric fluid. Kerosene/ EDM oil/deionized water is very common type of liquid dielectric although gaseous dielectrics are also used in certain cases.

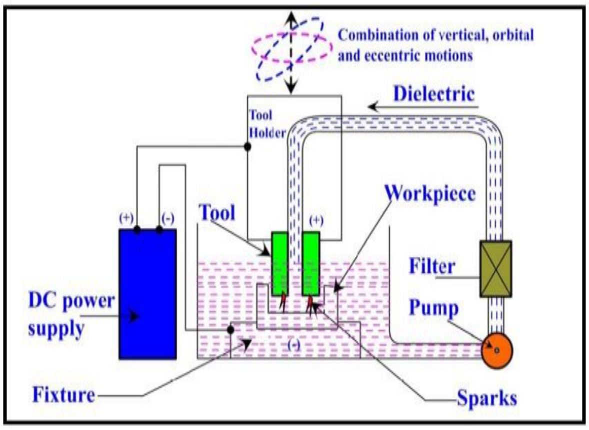

Figure 1: Layout of Electrical Discharge Machine

This figure 1 is shown the layout of the Electric discharge machine. The tool is cathode and work piece is anode. When the voltage across the gap becomes sufficiently high it discharges through the gap in the form of the spark in interval of from 10 of microseconds. And positive ions and electrons are accelerated, producing a discharge channel that becomes conductive. It is just at this point when the spark jumps causing collisions between ions and electrons and creating a channel of plasma. A sudden drop of the electric resistance of the previous channel allows that current density reaches very high values producing an increase of ionization and the creation of a powerful magnetic field. The moment spark occurs sufficiently pressure developed between work and tool as a result of which a very high temperature is reached and at such high pressure and temperature that some metal is melted and eroded.

Such localized extreme rise in temperature leads to material removal. Material removal occurs due to instant vaporization of the material as well as due to melting. The molten metal is not removed completely but only partially. As the potential difference is withdrawn as the plasma channel is no longer sustained. As the plasma channel collapse, it generates pressure or shock waves, which evacuates the molten material forming a crater of removed material around the site of the spark.

II. Literature Review

Yan – Cherng Lina, Jung-Chou Hungb, Han – Ming Chowc and A – Cheng Wangd [1] studied the Electrical Discharge Machining (EDM) is the most commonly used technique in mold and die manufacturing. The purpose of this investigation was to optimize the machining parameters of EDM on zirconium dioxide (ZrO_2) and aluminum oxide (Al_2O_3). During the EDM process, the surface of electrically nonconductive ceramic was covered with adhesive conductive copper (Cu) and aluminum (Al) foils to attain the threshold of electrical conductivity for the EDM process. The machining characteristics associated with the EDM process such as material removal rate (MRR) and surface roughness (SR) were explored through the experimental study according to an L18 orthogonal array using the Taguchi method. The analysis of variance (ANOVA) was conducted to examine the significant machining parameters which affect the machining characteristics. As the experimental results show, peak current and pulse duration significantly affected MRR and SR. In addition, the optimal combination levels of machining parameters were also determined from the response graph of signal-to-noise (S/N) ratios for each level of machining parameters. A practical and convenient process for shaping the electrically nonconductive ceramics was developed which featured high efficiency, high precision, and high-quality of surface integrity.

Jong Hyuk Jung and Won Tae Kwon [2] studied the Electrical discharge machining (EDM) is one of the most extensively used non-conventional material removal processes. The Taguchi method has been utilized to determine the optimal EDM conditions in several industrial fields. The method, however, was designed to optimize only a single performance characteristic. To remove that limitation, the Grey relational analysis theory has been used to resolve the complicated interrelationships among the multiple performance characteristics. In the present study, we attempted to find the optimal machining conditions under which the micro-hole can be formed to a minimum diameter and a maximum aspect ratio. The Taguchi method was used to determine the relations between machining parameters and process characteristics. It was found that electrode wear and the entrance and exit clearances had a significant effect on the diameter of the micro-hole when the diameter of the electrode was identical. Grey relational analysis was used to determine the optimal machining parameters, among which the input voltage and the capacitance were found to be the most significant. The obtained optimal machining conditions were an input voltage of 60V, a capacitance of 680pF, a resistance of 500Ω, the feed rate of 1.5 µm/s and a spindle speed of 1500rpm. Under these conditions, a micro-hole of 40µm average diameter and 10 aspect ratio could be machined.

Arjun Kumar, R.S. Jadoun, Sushil Kumar Choudhary [3] studied the EDM has become an important and cost- effective method of machining extremely tough and brittle electrically conductive materials. It is widely used in the process of making moulds and dies and sections of complex geometry and intricate shapes. The workpiece material selected in this study is AISI D2 Die Steel. The input parameters are voltage, current, pulse on time and pulse off time. L9 orthogonal array was selected as per the Taguchi method. The data have been analyzed using Minitab15 Software. The effect of above mentioned parameters upon machining performance characteristics such as Tool Wear Rate (TWR) are studied and investigated on the machine model C-3822 with PSR-20 Electric Discharge Machine. The copper alloy was used as tool material. The results obtained showed that the optimum condition for tool wear rate (TWR) is A3, B2, C2, D3 i.e. Ton (40µs), Toff (8 µs), Ip (8 amp) and Vg (60V). The order of process parameters influencing the tool wear rate is Toff > Ip > Ton > Vg. Hence, pulse off parameter has more contribution to tool wear rate whereas gap voltage has the least contribution. As per the optimal level of parameters, the optimum value of TWR is 0.117 mm^3 /min. These results were validated by conducting confirmation experiments and found satisfactory.

Dinesh Kumar, Naveen Beri, Anil Kumar [4] studied the Electric discharge machining (EDM) has been used mostly in the tool and die industry and the material normally used as tool electrode are copper, tungsten, graphite, brass, silver, copper tungsten and copper chromium alloys. In the present work, hastelloy steel is used as a work piece for investigating using sintered tool electrode of copper tungsten (CuW) with straight and reverse polarity setup in standard EDM oil. The dimensional accuracy is greatly influenced by the overcut resulting from discharge gap and electrode wear. In this paper the effects of input parameters i.e. polarity, tool electrode material, peak current, pulse on time, duty cycle and gap voltage on the overcut was analyzed using analysis of variance and scattered graph. It was found that powder metallurgy tool electrode with reverse polarity gives minimum overcut and Best parametric setting for minimum overcut was found at –ve polarity, CuW (Cu 40% W 60%) tool electrode, 4 amp current, 150 µsec pulse on time, 0.83 duty cycle and 60 volts gap voltage i.e A2B2C1D3E2F2 .

Vishnu D Asal, Prof.R.I. Patel, Alok B Choudhary [5] the objective of this paper is to investigate the optimum process parameters for a particular work piece-tool material combination on Fuzzy Logic Control based Electrical Discharge Machine. In this experiment, two levels of current, tools material and spark gap are kept as the main variables. The work piece material was taken as S.S.304, and tool material changed at various levels of the performance as copper and brass. The DEF-92 was used as the dielectric fluid. The Design of experiment is used to design the E.D.M experiments. The various tools of D.O.E are used to analyze the final results of the experiment with the help of graphs in this paper. The analysis is being done with the help of Minitab15 software. The analysis of variance (ANOVA) is also performed to indentify the statistical significance of parameters. The result of the experiments are the optimum values of MRR (material removal rate), TWR (tool wear ratio), and surface finish with the help of ANOVA. The conclusions arrived are discussed at the end.

Shahul Backer Cijo Mathew Sunny K. George [6] studied the 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.

III. Materials and Methods

The Electrode tool used in this experimental method is Copper – Tungsten and the work piece material chosen for the present investigation was 17-4 PH Stainless Steel is the most widely used of all the precipitation – hardening stainless steels. Its valuable combination of properties gives designers opportunities to add reliability to their products while simplifying fabrication and often reducing costs. It is used in many applications for Aerospace, Chemical, Petro – chemical, Food processing, Paper and general metal work industries. The chemical composition of material is given in Table 1.

Table 1. Chemical composition of 17-4 PH Stainless Steel

Element	% of composition	Element	%of composition
Carbon (C)	0.042	Chromium (Cr)	15.47
Silicon (Si)	0.5	Molybdenum (Mo)	0.27
Manganese (Mn)	0.7	Nickel (Ni)	4.37
Phosphorous (P)	0.028	Copper (Cu)	2.99
Sulphur (S)	0.008	Niobium (Nb)	0.34

Figure 2. Copper–Tungsten electrode tool

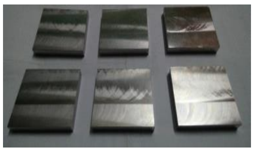


Figure 3. Workpiece 17-4 PH steel

3.1 Taguchi method

After the Second World War, the allied forces found that the quality of the Japanese telephone system was extremely poor and totally unsuitable for long term communication purposes. To improve the system the allied command recommended establishing research facilities in order to develop a state-of-the-art communication system. The Japanese founded the Electrical Communication Laboratories (ECL) with Dr. Genichi Taguchi in charge of improving the R&D productivity and enhancing product quality.

Taguchi started to develop new methods to optimize the process of engineering experimentation. He believed that the best way to improve quality was to design and build it into the product. He developed the techniques which are now known as Taguchi Methods. His main contribution lies not in the mathematical formulation of the design of experiments, but rather in the accompanying philosophy. His concepts produced a unique and powerful quality improvement technique that differs from traditional practices. He developed manufacturing systems that were "robust" or insensitive to daily and seasonal variations of environment, machine wear and other external factors.

Taguchi viewed quality improvement as an ongoing effort. He continually strived to reduce the variation around the target value. Taguchi designed experiments using especially constructed tables known as "Orthogonal Arrays" (OA). The use of these tables makes the design of experiments very easy and consistent.

Taguchi methods start with an assumption that we are designing an engineering system - either a machine to perform some intended function, or a production process to manufacture some product or item. Since we are knowledgeable enough to be designing the system in the first place, we generally will have some understanding of the fundamental processes inherent in that system. Basically, we use this knowledge to make our experiments more efficient. We can skip all the extra effort that might have gone in to investigating interactions that we know do not exist. It is used for static and dynmic problems.

3.1.1. Taguchi's Two Level Design Examples:

Table 2. L4 (2^3) Orthogonal array

Run	Columns		
	1	2	3
1	1	1	1
2	1	2	2
3	2	1	2
4	2	2	1

Table 3. L8 (2^7) Orthogonal Array

Run	Columns						
	1	2	3	4	5	6	7
1	1	1	1	1	1	1	1
2	1	1	1	2	2	2	2
3	1	2	2	1	1	2	2
4	1	2	2	2	2	1	1
5	2	1	2	1	2	1	2
6	2	1	2	2	1	2	1
7	2	2	1	1	2	2	1
8	2	2	1	2	1	1	2

3.1.2. Taguchi's Three Level Design Examples:

Table 4. L9(3^4)Orthogonal array

Run	Columns			
	1	2	3	4
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

3.1.3 Taguchi Experimental Design

(a) Traditional experimental design methods requires a large number of experiments when the number of process parameters increase.

(b) In order to minimize the number of tests required, Taguchi experimental design method was developed by Taguchi.

(c) This method uses a special design of orthogonal arrays to study the entire parameters space with small number of experiments only.

(d) There are 3 Signal-to-Noise of common interest for optimization of static problem:

1) Smaller-the-better

2) Larger-the-better

3) Nominal-the-better

Larger the better for Material Removal Rate (MRR) and Smaller the better for Tool Wear rate (TWR) so, regardless of category of the performance characteristics, the lower S/N ratio corresponds to better performance.

3.2. Signals to Noise Ratio

Dr. Taguchi proposed a class of statistics called signal-to-noise ratios (S/N) which can be used to measure the effect of noise factors on the process performance. By maximizing the S/N ratios, the loss functions are minimized. These S/N ratios take into account both the amount of variability and closeness to the average response, we will only consider three of them: smaller-is-better, larger-is-better and target value-is-best.

- Smaller-is-better (variance of response):

This S/N ratio assumes that the target for the response is zero and is appropriate

when specifications indicate an upper tolerance limit only.

$$S/N= -10Log\ (1/R \sum^{R}{}_{i}=1(y_i\ 2\ ))$$

The goal of an experiment for smaller-is-better situations is to minimize $\sum y_i^2$ and y. That is: we aim to maximize

$$10Log\ (1/R \sum^{R}{}_{i}=1(y_i^2\ ))$$

- Larger-is-better (mean of response):

This *S/N* ratio assumes that the goal is to maximize the response and is appropriate when specifications indicate a lower tolerance limit only.

$$S/N = -10\ Log\ (1/R \sum (y_i^2)$$

Again, the goal of an experiment for larger-is-better situations is to maximize the response (e.g., yield of a process). But maximizing y is the same as minimizing l/y. This means that we aim to maximize 10 Log $(1/R \sum (y_i^2)$

3.3 Analysis of Variance

Analysis of variance (ANOVA) is a collection of statistical models and their associated procedures (such as "variation" among and between groups) used to analyze the differences among group means. ANOVA was developed by statistician and evolutionary biologist Ronald Fisher. ANOVA is useful for comparing (testing) three or more means (groups or variables) for statistical significance. It is conceptually similar to multiple two-sample t-tests, but is more conservative (results in less type I error) and is therefore suited to a wide range of practical problems.

In short, we have to make two estimates of population variance viz., one based on between samples variance and the other based on within samples variance. Then the said two estimates of population variance are compared with F- test, wherein we work out.

$$F = \frac{\text{Estimate of population variance based on between samples variance}}{\text{Estimate of population variance based on within samples variance}}$$

This value of *F* is to be compared to the *F*-limit for given degrees of freedom.

IV. EXPERIMENTAL DETAILS

The experiments conducted according to the Taguchi technique with L27 orthogonal array design. The machining parameters chosen for the present investigation are discharge current, pulse on time, pulse off time and tool lift time. The machining parameters and their levels are presented in table 5.

All the experiments were done on V3545 GRACE die sinking machine. It is energized by pulse generator. As well flushing is controlled manually to ensure the adequate flushing of the EDM process debris from the gap zone is employed.

Table 5. The Machining Parameters and their Levels

PARAMETER	LEVEL 1	LEVEL 2	LEVEL 3
Discharge Current (A)	9	12	15
Pulse on time (µs)	50	100	200
Pulse off time (µs)	20	50	100
Tool lift (µs)	10	20	50

Pressure of the dielectric fluid is adjusted manually at the beginning of experiment. The work pieces and electrodes after the machining have thoroughly cleaned to remove the carbon deposition and the weight measurement were taken on electronic weighing machine, which has a resolution of 0.001 grams. Each experiments was repeated twice and the averaged MRR (grams/min) and TWR (grams/min).

$$MRR = (W_1 - W_2)*1000/t \quad (1)$$

Where, W_1, W_2, t are initial, final weight of work piece in grams and machining time in minutes respectively

$$TWR = (T_1 - T_2)*1000/t \quad (2)$$

Where, T_1, T_2, t are initial, final weight of tool in grams and machining time in minutes respectively

V. Results and Discussion

The Regression model has been developed for the MRR and TWR in terms of discharge current, pulse on time, pulse off time and tool lift time. The comparison of theoretical values of MRR and TWR using regression with the experimental values for different set of input values are shown in figure 9 and 10.

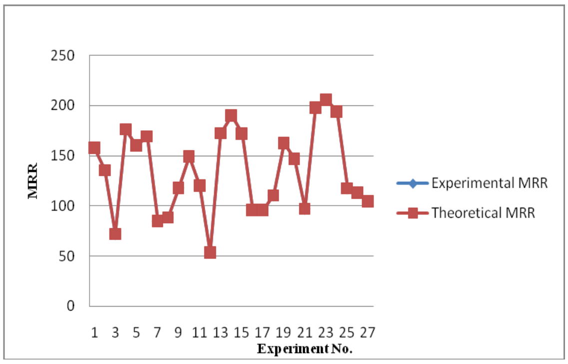

Figure 4. Comparison of results between Experimental and theoretical MRR

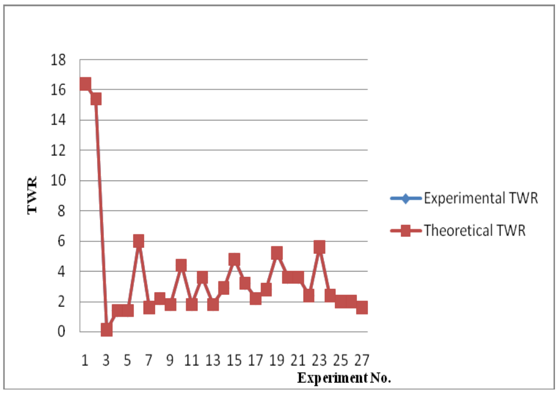

Figure 5. Comparison of results between Experimental and Theoretical TWR

VI. Conclusions

Based on the above discussion, the following conclusions are drawn.

1. Experiments were conducted on V3545 GRACE die sinking machine on 17-4 PH steel with copper-tungsten tool material. The data for MRR and TWR was collected under different input conditions of discharge current, pulse on time, pulse off time and tool lift time.
2. The regression model has been developed with the experimental results for predicting the MRR and TWR
3. The results of the study are highly encourages and suggests that Taguchi and regression approach is reasonable for modeling the EDM process.

Table 6. Experimental Conditions and Results

S.No	I	Ton	Toff	TL	Exp MRR	SNRA1	Theoretical MRR	Exp TWR	SNRA2	Theoretical TWR
1	9	50	20	10	158.0	43.9731	158.0	16.40	-24.2969	16.40
2	9	50	50	20	135.6	42.6452	135.6	15.40	-23.7504	15.40
3	9	50	100	50	71.8	37.1225	71.8	0.12	18.4164	0.12
4	9	100	20	20	176.2	44.9201	176.2	1.40	-2.9226	1.40
5	9	100	50	50	160.4	44.1041	160.4	1.40	-2.9226	1.40
6	9	100	100	10	169.2	44.5680	169.2	6.00	-15.5630	6.00
7	9	200	20	50	84.6	38.5474	84.6	1.60	-4.0824	1.60
8	9	200	50	10	88.4	38.9290	88.4	2.20	-6.8485	2.20
9	9	200	100	20	118.0	41.4376	118.0	1.80	-5.1055	1.80
10	12	50	20	20	149.4	43.4870	149.4	4.40	-12.8691	4.40
11	12	50	50	50	120.2	41.5981	120.2	1.80	-5.1055	1.80
12	12	50	100	10	53.2	34.5182	53.2	3.60	-11.1261	3.60
13	12	100	20	50	172.4	44.7307	172.4	1.80	-5.1055	1.80
14	12	100	50	10	190.2	45.5842	190.2	2.90	-9.2480	2.90
15	12	100	100	20	172.0	44.7106	172.0	4.80	-13.6248	4.80
16	12	200	20	10	95.8	39.6273	95.8	3.20	-10.1030	3.20
17	12	200	50	20	96.0	39.6454	96.0	2.20	-6.8485	2.20
18	12	200	100	50	110.4	40.8594	110.4	2.80	-8.9432	2.80
19	15	50	20	50	162.8	44.2331	162.8	5.20	-14.3201	5.20
20	15	50	50	10	147.0	43.3463	147.0	3.60	-11.1261	3.60
21	15	50	100	20	97.0	39.7354	97.0	3.60	-11.1261	3.60
22	15	100	20	10	198.0	45.9333	198.0	2.40	-7.6042	2.40
23	15	100	50	20	206.0	46.2773	206.0	5.60	-14.9638	5.60
24	15	100	100	50	194.0	45.7560	194.0	2.40	-7.6042	2.40
25	15	200	20	20	117.4	41.3934	117.4	2.00	-6.0206	2.00
26	15	200	50	50	113.0	41.0616	113.0	2.00	-6.0206	2.00
27	15	200	100	10	104.6	40.3906	104.6	1.60	-4.0824	1.60

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