Experimental Investigation of Inconel – 600 by Using Taguchi Method and ANOVA

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Abstract:-**Electric discharge machining is categorized as a thermoelectric process in which heat energy of spark is used to remove material from the work piece. The machining process involves controlled erosion of electrically conducting material by the initiation of rapid and repetitive electrical spark discharges between the tool and work piece separated by the dielectric medium. The present work is aimed at characterizing the electric discharge machining of Inconel-600 steels on EDM. Since an electrode with micro features is employed to cut its mirror image in the work piece, it is necessary to investigate the machining efficiency of the electrodes used. Furthermore, to improve the machining efficiency, it is momentous to consider the effect of various influencing input and output parameters. In this project, a series of experiments were conducted with copper electrode as a tool and Inconel steel as work piece to machine small depth on the work piece. The combination of gap voltage, Ampere setting were new line considered for maximum Material Removal Rate (MRR), Surface Roughness (SR), constrained circularity error and overcut. The main aim was to identify the electrode which could enhance the production of quality of impression and to have a significant contribution for modern industrial requirements. Taguchi method is applied to find optimal process parameters for EDM while hard machining of hardened steel (En-353)The experiments were carried out as per L9 orthogonal array with each experiment performed under different conditions of such as Discharge Current, Pulse on time and pulse off time.**

Keywords: **EDM, TAGUCHI Method, ANOVA**

I. INTRODUCTION

Electric discharge machining is a thermo-electric non-traditional machining process. Material is removed from the work piece through localized melting and vaporization of material. Electric sparks are generated between two electrodes when the electrodes are held at a small distance from each other in a dielectric medium and a high potential difference is applied across them. Localized regions of high temperatures are formed due to the sparks occurring between the two electrode surfaces. Work piece material in this localized zone melts and vaporizes. Most of the molten and vaporized material is carried away from the inter-electrode gap by the dielectric flow in the form of debris particles. To prevent excessive heating, electric power is supplied in the form of short pulses. Spark occurs wherever the gap between the tool and the work piece surface is smallest. After material is removed due to a spark, this gap increases and the location of the next spark shifts to a different point on the work piece surface. In this way several sparks occur at various locations over the entire surface of the work piece corresponding to the work piece-tool gap. Because of the material removal due to sparks, after some time a uniform gap distance is formed throughout the gap between the tool and the work piece. However if the tool is fed continuously towards the work piece then the process is repeated and more material is removed.

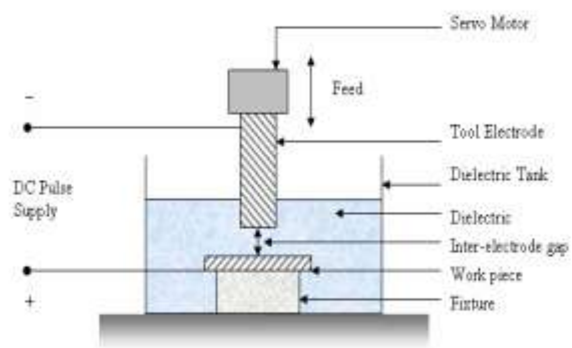


Figure 1.1: Schematic of an Electric Discharge Machining (EDM) machine tool

1.1. EDM Discharge Phenomena:

1.1.1 Phases of discharge:

The discharge process during EDM can be separated into three main phases .They are preparation phase, discharge phase and interval phase. Details of each phase are discussed below.

1.1.2 Preparation phase:

On switching on the power supply, electric field is set-up in the gap between the electrodes. The electric field reaches maximum value at the point where the gap between the electrodes is smallest. Spark location is determined by the gap distance and the gap conditions. In the presence of electrically conductive particles in the gap, thin particle bridges are formed. When the strength of the electric field exceeds the dielectric strength of the medium, electric breakdown of the medium takes place. Ionization of the particle bridges takes place and a plasma channel is formed in the gap between the electrodes. The steps in the phase are shown in Figure 2.1 (a).

1.1.3 Discharge phase:

During the discharge phase (Figure 2.1 (b)), a high current flows through the plasma channel and produces high temperature on the electrode surfaces. This creates very high pressure inside the plasma channel creating a shock wave distribution within the dielectric medium. The plasma channel keeps continuously expanding and with it the temperature and current density within the channel decreases. Plasma channel diameter stabilizes when a thermal equilibrium is established between the heat generated and the heat lost to evaporation, electrodes and the dielectric. This enlarged channel is still under high pressure

Due to evaporation of the liquid dielectric and material from the electrodes. The evaporated material forms a gas bubble surrounding the plasma channel. During this phase, high energy electrons strike the work piece and the positively charged ions strike the tool (for negative tool polarity). Due to low response time of electrons, smaller pulses show higher material removal from the anode whereas, longer pulses show higher material removal from the cathode.

1.1.4 Interval phase:

The plasma channel de-ionizes when power to the electrodes is switched off. The gas bubble collapses and material is ejected out from the surface of the electrodes in the form of vapors and liquid globules. The evaporated electrode material solidifies quickly when it comes in contact with the cold dielectric medium and forms solid debris particles which are flushed away from the discharge gap. Some of the particles stay in the gap and help in forming the particle bridges for the next discharge cycle. Power is switched on again for the next cycle after sufficient de-ionization of dielectric has occurred.

II. EXPERIMENTAL SETUP

Two electrodes were machined to a cylindrical shape of 10 mm diameter and 23mm length. A plate of 23 mm ×18 mm size and thickness 5 mm of INCONEL 600 was taken. It was subjected to a standard hardening cycle and it has a hardened at the range of 40 to 45 HRC.

One surface of the work piece was then ground on a surface grinder to remove surface irregularities and minor scaling. The hardness of this surface was measured on Rockwell Hardness Tester C scale using a diamond cone. After mounting the work piece and one of the electrodes on the machine, the depth of machining was set at 1mm. The work piece was machined with 12 A discharges current and other standard machine settings. The time of machining was recorded in minutes and final weights of the work piece were taken. The machining cycle was repeated for the next value of discharge current. Similarly, the observations were made for the other two electrodes.

For each electrode material, the effect of variation in discharge current was studied on output parameters, namely, material removal rate (MRR), machined surface roughness. Surface roughness readings were taken on the bottom surface of the machined cavity. Surface roughness was measured on Surf test equipment giving Ra value in microns.

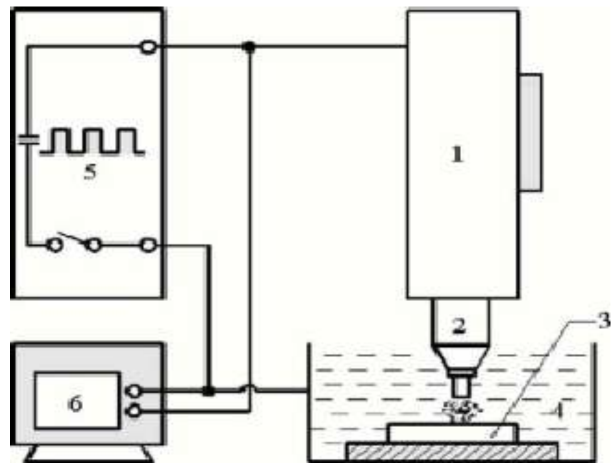


Fig. 2.1—Schematic diagram of EDM process (1- servo control, 2- electrode, 3- Specimen, 4- dielectric fluid, 5- pulse generator, 6- oscilloscope)

2.1. Electrode Materials

Electrode material has a significant influence on important output parameters, such as, material removal rate, surface roughness and dimensional accuracy. Copper and brass are two commonly used EDM electrode materials in the industry because these materials have high melting temperature and excellent electrical and

Table 2.1. Properties of Inconel work material and cooper electrode

PROPERTY	**UNIT**	**MATERIAL**
		COPPER
Thermal conductivity	W/m-K	391
Electrical resistivity	Ohm-cm	1.67
Specific heat capacity	J/g-deg C	0.385
Melting point	Deg C	1083

Thermal conductivity. Copper can be easily machined to any shape, suffers less wear, has good thermal conductivity, and is economical.

2.2. Work Material Details:

INCONEL® alloy 600 – A Ni-Cr-Fe alloy with resistance to stress-corrosion cracking and caustic corrosion, and with high-temperature strength and oxidation-resistance. Used for chemical and petrochemical processing, nuclear and automobile engineering and thermal processing. Available as billet, rod and bar, flat products, seamless tubing and wire.

2.3 CHEMICAL COMPOSITIONS OF INCONEL 600

Table 2.2. Chemical Composition.

ELEMENT	Nickel (Ni)	Cromium (Cr)	Iron (Fe)
COMPOSITION, wt%	72	14-16	6-10

2.4 Experimental Details

Dielectric Medium in EDM

Functions of Dielectric fluid plays an important role in the EDM process. Because of a high dielectric strength, the dielectric medium prevents premature discharge between the electrodes until a low discharge gap is established between them. Continuous dielectric flow in the discharge gap helps in carrying away the debris formed during the discharge and ensures a proper flushing. Also, dielectric medium cools the machining zone by carrying away excess heat from the tool electrode and the work pieces.

Properties / Medium	Dielectric strength	Dynamic viscosity	Thermal conductivity	Specific heat capacity
	MV/m	g/m-s	W/m-k	J/g-K
Kerosene	14-22	1.64	0.149	2.16

Table 2.3 Properties of Kerosene

S.No	Machining Factors	Symbol	Unit	Levels		
				1	2	3
1	Current	I	Amp	6	9	12
2	Pulse On	Ton	µs	300	600	900
3	Pulse Off	Toff	µs	30	60	90

Table 2.4 Machining Parameters and their levels

III. MECHANISM AND EVALUATION OF MRR

MRR is the rate at which the material is removed the work piece. Electric sparks are produced between the tool and the work piece during the machining process. Each spark produces a tiny crater and thus erosion of material is caused. The MRR is defined as the ratio of the difference in Volume of the work piece before and after machining to the machining time.

$$MRR = \frac{Vi - Vf}{Tmin}$$

Where,

Vi – Volume of before machining
Vf- Volume of after machining
Tmin – Time taken in machining

3.1 Mechanism and Evaluation of Surface Roughness

Surface Roughness is the measure of the texture of the surface. It is measured in µm. If the value is high then the surface is rough and if low then the surface is smooth. It is denoted by Ra. The values are measured using Portable style type profilometer, Talysurf

3.2 Experimental Design Calculation

3.2.1 Design of Experiments (DOE)

Design of Experiments (DOE) refers to planning, designing and analyzing an experiment so that valid and objective conclusions can be drawn effectively and efficiently. In performing a designed experiment, changes are made to the input variables and the corresponding changes in the output variables are observed. The input variables are called factors and the output variables are called response.

Table 3.1 Shows the design matrix used in this work.

S.NO	CURRENT	PULSE ON (Ton) **(µs)**	PULSE OFF (Toff) **(µs)**
1	6	300	30
2	6	600	60
3	6	900	90
4	9	300	60
5	9	600	90
6	9	900	30
7	12	300	90
8	12	600	30
9	12	900	60

3.3 Taguchi Method

Taguchi uses a special design of orthogonal arrays to study the entire process parameter space with only a small number of experiments. The taguchi design of experiments approach eliminates the need for repeated experiments and thus saves time, material, and cost. Taguchi technique is a powerful tool for the design of high quality systems. The taguchi approach to experimentation provides an orderly way to collect, analyze, and interpret data to satisfy the objectives of the study.

Taguchi's method is a well accepted methodology for experiment design. In this, signal-to-noise ratio(S/N) is used to represent a response or quality characteristics and the largest S/N ratio is required. There are three types of quality characteristics viz. nominal-the-better, larger-the-better and smaller-the-better. In this work, experimentally observed MRR value is "larger-the-better" and SR are "lower-the-better". Based on Taguchi's method, S/N ratio calculation is done as below)

Larger-the-better

S/N = -10 log $(1/n\sum_{i=1}^{n} 1/Yi\text{^}2)$

Smaller- the- better

S/N = -10 log (1/n$\sum_{i=1}^{n} Yi$^2)

Where Yi is the experimentally observed value and n is the repeated number of each experiment.

3.4 Calculation of Signal to noise (S/N) ratio:

Taguchi method is one of the simple and effective solutions for parameter design and experimental planning. In this method signal-to-noise ratio approach to measure the quality characteristic deviating from the desired value. S/N ratio is used as an objective function for optimizing parameters. Control factors are easily adjustable, and it is set by the manufacturer. These factors are most important in determining the quality characteristics. Noise factors are difficult, impossible, or expensive to control (weather, temperature, humidity, etc.). The S/N ratio is the ratio of mean (signal) to the standard deviation (noise). There are several S/N ratios available depending on the type of characteristics. There are three types of S/N ratio the lower-the- better, the higher the-better, and the nominal-the-better. The S/N ratio with a lower-the-better characteristic that can be expressed as:

Table 3.2 S/N ratios of different experiments for MRR and SR.

Ex.no	S/N Ratio for MRR	S/N Ratio for Surface roughness
1	37.02	-5.39
2	38.99	-2.41
3	20.61	0.175
4	40.17	-0.34
5	39.98	0.354
6	32.55	0.354
7	42.12	-0.34
8	42.30	-0.506
9	35.88	0.445

Larger-the-better (MRR)

S/N = -10 log (1/n$\sum_{i=1}^{n} 1/Yi$^2)

$$MRR = -10\ \frac{1}{1}\log\sum_{i=1}^{1}(\frac{1}{70.96*70.96})$$

MRR Value S/n Ratio = 37.02

Smaller- the- better (SR)

S/N = -10 log (1/n$\sum_{i=1}^{n} Yi$^2)

Surface Roughness Value S/n Ratio = 37.02

$$MRR = -10\ \frac{1}{1}\log\sum_{i=1}^{1}(1.86*1.86)$$

SR Value S/n Ratio = -5.39

IV. EXPERIMENTAL DATA ANALYSIS

4.1 Analysis of Variance (ANOVA)

ANOVA is to investigate the design parameters and to indicate which parameters are significantly affecting the output parameters. In the analysis the sum of squares and variance are calculated. An F-test value at 95 % confidence level is used to decide the significant factors affecting the process. Larger F- value indicates that the variation of process parameters makes a big change on the performance

Table 4.1 Response Table for Signal to Noise Ratios (MRR)

Level	Discharge current	Pulse On Time	Pulse Off Time
1	32.20	39.77	37.29
2	37.56	40.42	38.34
3	40.10	29.68	34.23
DELTA	7.9	11.39	5.16
RANK	2	1	3

Table 4.2 Analysis of Variance for S/N Ratio, using for F - Tests (MRR)

PARAMETERS	DOF	SUM OF SQUARE	MEAN VARIANCE	F-RATIO	P (% CONTRIBUTION)	RANK
Current	2	32.53	16.26	0	28.48	2
Pulse on	2	72.53	36.26	0	63.54	1
Pulse off	2	9.1226	4.56	0	7.98	3
Error	0	0	0	0	0	
Total	6	114.18	57.08	0	100	

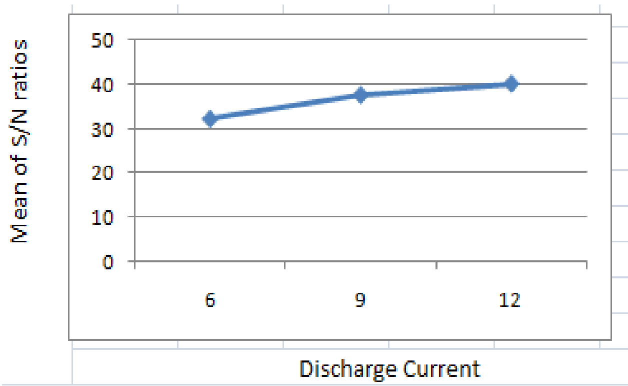
Table 4.3 Response Table for Signal to Noise Ratios (Surface Roughness)

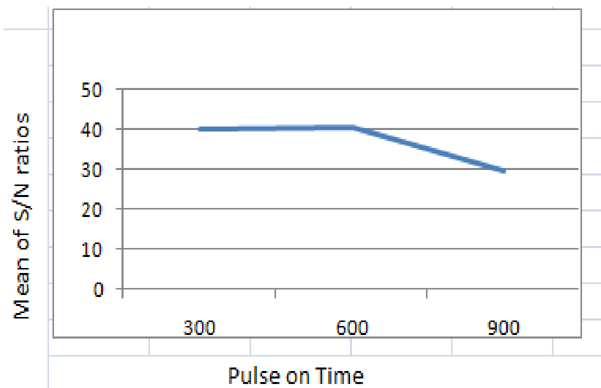
Level	Discharge current	Pulse On Time	Pulse Off Time
1	2.98	2.39	1.85
2	0.05	1.03	0.77
3	0.50	0.11	0.91
DELTA	2.93	2.28	1.08
RANK	1	2	3

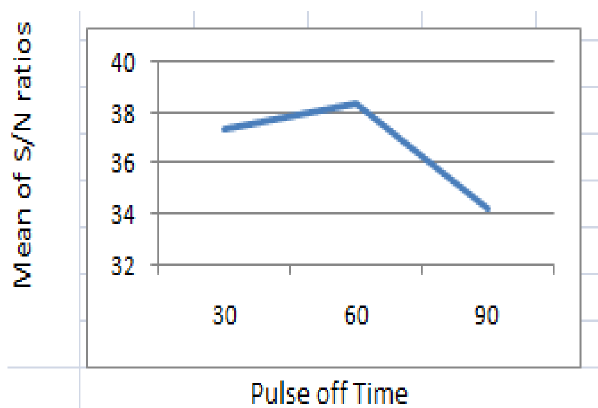
Table 4.4 Analysis of Variance for S/N Ratio, using for F - Tests (Surface Roughness)

PARAMETERS	DOF	SUM OF SQUARE	MEAN VARIANCE	F-RATIO	P (% CONTRIBUTION)	RANK
Current	2	4.97	2.48	0	59.98	1
Pulse on	2	2.63	1.31	0	31.70	2
Pulse off	2	0.69	0.34	0	8.33	3
Error	0	0	0	0	0	
TOTAL	6	8.30	4.15	0	100	

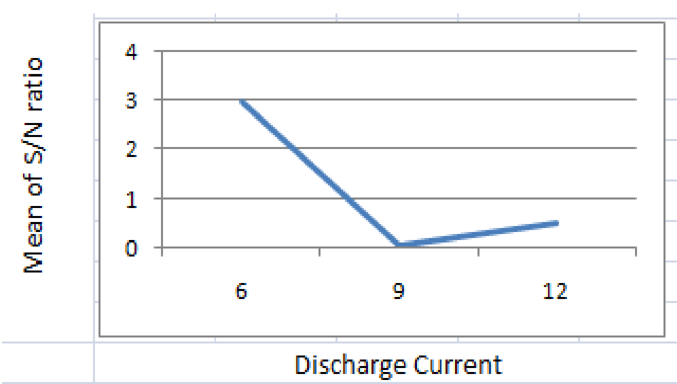
4.2 Main effect plot for mean value for MRR

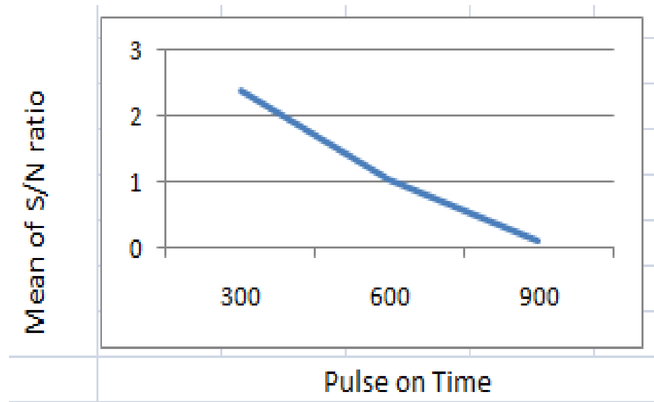


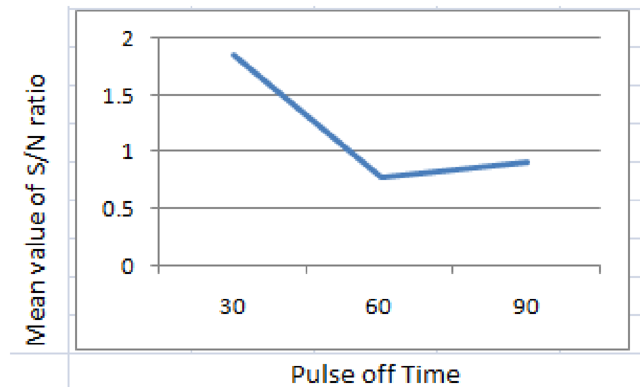




4.3 Main effect plot for mean value for SR







V. CONCLUSION

The above cause and effect diagram is very to sort out all the possible causes affecting the quality of EDM Process Performance

Taguchi method of experimental design has been applied for optimizing multi-response characteristics such as MRR (Material Removal Rate), Surface Roughness of INCONEL 600 during EDM process. For EDM while hard machining of hardened steel are optimized with L9 orthogonal array. Results obtained from taguchi method closely match with ANOVA.The conclusions of this work are summarized as follows:

- The optimal parameters combination MRR was determined as A2B1C3 i.e. Discharge current at 9A, pulse ON time at 300µs ,pulse OFF time at 90µs .
- The optimal parameters combination SR was determined as A1B2C3 i.e. Discharge current at 6A, pulse ON time at 600µs ,pulse OFF time at 90µs .

This work demonstrates the method of using Taguchi methods for optimizing the EDM parameters for multiple response characteristics.

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