

# Experimental Analysis And Optimization of Process Parameters In Machining Process of Titanium Alloys To Improve Performance on Die-Sinking Electric Discharge Machine

Aman Kumar Tiwari<sup>1</sup>, Abhishek Nigam<sup>2</sup>, Bharti Yadav<sup>3</sup>

<sup>1</sup>Dept of Mechanical Engineering

<sup>2</sup>Associate Professor, Mechanical Engineering

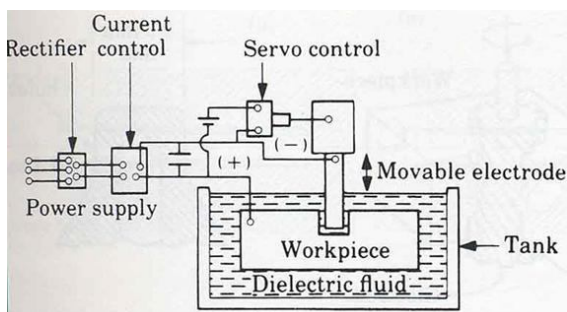
<sup>3</sup>Assistant Professor, Mechanical Engineering

<sup>1,2,3</sup> Naraina college of Engg. & Tech., Kanpur, India

**Abstract-** In electric discharge machining process, the control of erosion of the metal is achieved by the rapidly recurring spark discharges produced between two electrodes, one tool and the other work piece, and spark impinging against the surface of the work piece which must be an electrically conductive body. A suitable gap known as “spark gap” is maintained between the tool and the work piece by a servomotor which is actuated by the difference between a reference voltage and the gap breakdown voltage, which feeds the tool downwards towards the work piece.

The EDM process has become one of the most important and widely used production technologies in manufacturing.

The dielectric fluid fills up spark gap. The dielectric fluid may be typical hydrocarbon oil or de-ionized water which helps in cooling down the tool and the work piece, cleans the inter-electrode gap, and concentrates the spark energy into small cross-sectional area under the electrode.



. Fig.(a) Schematic Diagram of EDM Process

The principle of electrical-discharge machining (EDM) (also called electro-discharge or spark-erosion machining) is based on the erosion of metals by spark discharges. We know that when two current-conducting wires are allowed to touch each other, an arc is produced. If we look closely at the point of contact between the two wires, we note that a small portion of the metal has been eroded away, leaving a small crater. Although this phenomenon has been known since the discovery of electricity, it was not until the 1940s that a machining process based on that principle was developed.

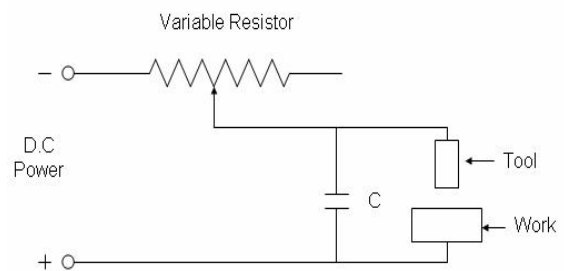


Fig. (b) Working Principle of EDM

**Keywords-** Machining, DOE, Taguchi, ANOVA, Orthogonal Array, Titanium alloy workpiece, MRR .

## I. INTRODUCTION

EDM has C type of construction. Its main components are given as under:

1. Control Unit
2. Electrode holder
3. Electrode feed mechanism
4. Tank
5. Fixture

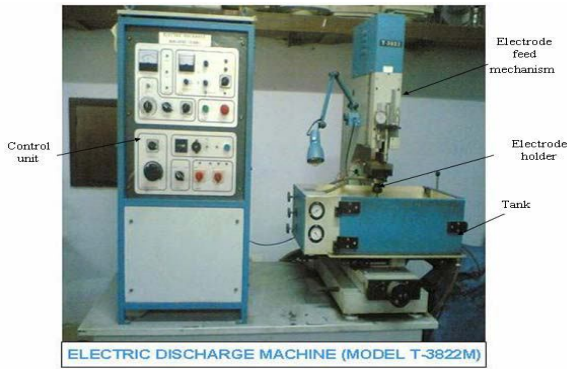


Figure (c) Electric Discharge Machine

**I.A. PRINCIPLE OF OPERATION**

The basic EDM system consists of a shaped tool (electrode) and the workpiece, connected to a DC power supply and placed in a dielectric (electrically nonconducting) fluid Fig.(d). When the potential difference between the tool and the work-piece is sufficiently high, the dielectric breaks down and a transient spark discharges through the fluid, removing a very small amount of metal from the work-piece surface. The capacitor discharge is repeated at rates between 200 and 500 kHz, with voltages usually ranging between 50 and 380 V and currents from 0.1 to 500 A. The volume of material removed per spark discharge is typically in the range from  $10^{-6}$  to  $10^{-4}$  mm<sup>3</sup>.The EDM process can be used on any material that is an electrical conductor.

The melting point and the latent heat of melting are important physical properties that determine the volume of metal removed per discharge.

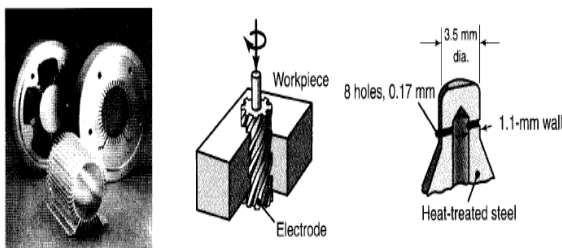
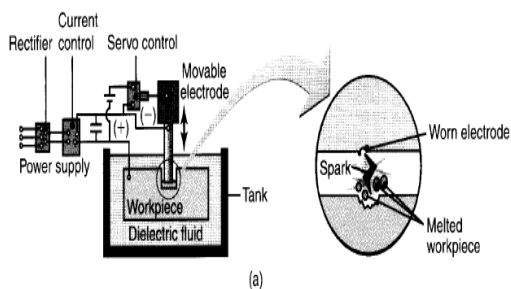


Figure (d) Working Principle of Basic EDM

**I.B. DIELECTRIC FLUIDS**

The functions of the dielectric fluid are to

1. Act as an insulator until the potential is sufficiently high.
2. Provide a cooling medium.
3. Act as a flushing medium and carry away the debris in the gap.

The most common dielectric fluids are mineral oils, although kerosene and distilled and de-ionized water also are used in specialized applications. Clear, low viscosity fluids also are available; although more expensive, these fluids make cleaning easier. The machines are equipped with a pump and filtering system for the dielectric fluid.

**I.C. ELECTRODES**

Electrodes for EDM usually are made of graphite, although brass, copper, or copper-tungsten alloys also are used. The tools can be shaped by forming, casting, powder metallurgy, or CNC machining techniques. Tungsten-wire electrodes as small as 0.1 mm in diameter have been used to produce holes with depth-to-hole diameter ratios of up to 400:1.

The sparks in this process also erode away the electrode, changing its geometry and adversely affecting the shape produced and its dimensional accuracy.

Tool (electrode) wear is thus an important factor. Wear ratio is defined as the ratio of the volume of workpiece material removed to the volume of tool wear. This ratio ranges from about 3:1 for metallic electrodes to as high as 100:1 for graphite electrodes.

**I.D.PROCESS CAPABILITIES**

Electrical-discharge machining has numerous applications, such as the production of dies for forging, extrusion, die casting, injection molding, and large sheet-metal automotive-body components (produced in die-sinking machining centers with computer numerical control). Other applications include deep, small-diameter holes with tungsten wire used as the electrode, narrow slots in parts, cooling holes in superalloy turbine blades, and various intricate shapes. Because of the molten and resolidified (recast) surface structure, high rates of material removal produce a very rough surface finish with poor surface integrity and low fatigue properties. Therefore, finishing cuts are made at low removal rates, or the recast layer is removed

subsequently by finishing operations, It has been shown that surface finish can be improved by oscillating the electrode in a planetary motion at amplitudes of 10 to 100 μm.

**I.E. DESIGN CONSIDERATIONS**

The general design guidelines for electrical-discharge machining are as follows:

- Parts should be designed so that the required electrodes can be shaped properly and economically.
- Deep slots and narrow openings should be avoided.
- For economic production, the surface finish specified should not be too fine.
- In order to achieve a high production rate, the bulk of material removal should be done by conventional processes (roughing out).

**II. MATERIAL-REMOVAL RATE IN EDM**

The material-removal rate can be estimated from the approximate empirical formula

$$MRR = 4 \times 10^4 I T_w^{-1.23}$$

where MRR is in mm<sup>3</sup>/min, I is the current in amperes, and T<sub>w</sub> is the melting point of the workpiece in °C.

Because the process doesn't involve mechanical energy, the hardness, strength, and toughness of the workpiece material do not necessarily influence the removal rate. The frequency of discharge or the energy per discharge, the voltage, and the current usually are varied to control the removal rate. The removal rate and surface roughness increase with (a) increasing current density and (b) decreasing frequency of sparks.[1]

**III.WORK PIECE MATERIAL**

**III.A. Chemical Composition of Material**

The work piece material taken for this study was Titanium Alloy Grade-V (Ti6Al4V). Its composition is presented in Table(a) as given below:

Table (a) Chemical Composition of Titanium Alloy of Grade-V

N	C	H	Fe	O	Al	V	Ti
0.05%	0.1%	0.0125%	0.04%	0.2%	5.50-6.75%	3.5-4.5%	Balance

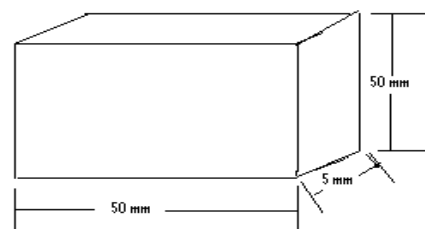
**III.B. Physical Properties of Work piece Material**

Work piece	-	Ti-6Al-4V
Hardness (HRC)	-	36-39
Solidus temperature (°C)	-	1,604±11
Liquides temperature (°C)	-	1,660±14
Density (g/cm <sup>3</sup> )	-	4.043
Elastic modulus (kg/mm <sup>2</sup> )	-	11,200
Yield strength (kg/mm <sup>2</sup> )	-	84.2
Tensile strength (kg/mm <sup>2</sup> )	-	91.3
Elongation (%)	-	10
Thermal conductivity (Cal/s.cm.°C)	-	0.016
Poisson ratio	-	0.33
Electrical resistivity (μΩ.m)	-	1.7

**III.C. DESCRIPTION OF WORK PIECE**

Material: Titanium Alloy Grade-V (Ti6Al4V)

Density of Material=4.37 x10<sup>-3</sup> g/mm<sup>3</sup>



Figure(e) Work piece

**IV. DESCRIPTION OF TOOL**

Material: Copper

**IV.A. Tool Material**

The tool material selected for this investigation was pure copper. The electrode is in the form of hook. The properties of copper electrode are given below in Table (b)-

Table (b) Properties of Copper Electrode

Density	Electrical Receptivity	Purity	Melting Point
8.9 kg/m <sup>3</sup>	0.0167 Ωmm <sup>2</sup> /m	99.9%	1083 °C

**IV.B. Dielectric Fluid**

The dielectric fluid used for experimentation was commercial grade kerosene. Table (c) shows the properties of kerosene oil.

Table(c) Properties of Commercial Grade Kerosene

Surface Tension (N/m)	Density (kg/m <sup>3</sup> )	Dynamic Viscosity (Pas)
0.028	820	2400

**V. PROCESS PARAMETERS (INPUT VARIABLES)**

The process parameters that were chosen for experimentation are given as under:

- Peak current
- Pulse on time (μs)
- Pulse off time (μs)
- Voltage (V)
- Fluid Pressure

**VI. OPTIMIZATION OF PROCESS PARAMETERS TO MAXIMIZE THE MRR**

Optimization of Process Parameter of Titanium Alloy (Ti6Al4V) On Die-Sinking Electric Discharge Machine are

- Pulse on time
- Pulse Off time
- Voltage and
- Fluid Pressure

To make analysis by using Taguchi method in optimizing Electrical Discharge Machine (EDM) parameters. Design Of Experiment (DOE) methodology is applied to define the main parameters and relationship between parameters. Study the material removal rate (MRR) to Analysis the material of work piece after Machining.

**VII. METHODOLOGY**

The purpose of this paper is to fulfill the criteria of optimization under which the MRR is to be increased. There are some proper steps by which the MRR will be optimized are falls under this categories:

1. To make a list of parameter involved which are mostly responsible to affect the MRR.
2. Based on the experimental conditions, collect the data related with machining process which is collected by orthogonal array and parameter level.
3. Now optimize the all individual parameter at the optimized level by the optimization techniques.
4. Verify the optimum settings result in the predicted result of metal removal rate.
5. The process parameters of the machining by EDM process can be listed as follows:
  - Pulse on time (Micron Sec.)
  - Pulse off time (Micron Sec.)
  - Voltage (V)
  - Fluid Pressure (Kg/cm<sup>2</sup>)

For each parameter during a process a range is decided between the different levels which optimize the parameter to a certain level and is acceptable in the manufacturing of a product of an organization for the purpose to increase Pulse Off time the production rate. The parameters, along with their ranges and different levels are given in the following Table-(d).

Table (d) Parameters and Level for Machining

Symbol	Control Factor	Unit	Level 1	Level 2	Level 3
W	Pulse on Time	Micron Sec.	120	125	130
X	Pulse off Time	Micron Sec.	40	45	50
Y	Fluid Pressure	Kg/cm <sup>2</sup>	3	4	5
Z	Voltage	V	45	50	55

**VIII. MEASUREMENT OF RATE OF MRR BY TAGUCHI METHOD**

Taguchi developed a special design of orthogonal arrays to study the entire parameter space with a small number of experiments only. The experimental results are then transformed into a signal-to-noise (S/N) ratio. It uses the S/N ratio as a measure of quality characteristics deviating from or nearing to the desired values. There are three categories of

quality characteristics in the analysis of the S/N ratio, i.e. the lower the better, the higher the better, and the nominal the better. The formula used for calculating S/N ratio is given below.

- Smaller the better: It is used where the smaller value is desired.

$$S/N \text{ Ratio}(\eta) = -10 \log_{10}[\sum(y_i^2/n)]$$

where  $y_i$  = observed response value and  $n$  = number of replications.

- Nominal the best: It is used where the nominal or target value and variation about that value is minimum.

$$S/N \text{ Ratio}(\eta) = -10 \log_{10}(\mu^2/\sigma^2)$$

where  $\mu$  = mean and  $\sigma$  = variance.

- Higher the better: It is used where the larger value is desired.

$$S/N \text{ Ratio}(\eta) = -10 \log_{10}[\sum(y_i^2/n)]$$

where  $y_i$  = observed response value and  $n$  = number of replications.

Taguchi suggested a standard procedure for optimizing any process parameters. The steps involved are:

- Determination of the quality characteristic to be optimized.
- Identification of the noise factors and test conditions.
- Identification of the control factors and their alternative levels.
- Designing the matrix experiment and defining the data analysis procedure.
- Conducting the matrix experiment.
- Analyzing the data and determining the optimum levels of control factors.
- Predicting the performance at these levels.

**(A) Formation of Orthogonal Array L9**

Formation of an orthogonal array depends upon the number of control factors and interaction of interest. It also depends upon number of levels for the control factors of interest. Therefore with one control factor Pulse on time of two levels and other control factors Pulse Off time, Voltage and Fluid Pressure; an orthogonal array is selected with 9 experimental runs and four columns.

Taguchi has provided in the assignment of factors and interaction to arrays. The assigned L9 orthogonal array is shown in Table (e) and the experimental orthogonal array having their levels are assigned to columns is shown in Table (f).

Table –(e) ORTHOGONAL ARRAY L9

Trail No.	W	X	Y	Z
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

**(B) Experimental Orthogonal Array L9:**

A Table can also be drawn on the basis of above designed orthogonal array, which is shown in the table(f)

Table –(f) EXPERIMENTAL ORTHOGONAL ARRAY L9

Trial No.	W	X	Y	Z
	Pulse on Time (Micron Sec.)	Pulse off Time (Micron Sec.)	Fluid Pressure (Kg/cm <sup>2</sup> )	Voltage (V)
1	120	40	3	45
2	120	45	4	50
3	120	50	5	55
4	125	40	4	55
5	125	45	5	45
6	125	50	3	50
7	130	40	5	50
8	130	45	3	55
9	130	50	4	45

**IX. RESULTS OF EXPERIMENT & S/N RATIO**

The result of this experiments is obtained by conducting thrice for the same set of parameters using a single-repetition randomization technique .The Metal Removal Rate (MRR), that occur in each trial conditions in Electro-discharge machining were found and recorded. The average of the Metal Removal Rate (MRR), was also determined for each trial condition as shown in Table (h). The Metal Removal Rate (MRR) is “Higher the better” type of quality characteristics. Higher the better S/N ratios were

computed for each of the 9 trials and the values are given in Table (g)-

Table (g) Experimental Results on E.D.M. Machine with S/N Ratio

Trial No.	Pulse on Time (Micron Sec.)	Pulse off Time (Micron Sec.)	Fluid Pressure (Kg/cm <sup>2</sup> )	Voltage (V)	MRR (mm <sup>3</sup> /min)	S/N Ratio
1	120	40	3	45	1.7816	-5.016
2	120	45	4	50	1.9099	-5.621
3	120	50	5	55	2.019	-6.103
4	125	40	4	55	1.9626	-5.857
5	125	45	5	45	1.9344	-5.731
6	125	50	3	50	2.0366	-6.178
7	130	40	5	50	1.747	-4.845
8	130	45	3	55	1.9581	-5.837
9	130	50	4	45	1.9246	-5.687

The initial weight, final weight and machining time for each of the 9 trial in EDM with MRR is given in below table for better understanding in table (h)-

Table (h) Weight Calculation of Workpiece before and after Machining

Trial No.	Initial Weight W <sub>i</sub>	Final Weight W <sub>f</sub>	Machining Time t(min)	MRR (mm <sup>3</sup> /min) = (W <sub>i</sub> - W <sub>f</sub> ) / ρ × t
1	54.3328	54.0603	35	1.7816
2	54.0603	53.8099	30	1.9099
3	53.8099	53.5452	30	2.019
4	56.0217	55.7644	30	1.9626
5	52.8515	52.5979	30	1.9344
6	55.5106	55.2436	30	2.0366
7	51.4689	51.2403	28	1.747
8	51.2403	51.0007	28	1.9581
9	51.0007	50.7652	28	1.9246

**X . MEAN EFFECT PLOTS TABLE FOR S/N RATIO**

The table (i) for the mean effects of various parameters on the S/N Ratio is given in the following table-

Level No.	Pulse on Time (Micron Sec.)	Mean S/N Ratio	Pulse off Time (Micron Sec.)	Mean S/N Ratio
1	120	-5.580	40	-5.239
2	125	-5.922	45	-5.729
3	130	-5.456	50	-5.989

Level No.	Fluid Pressure (Kg/cm <sup>2</sup> )	Mean S/N Ratio	voltage (V)	Mean S/N Ratio
1	3	-5.677	45	-5.478
2	4	-5.722	50	-5.548
3	5	-5.559	55	-5.932

Table (i) Mean effects of various parameters with S/N Ratio

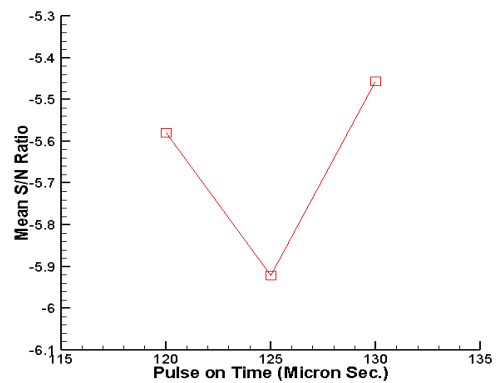


Fig.(a)

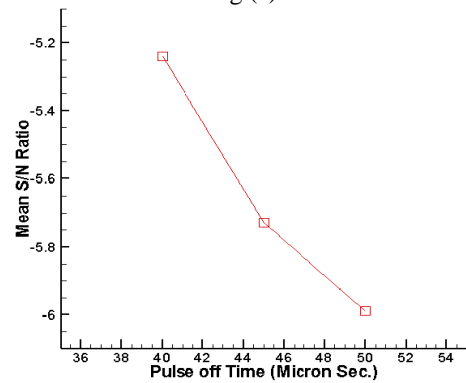


Fig.(b)

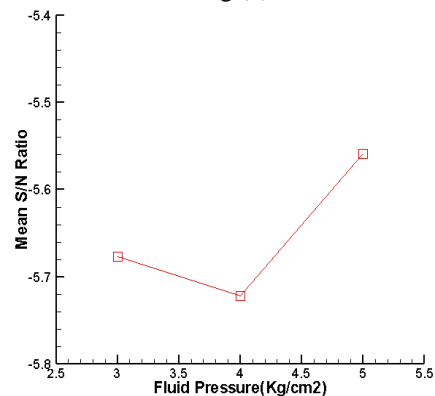


Fig.(c)

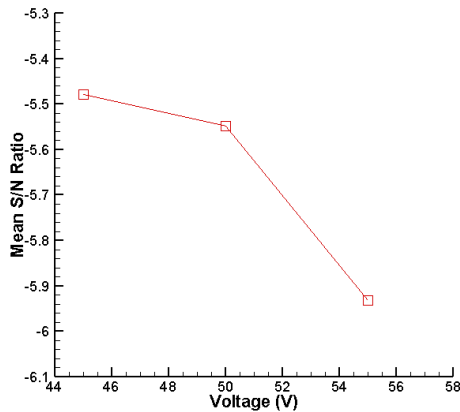


Fig.(d)

**Fig.7-** (S/N) Ratio v/s different machining process properties referring fig (a),(b),(c) and (d).

### IX. CONCLUSION

The optimum conditions for the parameter computed for the EDM process are given below as (in trial no.7 due to Maximum S/N Ratio)-

Pulse on time (Micron Sec.)– level 3 –130

Pulse off time (Micron Sec.)– level 1 – 40

Fluid Pressure (Kg/cm<sup>2</sup>)– level 3 – 5

Voltage (V)– level 2 – 50

The improvement expected in maximization of the material-removal rate (MRR) with EDM is 16.57% more than the present value which means the material-removal rate (MRR) is optimized at the maximum extent of 16.57% more than the present value. This also reflect that by using Taguchi method the factor levels when optimized will result in increase of material-removal rate and increase the yield percentage of the accepted machined product without any additional investment. A usage of quality tools like pareto chart is useful for finding the maximum MRR in the daily operations of machining. Quality of machined surface can be improved by aesthetic look, dimensional accuracy, better understanding of noise factor and interaction between variables, quality cost system based on individual product, scrap reduction, reworking of machining and process control.

### X. FUTURE SCOPE

The present method adopted to solve the optimization problem of EDM process is simple enough and is flexible in selection of objective functions for such manufacturing processes. During the solution of the problem, it has been found that the results obtained by the Taguchi method towards the exact solutions. This approach may be coupled to other

optimization algorithms to get multistage multi-criterion optimization by Taguchi approach. Then this method will be able to show its importance in real life complex manufacturing problem solution.

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