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An Experimental Investigation of Tool Wear Rate And Surface Roughness In Machining Process of Titanium Alloys on Die-Sinking Electric Discharge Machine

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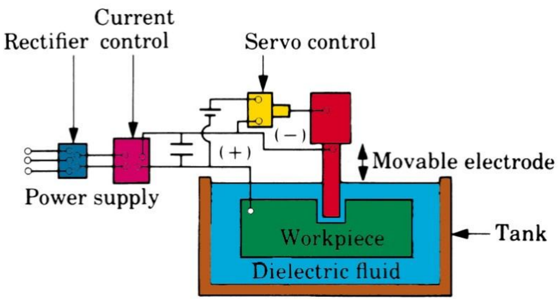
Abstract- *In electric discharge machining process, the control of erosion of the metal is achieved by the rapidly recurring spark discharges produced between two electrodes, one tool and the other work piece, and spark impinging against the surface of the work piece which must be an electrically conductive 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.*



. 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.

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.

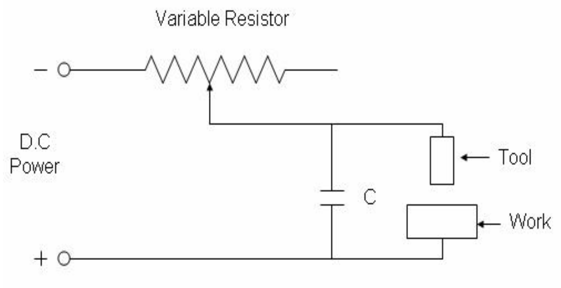


Fig. (b) Working Principle of EDM

Keywords- Machining, DOE, Taguchi, ANOVA, Orthogonal Array, Titanium alloy workpiece, TWR and Surface Roughness.

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

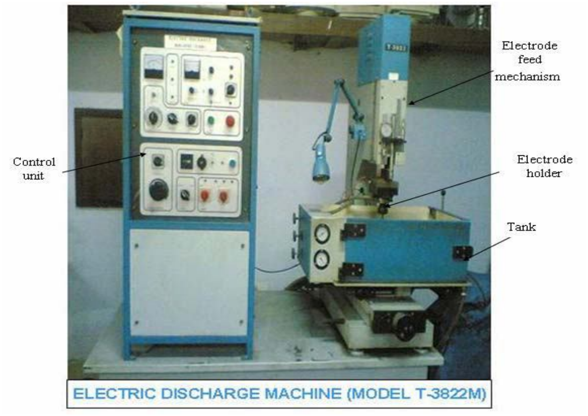


Figure (c) Electric Discharge Machine

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^3.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.

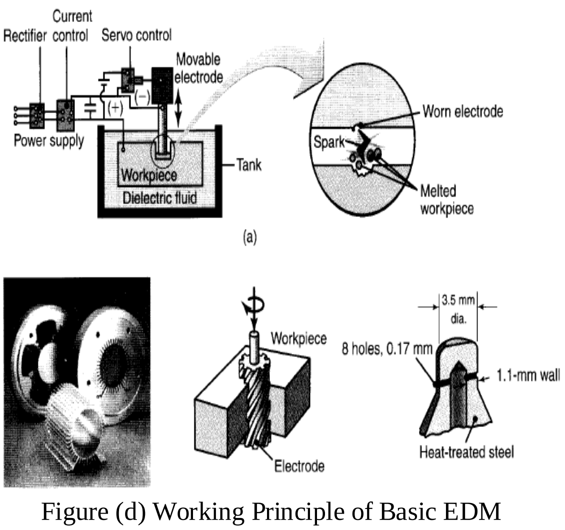


Figure (d) Working Principle of Basic EDM

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. Tungtsen-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).
- In order to achieve minimum tool wear rate and surface roughness ,lubricant and fluid pressure is also required.

II. TOOL WEAR RATE (TWR) AND SURFACE ROUGHNESS IN EDM

The Tool Wear Rate can be estimated from the approximate empirical formula

$$\textbf{TWR} = \frac{Wi-Wf}{\rho \times t}\ mm3/min$$

Where,

W_i = Weight of Tool before machining
W_f = Weight of Tool after machining
ρ = Density of Tool material=8.9 kg/m^3
t = Machining Time.

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]

The surface roughness's (Ra) of machined surfaces were measured using a Rant Taylor Hobson-SURTRONICS 3P with the cut-off length set as 1.88 mm. Each trail was repeated for three times and the average roughness values were obtained. Then, Design-Expert 8.0.7.1 software based orthogonal array was used in this multi-objective optimization and process parameters were optimized .

This instrument is a shop–floor type surface-roughness measuring instrument, which traces the surface of various machine parts and calculates the surface roughness based on roughness standards, and displays the results in µm. The vertical stylus displacement during the trace is processed and digitally displayed on the liquid crystal display of the SJ-201P is as shown in figure (e).

Figure (e) Surface Roughness machine

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 %	0.4 %	0.20 %	5.50-6.75 %	3.5-4.5 %	Balance%

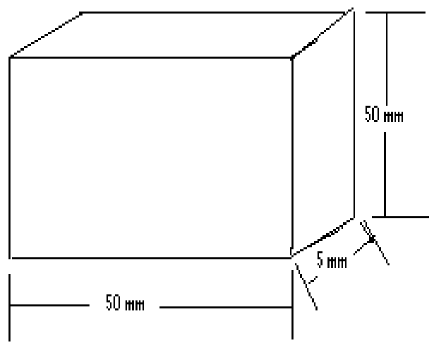
III.B. Physical Properties of Work piece Material

Work piece	-	Ti–6Al–4V
Hardness (HRC)	-	36~39
Solidus temperature (°C)	-	1,604±11
Liquides temperature (°C)	-	1,660±14
Density (g/cm^3)	-	4.043
Elastic modulus (kg/mm^2)	-	11,200
Yield strength (kg/mm^2)	-	84.2
Tensile strength (kg/mm^2)	-	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^{-3} g/mm^3



Figure(f) 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/m3	0.0167 Ωmm^2/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^3)	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 MINIIMIZE THE TWR

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 tool wear rate (TWR) and surface roughness 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 TWR and surface roughness is to be decreased. There are some proper steps by which the TWR and surface roughness will be optimized are falls under this categories:

1. To make a list of parameter involved which are mostly responsible to affect the TWR and surface roughness.
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^2)

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
A	Pulse on Time	Micron Sec.	120	125	130
B	Pulse off Time	Micron Sec.	40	45	50
C	Fluid Pressure	Kg/cm^2	3	4	5
D	Voltage	V	45	50	55

VIII. MEASUREMENT OF RATE OF TOOL WEAR AND SURFACE ROUGHNESS 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.

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

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.

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

where μ = mean and σ = variance.

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

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

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

Trial No.	A Pulse on Time (Micron Sec.)	B Pulse off Time (Micron Sec.)	C Fluid Pressure (Kg/cm^2)	D 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

(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

Trail 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

IX. RESULTS OF EXPERIMENT

The result of this experiments is obtained by conducting thrice for the same set of parameters using a single-repetition randomization technique .The Tool Wear Rate (TWR) and surface roughness , that occur in each trial conditions in Electro-discharge machining were found and recorded. The average of the Tool Wear Rate (TWR) and surface roughness, was also determined for each trial condition as shown in Table (h). The Tool Wear Rate (TWR) and surface roughness is “Smaller the better” type of quality characteristics. Smaller the better values were computed for each of the 9 trials and the values are given in Table (h)-

Table (g) Experimental OA on E.D.M. Machine with Machining Time

Trial No.	Pulse on Time (Micron Sec.)	Pulse off Time (Micron Sec.)	Fluid Pressure (Kg/cm^2)	Voltage (V)	Machin-ing Time (min.)
1	120	40	3	45	35
2	120	45	4	50	30
3	120	50	5	55	30
4	125	40	4	55	30
5	125	45	5	45	30
6	125	50	3	50	30
7	130	40	5	50	28
8	130	45	3	55	28
9	130	50	4	45	28

After the formation of Experimental orthogonal array on E.D.M. machine ,some values of different parameters was calculated and applied for the experiment to determine the different values of Tool Wear Rate (TWR) and surface roughness.

The initial weight, final weight , Tool Wear Rate (TWR) and surface roughness for each of the 9 trial in EDM 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_i(gram)	Final Weight W_f(gram)	TWR= $\frac{Wi-Wf}{\rho \times t}$ (mm^3 / min)	Roughness Value R_a(μm)
1	11.4893	11.4855	35	0.68
2	11.4855	11.4834	30	1.16
3	11.4834	11.4815	30	0.76
4	11.4815	11.4794	30	0.85
5	11.4706	11.4704	30	0.86
6	11.4797	11.4777	30	0.92
7	11.4777	11.474	28	1.03
8	11.4740	11.4719	28	2.13
9	11.4719	11.4706	28	0.48

X . MEAN EFFECT PLOTS TABLE FOR TWR AND SURFACE ROUGHNESS W.R.T. PARAMETERS

The table (i) for the mean effects of various parameters on the TWR is given in the following table-

Table (i) Mean effects of various parameters with Mean TWR

Level No.	Pulse on Time (Micron Sec.)	Mean TWR	Pulse off Time (Micron Sec.)	Mean TWR
1	120	31.67	40	31
2	125	30	45	29.33
3	130	28	50	29.33
Level No.	**Fluid Pressure (Kg/cm^2)**	**Mean TWR**	**Voltage (V)**	**Mean TWR**
1	3	31	45	31
2	4	29.33	50	29.33
3	5	29.33	55	29.33

The table (j) for the mean effects of various parameters on the Surface Roughness is given in the following table-

Level No.	Pulse on Time (Micron Sec.)	Mean Surface Roughness	Pulse off Time (Micron Sec.)	Mean Surface Roughness
1	120	0.86	40	0.85
2	125	0.87	45	1.38
3	130	1.21	50	0.72
Level No.	**Fluid Pressure (Kg/cm^2)**	**Mean Surface Roughness**	**Voltage (V)**	**Mean Surface Roughness**
1	3	3.73	45	2.02
2	4	2.49	50	3.11
3	5	2.63	55	3.74

Table (j) Mean effects of various parameters with Mean Surface Roughness

The various graphs along with mean effects of various parameters on the TWR and Surface Roughness are given in below diagrams-

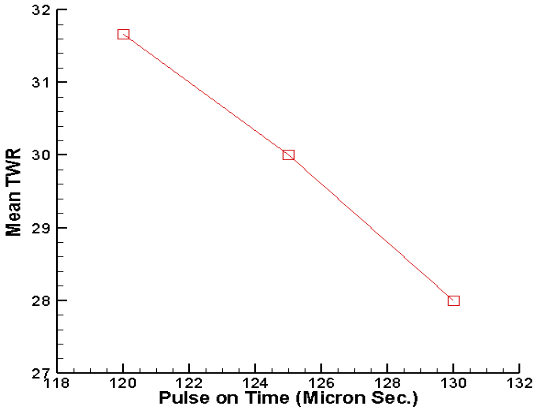


Figure (g) Pulse on Time **(**Micron Sec.) vs Mean TWR

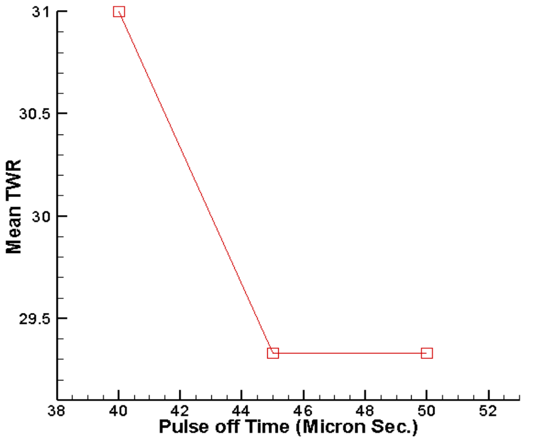


Figure (h) Pulse off Time **(**Micron Sec.) vs Mean TWR

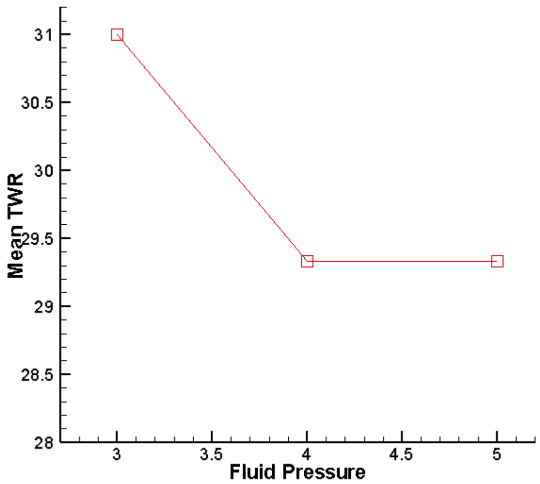


Figure (i) Fluid Pressure (Kg/cm^2) vs Mean TWR

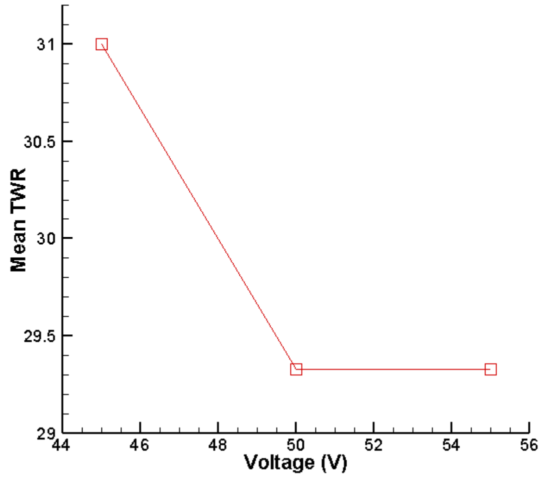


Figure (j) Voltage (V) vs Mean TWR

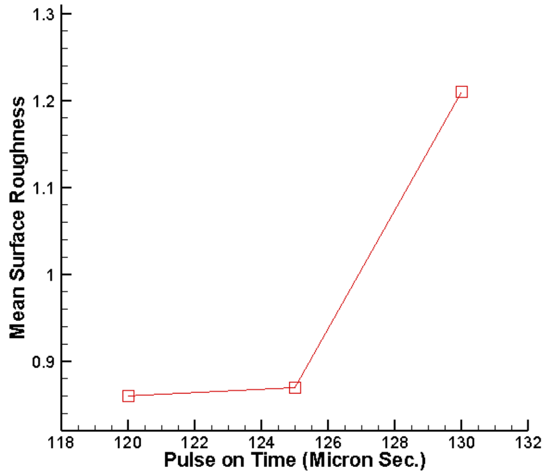


Figure (k) Pulse on Time **(**Micron Sec.) vs Mean Surface Roughness

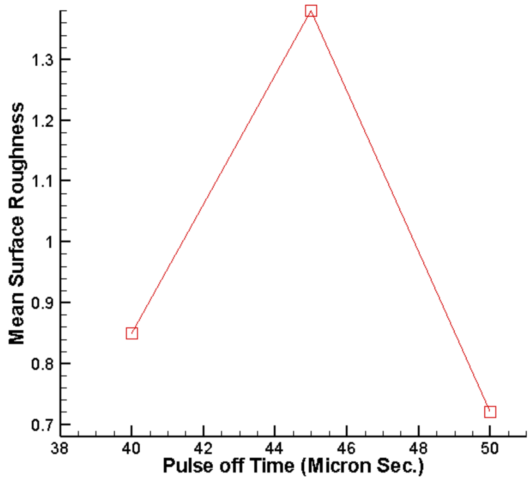


Figure (l) Pulse off Time **(**Micron Sec.) vs Mean Surface Roughness

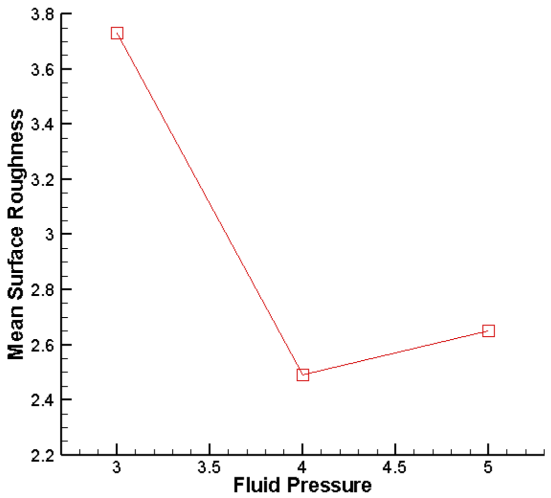


Figure (m) Fluid Pressure (Kg/cm^2) vs Mean Surface Roughness

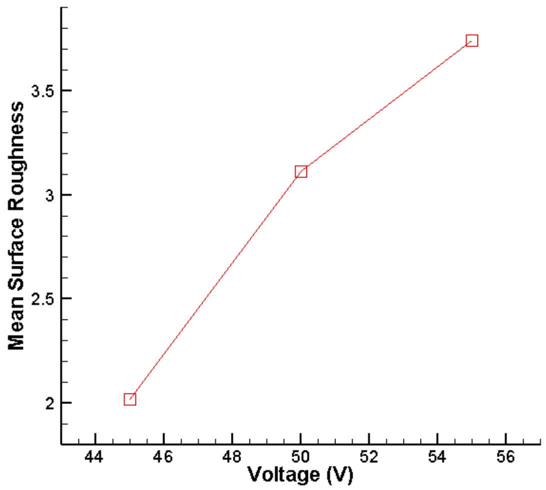


Figure (n) Voltage (V) vs Mean Surface Roughness

IX. CONCLUSION

The optimum conditions for the tool wear rate computed for the EDM process are given below –

Pulse on time (Micron Sec.)– level 3 –130
Pulse off time (Micron Sec.)– level 2 – 45
Fluid Pressure (Kg/cm^2)– level 2 –4
Voltage (V)– level 2 – 50
The optimum conditions for the surface roughness computed for the EDM process are given below -
Pulse on time (Micron Sec.)– level 1 –120
Pulse off time (Micron Sec.)– level 3 – 50
Fluid Pressure (Kg/cm^2)– level 2 – 4
Voltage (V)– level 1 – 45

The improvement expected in minimization of the tool wear rate (TWR) and surface roughness with EDM is 10% and 77% respectively. This also reflect that by using Taguchi method the factor levels when optimized will result in decrease of tool wear rate and surface roughness of the accepted machined product without any additional investment. A usage of quality tools like pareto chart is useful for finding the minimum tool wear rate and surface roughness 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 experimental 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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