# Optimization of Process Parameters of Electrical Discharge Machining For Stainless Steel 410

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***Abstract*— In this EDM process various techniques are applied to improve the material removal rate (MRR) and surface roughness (SR) with different electrode combinations and input parameters. However, the machining parameters are also effective while machining. In this study, an experiment is performed to analyze the effect of machining parameters viz. discharge current (I), pulse on time (Ton), pulse off time (Toff) and voltage (V) over the responses of MRR and SR. For this Copper tool or electrode is used while the workpiece is chosen as AISI 410 stainless steel which is utilized for manufacturing of various products in our daily life. For the conduction of experiments we used analysis of variance and we found that pulse off time (Toff) is most significant factor after that pulse on time (Ton), discharge current (I) and voltage (V) over response of MRR and in case of SR discharge current (I) is the effective parameter. For analysis and explanations ANOVA software Minitab18 is used.**

***Index Terms:*** **EDM, Material Removal Rate, Surface Roughness, Discharge current, Pulse-on time, Pulse-off time, Voltage, Copper, AISI 410 Stainless steel, ANOVA.**

## 1.INTRODUCTION

Electrical Discharge Machining is a most basic non-traditional machining process, where material is removed by thermal energy of spark occurring by means of repeated sequences of electrical ejections between the small gap of an electrode and a work piece. EDM is commonly used for machining of electrically conductive hard metals and alloys in automotive, aerospace and die making industries. EDM process is removing undesirable material in the form of debris and produce shape of the tool surface as of a metal portion by means of a recurring electrical ejection stuck between tool i.e. cathode and the workpiece i.e. anode material in the existence of dielectric liquid. In this machining process work piece is called the anode because it is connected with a positive terminal and electrode is connected with negative terminal i.e. called cathode. Dielectric fluid may be kerosene, transformer oil, distilled water, etc.

In this machining method the metallic particle is removed as of the workpiece owed to controlled wearing away action by means of repeatedly occurring spark ejection with the help of discharge current applied by power supply taking place in a small gap in the range of 10 –125 µm between the tool and work piece. A small break is kept among the tool and workpiece through a servo control arrangement in which the tool is attached. Both the electrode and workpiece stay immersed in a dielectric liquid. Kerosene/EDM oil/deionized water is use for liquid dielectric as a catalyst for the machining process.

## 2.LITERATUREREVIEW

Vishnu D Asal et al. conducted [1] an experiment on Process parameters of EDM by using the ANOVA method. In this experiment, two levels of current, tool material, and spark gap are kept as the main variable. They use the material of S.S.304 as the work piece and copper and brass as the tool electrode and also DEF-92 as dielectric fluid. The design of the experiment is used to design the EDM experiments. The various tools of DOE are used to analyze the final result of the experiment with the help of graphs in research. The analysis is being done with the help of Minitab 15 software. ANOVA is performed to identify the statistical significance of parameters. They conclude that the Material Removal Rate process accounts for over 88.31 percent main effects of the total variability. The MRR is maximum achieved when tool material is Copper, current is higher level (17 amp), and spark gap volts is set as low (5 volts). The TWR is achieved maximum at the tool is Copper, current is higher level (17 amp), and spark gap voltage is low level (5 volts). For surface roughness is minimum at the current is at low level (9 amp) and spark gap voltage at low level (5 volts). It also noticed that tool material does not show any effect on surface roughness.

Chandramouli S et al. conducted [2] investigating EDM process parameters by using the Taguchi method and selected the optimum result from that. The effect of various process parameters on machining performance is investigated by the Taguchi method. They use the input parameters as current, pulse time on, and pulse time off and the other side of Material removal rate (MRR), Tool wear rate (TWR), and surface roughness (SR). The Taguchi method is used to formulate the experimental layout, Parameter optimization of Electro Discharge Machine of AISI 304 Steel by using Taguchi Method. Kapil Banker1, et al. [3] ANOVA method is used to analysis the effect of input parameters on machining characteristics and find the optimum process parameters. They conclude that for getting optimum MRR the set of process parameters are current is high level (24 amp), pulse time on is low level (10 µs) and pulse off time is high level (50 µs). The TWR is decreasing with increase in pulse time on and it increases with pulse time off increase. The optimum set of surface roughness is current is low level (6 amp), pulse time on is low level (10 µs), and pulse time off is high level (50 µs).

B. Sidda Reddy et al.[4] studied that influence by design four factors such as current, servo control, duty cycle and open circuit voltage over the outputs on MRR, TWR, SR and hardness on the die-sinker EDM of machining AISI 304 SS. They had employed DOE technique with mixed level design and analyze for performing a minimum number of runs. They achieved that for higher MRR, the current, servo and duty cycle should be fixed as high levels and 95% confidence level with descending order in case of TWR with the same factors.

M.M. Rahman et al. [5] experimentally found out the machining characteristic of austenitic stainless steel 304 through electric discharge machining. The investigation shows that increasing current increases the MRR and surface roughness. The TWR increases with peak current until 150 µsec pulse on time. And from the results they were found for copper electrodes with a long pulse on time no tool wear with reverse polarity.

S. K. Dewangan investigated [6] the effect of machining parameter settings like pulse on time, discharge current and diameter of tool of AISI P20 tool steel material using U-shaped copper electrode with interior flushing technique. Experiments were conducted with the L18 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), overcut (OC) and Tool Wear Rate (TWR).

S. H. Tomadi et al.[7] analyzed the effect of machining settings of tungsten carbide on the outputs such as TWR, MRR and Surface finish. Confirmation test performed to evaluate error between predicted values and by experimental runs in terms of machining characteristics. They were found out copper tungsten tool use for better surface finishing of the workpiece. They were using full factorial DOE for optimization and found out with greater pulse off time lesser tool wear of tungsten carbide and with current, voltage and pulse on time increment tool wear increased.

AKM Asif Iqbal and Ahsan Ali Khan [8] optimized the machining process parameters for the EDM milling operation of a stainless steel workpiece with copper tools. Input parameters are RPM of tool, feed rate and voltage while the outputs are MRR, TWR and Ra. Central composite design is utilized for optimization to get higher MRR, TWR and Ra. From the results the machining settings for optimal condition are done at 1200 RPM, voltage 120V and feed rate 4µm/Sec.

Norliana Mohd Abbas et al. [9] reviewed the trends of various research on EDM such as ultrasonic vibration assisted EDM, dry EDM, powder mixed EDM, water based EDM and various modelling techniques of EDM to precise and accurate EDM performance. They found that ultrasonic vibration assisted EDM is suited for micro machining, dry EDM is cost effective, water based EDM provides a safe and conductive working environment, powder mixed EDM provides increasing surface quality, MRR and TWR.

Singh et al [10] investigated the influence of machining settings such as peak current on MRR, overcut, TWR and Ra in EDM of E31 tool steel heat treated with different tools such as copper, brass, aluminium and copper tungsten. From the results copper and aluminium electrodes give higher MRR, Overcut in diameter is minimum with these tools.

Sanjeev Kumar et al [11] reviewed on the new uses of electrical discharge machining (EDM) process, with certain prominence on the perspective of this process for surface alteration. Above and beyond removal of work material during machining, the fundamental nature of the process results in erosion of tool material also. Creation of the plasma passage containing material vapours from the eroding work material and tool electrode; and pyrolysis of the dielectric affect the surface composition after machining and hence, its properties. Deliberate material transfer may be carried out under specific machining conditions by using either composite electrodes or by a break up of metallic powders in the dielectric or both.

## 3. EXPERIMENTAL SETUP

The experimentations are performed by operating on an Electric Discharge Machine classified as (die-sinking type) ELECTRONICA-ELEKTRAPLUS PS 50ZNC is shown in figure 3.1 whose polarization on the electrode is located as negative whereas that of the workpiece is located as positive. The dielectric liquid recycled was EDM oil having specific gravity - 0.763.


Fig 3.1 Experimental set-up

## 4. EXPERIMENTAL DETAILS

### 4.1Selection of Workpiece

In this experiment AISI 410 stainless steel of diameter 37mm and width 26.60mm rod is chosen for conducting the experiment. Grade 410 stainless steels are general-purpose martensitic stainless steels containing 11.5% chromium, which provide good corrosion resistance properties. However, the corrosion resistance of grade 410 steels can be further enhanced by a series of processes such as hardening, tempering and polishing. Quenching and tempering can harden grade 410 steels. They are generally used for applications involving mild corrosion, heat resistance and high strength.

Martensitic stainless steels are fabricated using techniques that require final heat treatment. These grades are less resistant to corrosion when compared to that of austenitic grades. Their operating temperatures are often affected by their loss of strength at high temperatures, due to over-tempering and loss of ductility at sub-zero temperatures. The composition of AISI 410 stainless steel is shown in the table 3.1, therefore it is applicable in dental and surgical instruments, pipelines, valves, refineries, oil, gas industries, nozzles and many automotive parts and chemical plant

Table.3.1 Composition of ASI 410

| Grade | Cr | Ni | C | Mn | P | S | Si |
|---|---|---|---|---|---|---|---|
| Min | 11.5 | - | 0.08 | - | - | - | - |
| Max | 13.5 | 0.75 | 0.15 | 1.0 | 0.04 | 0.03 | 1.0 |

### 4.2 Selection of Tool

In this experiment copper (Cu) rod of diameter 10mm and width 26.60mm used. As a chemical element, copper is represented by the symbol Cu in the periodic table and has the atomic number 29. As a metal, copper is ductile and malleable and valued for its high thermal and electric conductivity. Copper occurs naturally but its greatest source is in minerals like chalcopyrite and bornite, and you can easily identify it by its reddish-gold colour. Copper has a huge range of applications. Because this metal conducts heat and electricity extremely well, it is used in electrical equipment, such as wiring, connectors and engines. Copper is also often used in construction (plumbing, for example) and industrial machinery. It can also be found in boat propellers, saucepan bottoms, water tanks, underfloor heating, car radiators, TV sets, computers, and so much more. The antibacterial properties of copper and its alloys make them incredibly useful for food preparation, plumbing systems, door knobs and hospitals. Copper sulphate can be found in agriculture as a poison and an algicide in water purification. Copper, brass or bronze can also be used for decorations, such as jewellery, statues and building parts (like roofing)

4.3 Mechanism of MRR

Mechanism behind material removal of EDM process is based on the conversion of electrical energy to thermal energy that categorized it to electro thermal process. During machining both the surfaces may have present smooth and irregularities causing minimum and maximum gap in between tool and work piece. At a given instant at minimum point suitable voltage is developed that produces an electrostatic field for emission of electrons from the cathode where electrons accelerate towards the anode. After getting velocity of electrons collides with the dielectric moleculesbreaking them into negative and positive ions. Because of that spark is generated with high temperature causing melting and vaporization of material from the workpiece and made the shape of tool on to the workpiece.

Formula for MRR

MRR is calculated as the proportion of the change of weight of the workpiece before and after machining to the product of machining period and density of the material.

$$MRR = \frac{W1-W2}{t \times \rho}$$

Whereas:

W1 = Weight of workpiece before machining.

W2 = Weight of workpiece after machining.

t = Machining period = 15 min.

ρ = Density of AISI 410 stainless steel work piece

4.4 Analysis of Variance

The Analysis of Variance (ANOVA) is a powerful and common statistical procedure. It is the application to identify the effect of individual factors [40]. In statistics, ANOVA is a collection of statistical models, and their associated procedures, in which the observed variance is partitioned into components due to different explanatory variables. In its simplest form ANOVA gives a statistical test of whether the means of several groups are all equal, and therefore generalizes.

4.5 Conduct of Experiments

Copper tool material individually was used having 10 mm solid diameter and 26.60 mm width. And the die-sinking type PS50 ZNC EDM machine is used. Marketable grade EDM oil (specific gravity= 0.763, freezing point= 94˚C) was used as dielectric liquid to perform the experiment. Side flushing with nozzles was recycled to flush away the eroded materials from the sparking zone. In this experiment duty cycle is kept constant 5. For a three level factor are attempted with an overall number of 9 trials completed on die sinking EDM. The calculation of material removal rate has been done by using an electronic sense of balance weight machine. For each weight measurement first soak the workpiece from paper or cloth to prevent extra weight measurement.

## 5 RESULT AND DISCUSSION

We are discussing about the effects or influence of machining parameter, i.e. Discharge current (I), Pulse on time (Ton), pulse off time (Toff) and voltage (V) on material removal rate (MRR), surface roughness (SR) of AISI 410 machined

workpiece with copper tool and find out which parameter is most important during an experiment with the help of Analysis of variance in Minitab 18 is shown in the table 5.1 & 5.2.

| Experiment No. | Pulse On time T on | Pulse Off time T off | Voltage V | Current I |
|---|---|---|---|---|
| 1 | 40 | 4 | 4 | 10 |
| 2 | 40 | 6 | 6 | 15 |
| 3 | 40 | 8 | 8 | 20 |
| 4 | 50 | 4 | 6 | 20 |
| 5 | 50 | 6 | 8 | 15 |
| 6 | 50 | 8 | 4 | 10 |
| 7 | 60 | 4 | 8 | 15 |
| 8 | 60 | 6 | 4 | 20 |
| 9 | 60 | 8 | 6 | 10 |

Table.5.1 Input parameters

| Experiment no | MRR ($cm^3$ / min) | Roughness value (Ra) (µm) |
|---|---|---|
| 1 | 0.0263 | 12.91 |
| 2 | 0.0348 | 11.82 |
| 3 | 0.0346 | 11.95 |
| 4 | 0.0173 | 12.37 |
| 5 | 0.0606 | 12.65 |
| 6 | 0.0087 | 13.72 |
| 7 | 0.0173 | 13.64 |
| 8 | 0.1590 | 11.24 |
| 9 | 0.0431 | 13.54 |

Table.5.2 MRR & Roughness Value

Analysis of MRR

From the interval plots, figure 5.1, figure 5.2, figure 5.3 and figure 5.4 indicates that MRR at 20A discharge current, 60 µs pulse on time, 6 µs pulse off time and at voltage of 4 V voltage respectively gives the best results on input parameters and is shown in the table 5.3.

Table 5.3 analysis of MRR

| Source | DF | Adj SS | Adj MS | F-Value | P-Value | % contribution |
|---|---|---|---|---|---|---|
| I | 2 | 0.003164 | 0.001582 | 0.70 | 0.532 | 19.70% |
| Ton | 2 | 0.003669 | 0.001834 | 0.85 | 0.474 | 22.85% |
| Toff | 2 | 0.007368 | 0.003684 | 2.38 | 0.173 | 45.89% |
| V | 2 | 0.007368 | 0.003684 | 2.38 | 0.173 | 11.56% |

5.1.1 Analysis of variance of MRR vs I

Table 5.4 analysis of MRR vs I

| Source | DF | Adj SS | Adj MS | F-Value | P-Value |
|---|---|---|---|---|---|
| I | 2 | 0.003164 | 0.001582 | 0.70 | 0.532 |
| Error | 6 | 0.013492 | 0.002249 | | |
| Total | 8 | 0.016656 | | | |

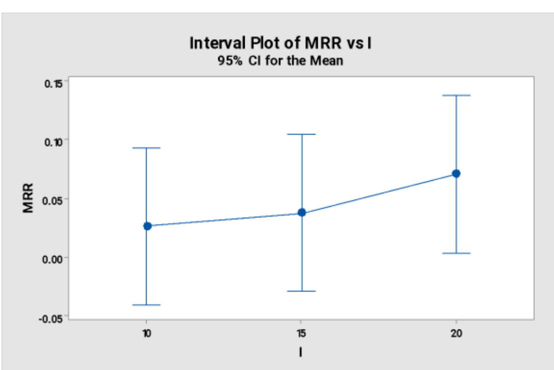


Fig 5.1 interval plot of MRR vs I

5.1.2 Analysis of variance of MRR vs Ton

Table 5.5 analysis of MRR vs Ton

| Source | DF | Adj SS | Adj MS | F-Value | P-Value |
|---|---|---|---|---|---|
| Ton | 2 | 0.003669 | 0.001834 | 0.85 | 0.474 |
| Error | 6 | 0.012987 | 0.002164 | | |
| Total | 8 | 0.016656 | | | |

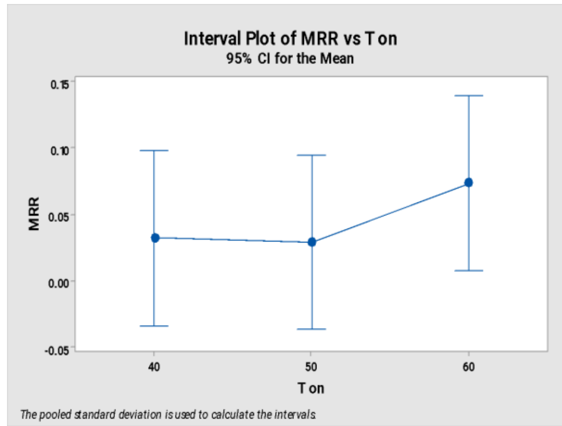


Fig 5.2 interval plot of MRR vs Ton

5.1.3 Analysis of variance of MRR vs Toff

Table 5.6 analysis of MRR vs Toff

| Source | DF | Adj SS | Adj MS | F-Value | P-Value |
|---|---|---|---|---|---|
| Toff | 2 | 0.007368 | 0.003684 | 2.38 | 0.173 |
| Error | 6 | 0.009287 | 0.001548 | | |
| Total | 8 | 0.016656 | | | |

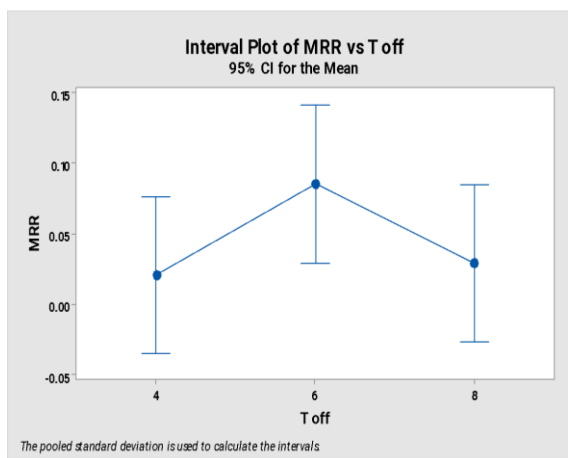


Fig 5.3 interval plot of MRR vs Toff

5.1.4 Analysis of variance of MRR vs V

Table 5.7 analysis of MRR vs V

| Source | DF | Adj SS | Adj MS | F-Value | P-Value |
|---|---|---|---|---|---|
| V | 2 | 0.001856 | 0.000928 | 0.38 | 0.702 |
| Error | 6 | 0.014800 | 0.002467 | | |
| Total | 8 | 0.016656 | | | |

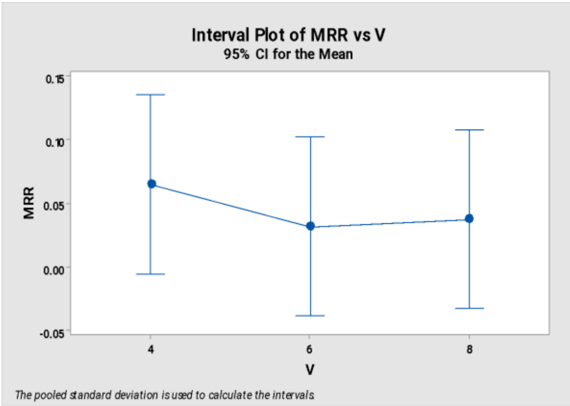

Fig 5.4 interval plot of MRR vs V

5.2 Analysis of Surface Roughness

According to Figure 5.5, Figure 5.6, Figure 5.7 and Figure 5.8, it shows that SR at 10 A of discharge current, 50 μs of pulse on time, 8 μs of pulse off time and at voltage of 4 V respectively gives the best results for surface roughness (μm) and is shown in table 5.8.

Table 5.8 analysis of surface roughness

| Source | DF | Adj SS | Adj MS | F-Value | P-Value | % contribution |
|---|---|---|---|---|---|---|
| I | 2 | 3.555 | 1.7777 | 3.99 | 0.079 | 37.80% |
| Ton | 2 | 0.8193 | 0.4096 | 0.45 | 0.655 | 8.72% |
| Toff | 2 | 2.515 | 1.2577 | 2.03 | 0.212 | 26.74% |
| V | 2 | 2.515 | 1.2577 | 2.03 | 0.212 | 26.74% |

5.2.2 Analysis of variance of Ra vs I

Table 5.9 analysis of Ra vs I

| Source | DF | Adj SS | Adj MS | F-Value | P-Value |
|---|---|---|---|---|---|
| I | 2 | 3.555 | 1.7777 | 3.99 | 0.079 |
| Error | 6 | 2.675 | 0.4458 | | |
| Total | 8 | 6.230 | | | |

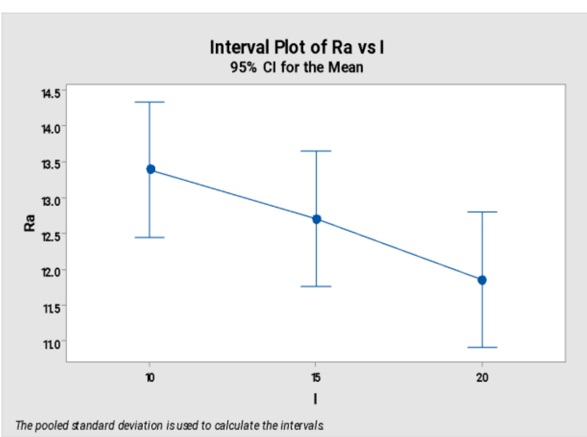

Fig 5.5 interval plot of Ra vs I

5.2.3 Analysis of variance of Ra vs Ton

Table 5.10 analysis of Ra vs Ton

| Source | DF | Adj SS | Adj MS | F-Value | P-Value |
|---|---|---|---|---|---|
| Ton | 2 | 0.8193 | 0.4096 | 0.45 | 0.655 |
| Error | 6 | 5.4108 | 0.9018 | | |
| Total | 8 | 6.2301 | | | |

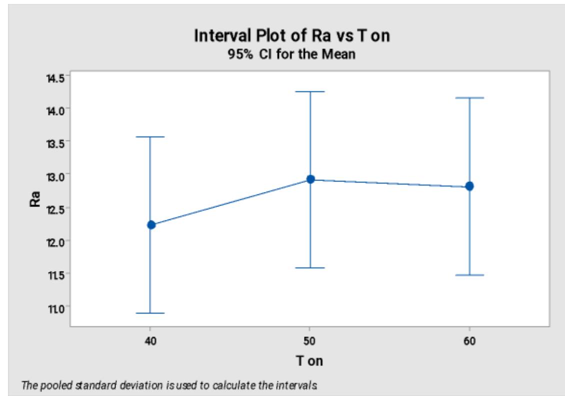

Fig 5.6 interval plot of Ra vs Ton

5.2.4 Analysis of variance of Ra vs Toff

Table 5.11 analysis of Ra vs Toff

| Source | DF | Adj SS | Adj MS | F-Value | P-Value |
|---|---|---|---|---|---|
| Toff | 2 | 2.515 | 1.2577 | 2.03 | 0.212 |
| Error | 6 | 3.715 | 0.6191 | | |
| Total | 8 | 6.230 | | | |

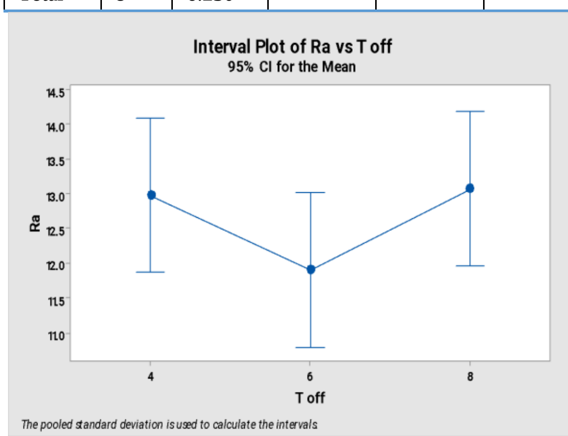

Fig 5.7 interval plot of Ra vs Ton

5.2.5 Analysis of variance of Ra vs V

Table 5.11 analysis of Ra vs V

| Source | DF | Adj SS | Adj MS | F-Value | P-Value |
|---|---|---|---|---|---|
| V | 2 | 2.515 | 1.2577 | 2.03 | 0.212 |
| Error | 6 | 3.715 | 0.6191 | | |
| Total | 8 | 6.230 | | | |

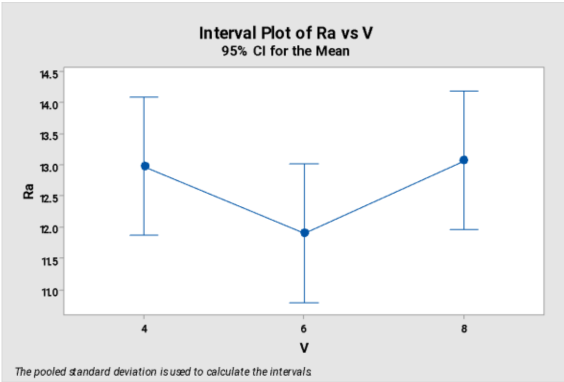


Fig 5.8 interval plot of Ra vs V

## 6.CONCLUSION

In this investigational experiment on EDM to know the effect of machining outputs taken for consideration are material removal rate and surface roughness of the AISI 410 SS workpiece using the copper tool with side flushing method have been investigated.

1. % contribution for MRR

I - 19.70%
Ton - 22.85%
Toff - 45.89%
V - 11.56%

From the results of MRR, we conclude that the pulse off time (Toff) is more significant or influencing parameter than pulse on time (Ton), discharge current (I) and voltage (V) on the given input. The above contribution is obtained when the values of parameters are 20A discharge current, 60 µs pulse on time, 6µs pulse off time and at voltage of 4 V voltage respectively

2. % contribution for SR

I - 37.80%
Ton - 8.72%
Toff - 26.74%
V - 26.74%

From the results of surface roughness (SR), we conclude that the discharge current (I) is the most effective parameter than pulse off time (Toff), voltage (V) and pulse on time (Ton). The above contribution is obtained when the values of process parameters are 10 A of discharge current, 50 µs of pulse on time, 8 µs of pulse off time and at voltage of 4 V respectively.

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