# Effect of Tool geometry and Process parameters on Surface roughness and MRR in EDM of Tool Steel

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ABSTRACT : Electrical discharge machining (EDM) is a nontraditional process that uses electrical spark discharge to machine electrically conducting materials such as tool and dies steels, ceramics, etc., for geometrically complex shapes, which are difficult to machine using a more traditional approach. However due to the process nature there is still failure to accurately understand process parameter influence on the surface quality, material removal rate etc. On the other hand, designing and re-shaping of required electrodes for each feature are time consuming and the number of electrode stored is very high. Therefore to increase the productivity, quality and flexibility standardized simple electrode shapes, capable to machine different features, must be analyzed. This study present the analysis based on Taguchi design and Analysis of Variance (ANOVA) we conduct experiment and find the contribution of Tool Geometry on the Surface Roughness and Material Removal Rate (MRR) with other processing parameters. And find the most significant parameter for both output parameters.

Keywords– MRR, Surface Roughness, ANOVA, Tool Geometry

## 1. INTRODUCTION

Electrical discharge machining (EDM) is a non-traditional machining method commonly used to produce die cavities via the erosive effect of electrical discharges. The electrically conductive tool electrode, which has the male shape of the die cavity, is prepared to machine the die cavity? The method is especially effective in machining hard die steels, complex cavities and small work pieces. Die casting, injection moulding, forging, extrusion, upset forging and power compaction dies are manufactured using EDM technology [1]

In EDM, a power supply delivers high-frequency electric pulses to the tool and the workpiece. The gap between the tool and workpiece is flushed with a stream of dielectric liquid. When an electric pulse is delivered from the power supply, the insulating property of the die electric fluid is momentarily broken down. This allows a small spark to jump the shortest distance between the tool and workpiece. A small pool of molten metal is formed on the work piece and the tool at the point of discharge. A gas bubble forms around the discharge and the molten pools. As the electric pulse ceases and the discharge disappears, the gas bubble collapses. The onrush of cool dielectric causes the molten metal to be ejected from the workpiece and the tool, leaving small craters. This action is repeated hundreds of thousands of times each second during EDM processing. This removes material from the work piece in a shape complementary to that of the tool. [2]Yan et. al. studied that Depending on the kind of material used and other requirements, positive or negative polarity can be applied. This is one of the most important parameters that affect Electrode Wear Rate, Surface Roughness, MRR[3].Pradhan et al. & Y. Lin & Sundaram et al. studied that Process modeling is an important issue to cheapen manufacturing process because it facilitates the process basics understanding for optimizing the final process performance. However the complex nature of the EDM process interaction However, the complex nature of the EDM process interaction between the electrode (tool) and the workpiece material does not facilitate this task. To solve this question many authors have applied statistic methods such as analysis of variance (ANOVA) models and S/N ratios in order to analyze and optimize the process performance measures (process outputs) in comparison of the process parameters (process inputs). Taguchi method is very effective to deal with response influenced by multi-variables, which is clearly the case of EDM process The signal-to-noise ratio is a quality ratio that permits to evaluate the effect of changing a particular design parameter on the performance of the process[4][5][6].

M. Kiyak et al, Y Guu et al & M. Mahardika et al studied that EDM-workpiece material interaction is influenced by many process parameters and considered highly non-linear. There are a number of operational parameters which must be set when manufacturing process is done. These operation parameters are variable and can be adjusted in areas to optimize the desired quality of the machined features. However, there have been many studies aimed at systematically investigating the influence of process variables during EDM machining.[7][8][9]. Results given in this paper helps to select appropriate EDM parameters when user designs process planning based on product requirements such as geometrical features and surface roughness.

## 2. EXPERIMENTAL SETUP.

### 2.1 The setup

The experments have been conducted on the Joemars make EDM machine. The machine is equiped with fuzzy controller to get a hold of utmost accuracy during the operation. Fig 1 shows the main parts and overall set up of the expermental work.

**Fig. 1** JOEMARS EDM Machine

### 2.2 Workpiece material

To conduct experiments we make use of AISI H13 steel of 6 mm thick size. The reason behind selection of this material is the vast application of this material in Extrusion tools, Forging Dies, Plastic moulds, Die casting Dies. Mandrels, Ejector pin.etc.. The Chemical compositions of AISI H13 steel as per testing by Divine Laboratory Services, Ahmedabad given in table 1.

**Table 1** Chemical composition of AISI H13 steel

| Composition In % | C | Si | Mn | Cr | Mo | V |
|---|---|---|---|---|---|---|
| | 0.40 | 0.97 | 0.45 | 5.30 | 1.35 | 0.80 |

### 2.3 Electrode material

Among the various metallic and non metallic electrode, copper electrode with 15 mm diameter was selected as tool. Its material characteristics are listed below.

- Melting point at 1083°C
- Density = 8.9 g/cm3
- Electrical resistivity of 0.0167 ohm mm2/m
- Coefficient of expansion of 4.318 X 10-4 mm mm/°K

Copper is machinable but wheel loading in grinding seriously affect surface finish and accuracy. Copper is most often used when high surface finish in work material is required. The tool can be policed to about 0.25 micron Ra to provide best surface integrity in the work Material.

### 2.4 Electrode Geometry

There are four different electrode geometry is taken into consideration. They are Round(C) – Ø15, Square(S) – 15 x 15, Rectangle(R) – 15 x 19, Triangle (T) – 15 x 15 x 15. The dimensiones are in mm.

### 2.5 Surface Roughness

Surface topography or surface roughness, also known as surface texture are terms used to express the general quality of a machined surface, which is concerned with the geometric irregularities and the quality of a surface [9]. Surface Roughness measures as the arithmetic average, Ra (μm).


**Fig. 2** Mitutoyo SJ210P surface roughness tester.

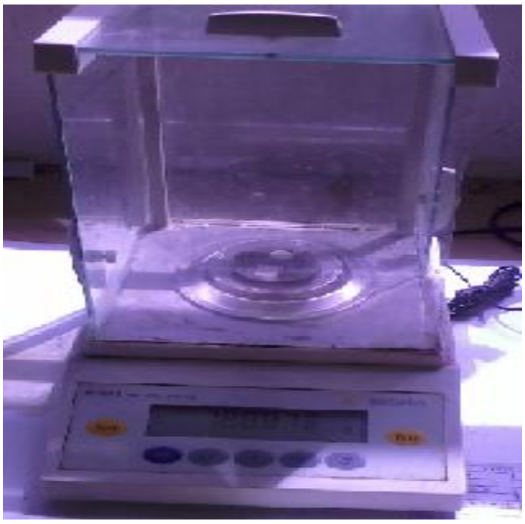


**Fig. 3** precise weighing machine

The Ra value, also known as centre line average (CLA) and arithmetic average (AA) is obtained by averaging the height of the surface above and below the centre line. The Ra will be measured using a surface roughness tester from Mitutoyo, Model: SJ 210P. The Ra values of the WEDMed surface were obtained by averaging the surface roughness values of 5 mm measurement length.

### 2.6 Material Removal Rate

It is well-known and elucidated by many EDM researchers by Roethel that Material Removal Mechanism (MRM) is the process of transformation of material elements between the work-piece and electrode. The transformation are transported in solid, liquid or gaseous state, and then alloyed with the contacting surface by undergoing a solid, liquid or gaseous phase reaction.

The material MRR is expressed as the ratio of the difference of weight of the workpiece before and after machining to the machining time and density of the material.

$$MRR = \frac{(W_{tb} - W_{ta})}{D \times t}$$

Where, $W_{tb}$ = Weight before machining in gm, $W_{ta}$ = Weight after machining in gm, D = Density of work piece material in gm/m$^3$, t=time consumed for machining in minute.

The weight of the work piece and tool is measured on precise weighing machine having least count of 0.001 gm.

## 3. DESIGN OF EXPERIMENTS.

To determine influential parameters for EDM groove machining, 24 experiments have been carried out based on Taguchi Orthogonal Array $OA_{16}(4^5)$ has been chosen in order to have representative data[11]

Gap Voltage, Current Intensity, Pulse on time, pulse off time are influential parameter to the common performance measures like MRR and Surface roughness [10].In addition, tool geometry is also considered to identify its influence on these process performance measures and especially on final accuracies. Table 2 presents the five different EDM process parameters chosen and their levels. The rest of EDM parameters, presented in Table 3, must be kept constant during the experimentation to ensure a right comparison between the 24 tests.

The Taguchi method aims to find an optimal combination of parameters that have the smallest variance in performance. The signal-to-noise (S/N) ratio measures how the response varies relative to the nominal or target value under different noise conditions.

**Table 2** EDM process parameters and levels

| Parameter | Level | | | |
|---|---|---|---|---|
| | L1 | L2 | L3 | L4 |
| Gap Voltage(V) | 16 | 12 | 8 | 4 |
| Current Intensity (A) | 50 | 43 | 36 | 28 |
| Pulse on time(μs) | 22 | 42 | 52 | 62 |
| Pulse off time(μs) | 22 | 32 | 42 | 52 |
| Tool Geometry. | ROUND | SQUARE | RECT. | TRIANG LE |

**Table 3** Constant EDM parameters

| Parameter | Level | |
|---|---|---|
| Polarity | + | |
| Servo Sensitivity | 7 | |
| Flushing Height | 10 | |
| Working Time | 10 | |
| Low Wear Factor | 0 | |

The analysis of variance (ANOVA) is the statistical treatment most commonly applied to the result of the experiments to determine the percentage contribution of each factors. Study of ANOVA table for a given analysis helps to determine which of the factors need control and which do not. Once the optimum condition is determined, it is usually good practice to run a confirmation experiments. Analysis provides the variance of controllable and noise factors. By understanding the source and magnitude of variance, robust operating condition can be predicted.

**Table 4** Experimental results and respective S/N ratio of the 24 Experiment for Surface roughness and MRR.

| V | A | $P_{on}$ | $P_{off}$ | Tool | SR | S/N (Ra) | MRR | S/N (MRR) |
|---|---|---|---|---|---|---|---|---|
| 16 | 50 | 22 | 22 | C | 8.561 | -18.6505 | 54.23 | 34.68479 |
| 16 | 43 | 42 | 32 | S | 6.047 | -15.6308 | 36.54 | 31.25537 |
| 16 | 36 | 52 | 42 | R | 3.014 | -9.58286 | 39.63 | 31.96048 |
| 16 | 28 | 62 | 52 | T | 2.335 | -7.36574 | 35.35 | 30.96779 |
| 12 | 50 | 42 | 42 | T | 8.304 | -18.3857 | 50.73 | 34.1053 |
| 12 | 43 | 22 | 52 | R | 3.105 | -9.84123 | 44.48 | 32.9633 |
| 12 | 36 | 62 | 22 | S | 2.325 | -7.32846 | 27.36 | 28.74232 |
| 12 | 28 | 52 | 32 | C | 9.14 | -19.2189 | 26.46 | 28.4518 |
| 8 | 50 | 52 | 52 | S | 7.921 | -17.9756 | 43.74 | 32.81758 |
| 8 | 43 | 62 | 42 | C | 5.513 | -14.8278 | 45.64 | 33.18691 |
| 8 | 36 | 22 | 32 | T | 2.63 | -8.39911 | 40.29 | 32.10395 |
| 8 | 28 | 42 | 22 | R | 2.223 | -6.93879 | 38.38 | 31.6821 |
| 4 | 50 | 62 | 32 | R | 8.507 | -18.5955 | 38.42 | 31.69115 |
| 4 | 43 | 52 | 22 | T | 6.503 | -16.2623 | 35.65 | 31.04119 |
| 4 | 36 | 42 | 52 | C | 5.648 | -15.0379 | 48.95 | 33.79505 |
| 4 | 28 | 22 | 42 | S | 3.688 | -11.3358 | 25.61 | 28.16819 |
| 8 | 50 | 42 | 22 | R | 8.726 | -18.8163 | 57.86 | 35.24757 |
| 12 | 43 | 62 | 42 | C | 6.981 | -16.8784 | 48.62 | 33.7363 |
| 4 | 36 | 52 | 32 | S | 6.595 | -16.3843 | 40.21 | 32.08668 |
| 16 | 50 | 62 | 22 | T | 10.531 | -20.4494 | 53.93 | 34.63661 |
| 8 | 36 | 52 | 32 | C | 6.261 | -15.9329 | 31.05 | 29.84123 |
| 12 | 28 | 62 | 52 | R | 3.75 | -11.4806 | 35.63 | 31.03632 |
| 4 | 28 | 52 | 52 | S | 2.84 | -9.06637 | 35.49 | 31.00212 |
| 16 | 28 | 22 | 22 | R | 3.208 | -10.1247 | 15.48 | 23.79542 |

C-Round, S-Square, R-Rectangle, T-Triangle

**Table 5** ANOVA for surface roughness.

| Source | DF | Seq SS | Adj SS | Adj MS | F | P |
|---|---|---|---|---|---|---|
| A | 3 | 2.241 | 19.48 | 6.493 | 0.89 | 0.487 |
| B | 3 | 248.555 | 247.12 | 82.373 | 11.28 | 0.003 |
| C | 3 | 38.594 | 27.49 | 9.165 | 1.26 | 0.353 |
| D | 3 | 42.810 | 32.50 | 10.833 | 1.48 | 0.291 |
| G | 3 | 65.718 | 65.72 | 21.906 | 3.00 | 0.095 |
| Residual Error | 8 | 58.414 | 58.41 | 7.302 | | |
| Total | 23 | 456.332 | | | | |

**Table 6** Response Table for Signal to Noise Ratios (Smaller is better)

| | A | B | C | D | G |
|---|---|---|---|---|---|
| 1 | -14.45 | -10.79 | -11.67 | -14.08 | -16.76 |
| 2 | -13.82 | -12.11 | -14.96 | -15.69 | -12.95 |
| 3 | -13.86 | -14.69 | -14.92 | -14.20 | -12.20 |
| 4 | -13.63 | -18.81 | -13.85 | -11.79 | -14.17 |
| Delta | 0.81 | 8.02 | 3.29 | 3.90 | 4.56 |
| Rank | 5 | 1 | 4 | 3 | 2 |

**Table 7** ANOVA for MRR

| Source | DF | Seq SS | Adj SS | Adj MS | F | P |
|---|---|---|---|---|---|---|
| A | 3 | 6.114 | 1.867 | 0.6225 | 0.11 | 0.951 |
| B | 3 | 67.888 | 56.761 | 18.9204 | 3.39 | 0.074 |
| C | 3 | 9.929 | 8.994 | 2.9981 | 0.54 | 0.670 |
| D | 3 | 14.973 | 16.003 | 5.3345 | 0.95 | 0.459 |
| G | 3 | 5.944 | 5.944 | 1.9812 | 0.35 | 0.787 |
| Residual Error | 8 | 44.698 | 44.698 | 5.5872 | | |
| Total | 23 | 149.546 | | | | |

**Table 8** Response Table for Signal to Noise Ratios (Larger is better)

| | A | B | C | D | G |
|---|---|---|---|---|---|
| 1 | 31.30 | 29.30 | 30.34 | 31.40 | 32.28 |
| 2 | 32.48 | 31.42 | 33.22 | 30.91 | 30.68 |
| 3 | 31.51 | 32.44 | 31.03 | 32.23 | 31.20 |
| 4 | 31.22 | 33.86 | 32.00 | 32.10 | 32.57 |
| Delta | 1.26 | 4.56 | 2.87 | 1.33 | 1.89 |
| Rank | 5 | 1 | 2 | 4 | 3 |

## 4. RESULT AND DISCUSSION.

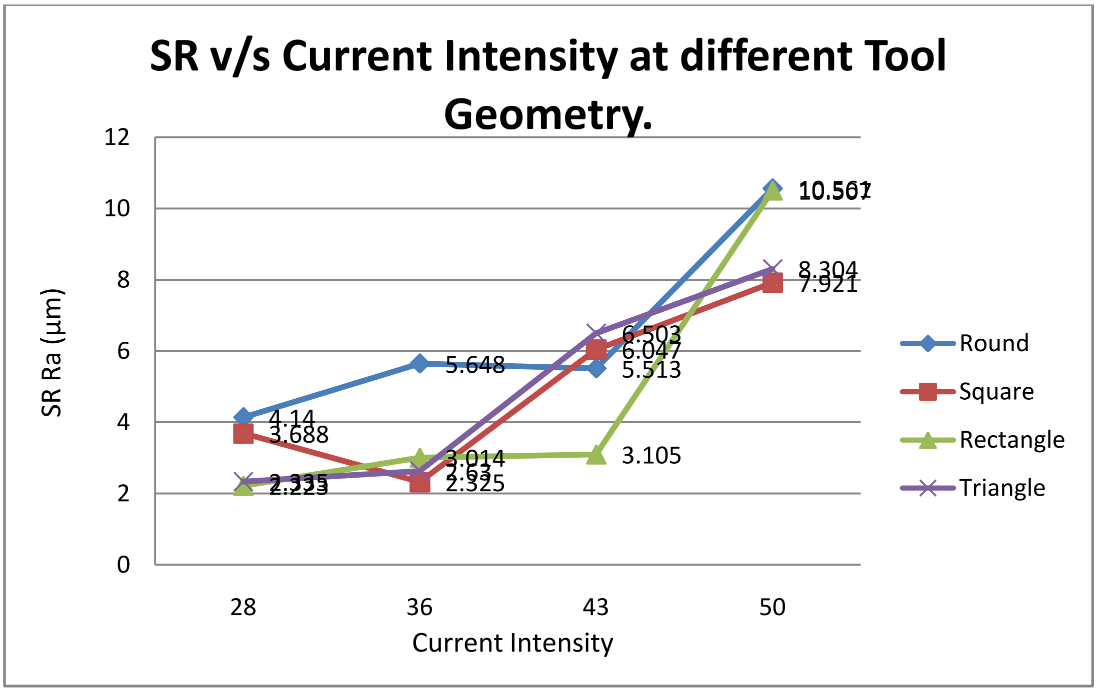
All 24 experiments are carried out by the process parameters shown in Table 2 and Table 3.Table 4 shows the final results of five input variable like, Gap voltage(V), Current Intensity (A), Pulse on time (µs), Pulse off time (µs) and Tool Geometry. S/N ratio is give for Surface roughness and MRR.

Table 5 and Table 7 present the final results of ANOVA. From this Table we can see the p-value for B is 0.003 so this is most significant parameter that affects surface roughness. It is same for MRR that p-value for B is less than others so it is the most significant factor and it is Current intensity.

Table 6 and Table 8 present the response table for S/N ratio for Surface roughness and MRR. From this rank is provided that which parameter affects the most to the least.

For Surface roughness it is 1. Current intensity 2. Tool Geometry .3.Pulse off time 4. Pulse on time 5. Gap voltage.

For MRR it is 1. Current Intensity 2. Pulse on time 3.Tool Geometry. 4. Pulse off time 5. Gap Voltage. From these results we can say that Tool Geometry is the significant factor for the Material Removal Rate and Surface Roughness



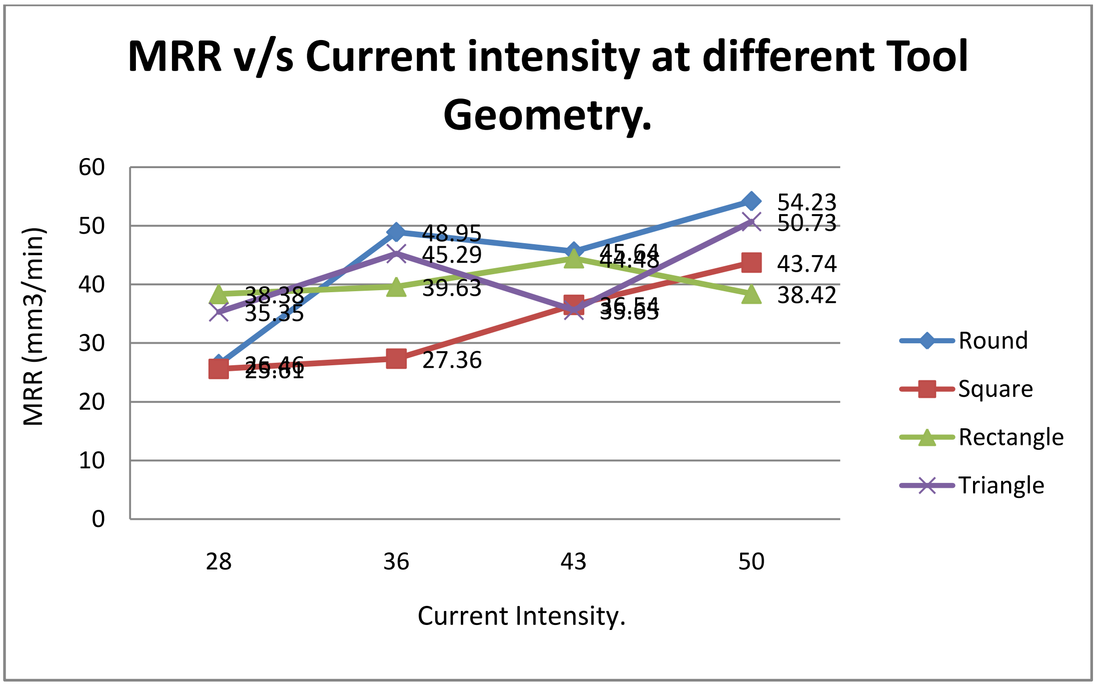
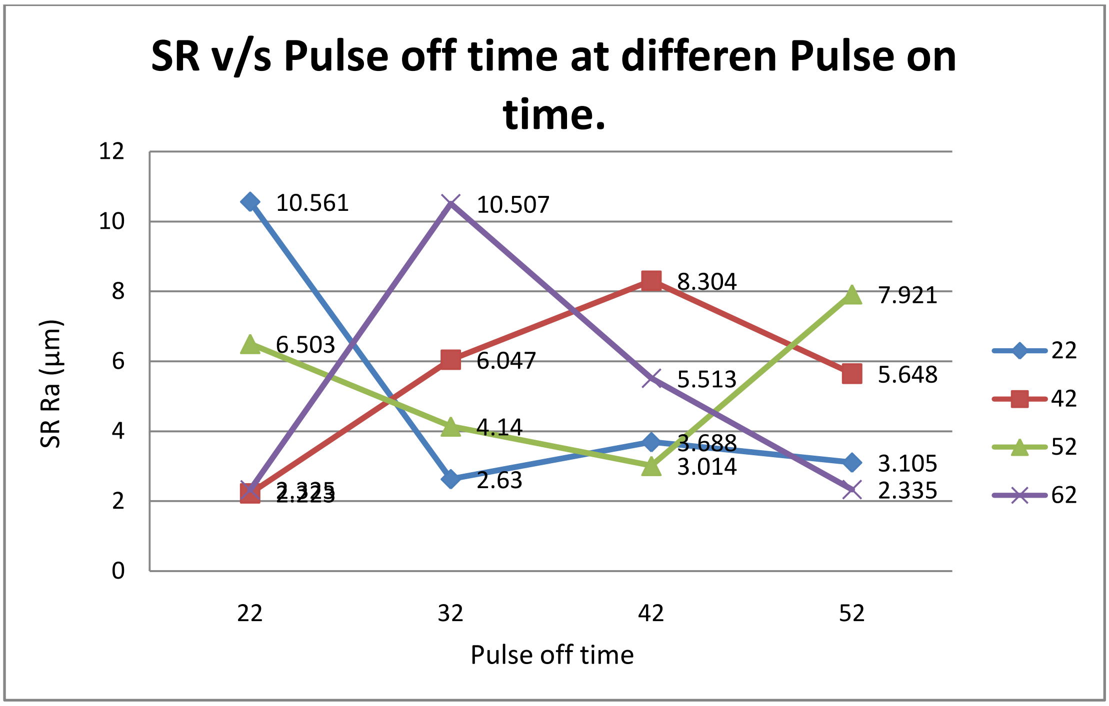




**Figure 4** Comparison of MRR and SR with current intensity at different tool geometry.

Figure 4 shows that as current intensity increases the MRR increases and so the surface Quality is decreases. Both the graph shows a same result that is the basic rule. But for current intensity 36 the results are different and the MRR is good and Surface Quality also good tor triangle and Rectangle Geometry.



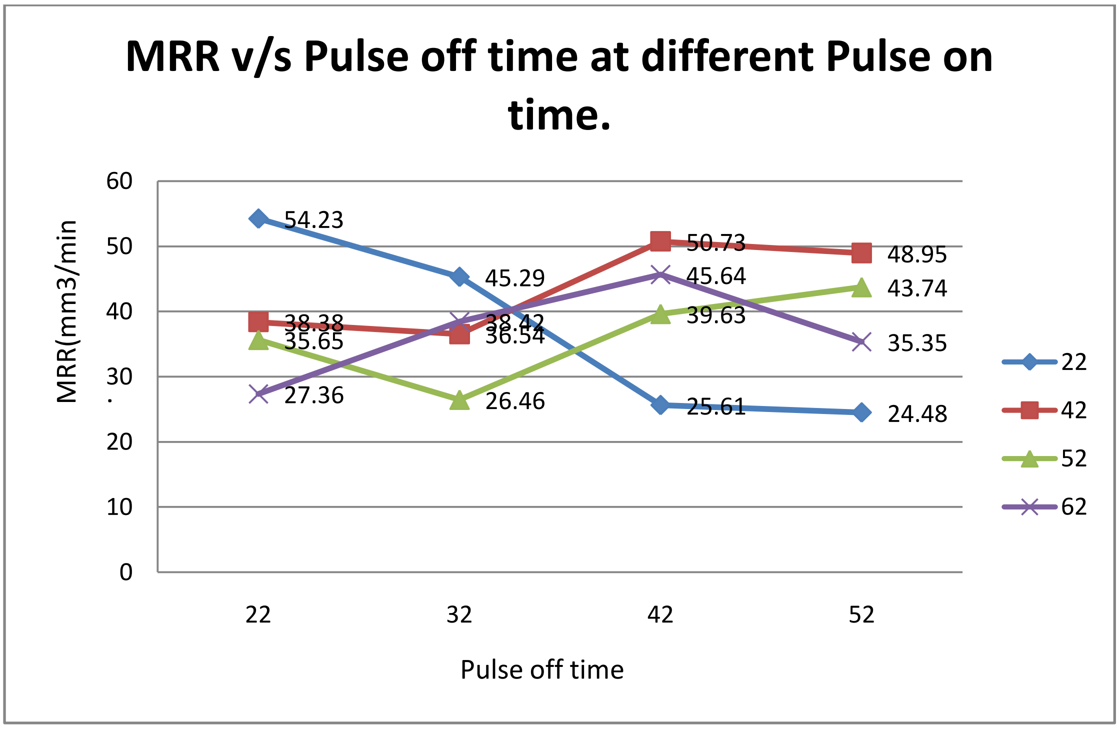




**Figure 5** Comparison of MRR and SR with pulse off time at different pulse on time.

Fig. 5 shows that as the pulse on time and pulse off time difference increases the MRR and SR both give negative results that MRR decreases and SR increases. But as they come nearer to each other both the output parameter showing good results.

## 5. CONCLUSION

Influence of process parameters (Gap voltage, Current intensity, Pulse on time, pulse off time, Tool Geometry) on MRR and Surface roughness has been analyzed for copper electrode and AISI H13 workpiece material on sinking EDM process using ANOVA.

Tool geometry is not the most significant factor that affects the performance measures the most but it is a significant factor that affects the performance measures.

As per the S/N ratio and ANOVA the percentage contribution of the tool Geometry is varies from 10% to 20%.By this we can say that by changing the geometry we can get better MRR & SR up to certain extent From Fig. 4 The Rectangle Geometry at 43 A current give good results for both the performance measures.

Now, Pulse on time and Pulse off time range is also affects the MRR and SR.At $P_{ON}$=22 & $P_{OFF}$=22 we get good results but at $P_{ON}$=22 & $P_{OFF}$=62 we cannot achieve that much good results.

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