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Investigation of the Effects of EDM Parameters on Surface Roughness

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Abstract

In this experiment a novel machining methodology is presented for hardened powder tool steel (PMD23) which has better mechanical properties than conventional high speed steels. Electric discharge machining (EDM) is a non-traditional method that mainly used for extremely hard and complex shaped metals which is very difficult to machine with conventional methods. Effects of the electric discharge machining on surface roughness (Ra) and material removal rate (MRR) is experimentally studied. The selected machining parameters were current (12, 16 and 20A), pulse on time (600, 400, and 200µs) and time interval (400, 200 and 100µs). Changes on the EDM parameters result in the changes in the surface roughness and material removal rate, higher values of current, pulse on time and time interval increased the Ra and MRR.

Keywords: *EDM, Tool Steel, Machining Parameters, Surface Roughness, Material Removal Rate*.

1. Introduction

Electric discharge machining is one of the main methods in the nontraditional manufacturing process. In automotive aerospace, nuclear, medical and especially in die-tool industry EDM has become an essential method. EDM's first erosion effect on metal-based part is discovered by an English scientist Joseph Priestly at 1770. In 1944 Russian scientist B.R. Lazarenko and N.I. Lazarenko improved a method that can control the erosion effects of the EDM. EDM's first commercial usage has been started around 1950s. [1-3]

The schematic figure 1 shows the basic EDM machine system. The system Electrode approaching to the work piece and electrical discharge occurs in spark gap as shown in the figure 1. Oscillation head comes closer and goes by periodical times to make the particles out of the channel. The high-pressure dielectric fluid that comes from nozzle removes ionized materials then the fluid particle mixture is filtered by the filter system like an aquarium but more powerfully. The cleaned fluid goes into the system and cycles continues until the settled depth cached. [6-8]

EDM process is used in particularly in the die industry for complex geometries and hard materials. It can remove material easily and achieve better results. Simply it is a manufacturing process that uses an electrode that has reverse shape of the finished geometry. In the process, the material removal status is more complex in a small gap between workpiece and electrode electrical transition zone occurs. Naturally main feature of the process the controlling the electrical current zones. An electrode is not taken a touch with the workpiece. [8-12]

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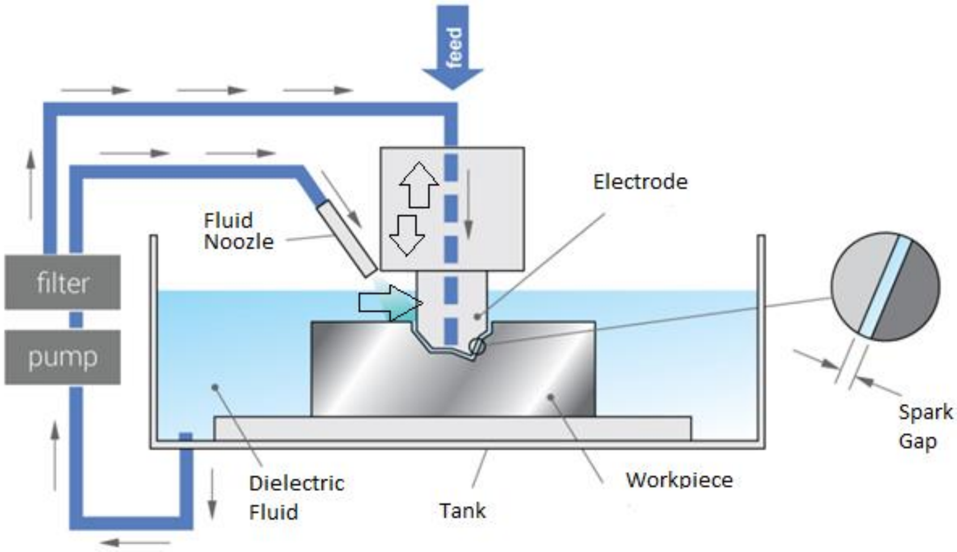

Figure 1. Schematic Representation of EDM machine System [4]

EDM is a process that removes the material with electrical discharge between work piece and electrode. EDM is a thermal-based process that converts electrical energy into heat energy. During the process, workpiece ionized by melting and vaporization. And the ionized particles removed by mixing with the dielectric fluid then these particles filtered by the system. The main principle of the EDM is the conversion of the electric energy into heat energy. In the process, electrical energy is working for the create sparks and thermal energy which removes material from the surface of the workpiece. Electrode oscillates on the surface of the work piece during the time the gap between them becomes smaller and the sparking occurs. [11-15]

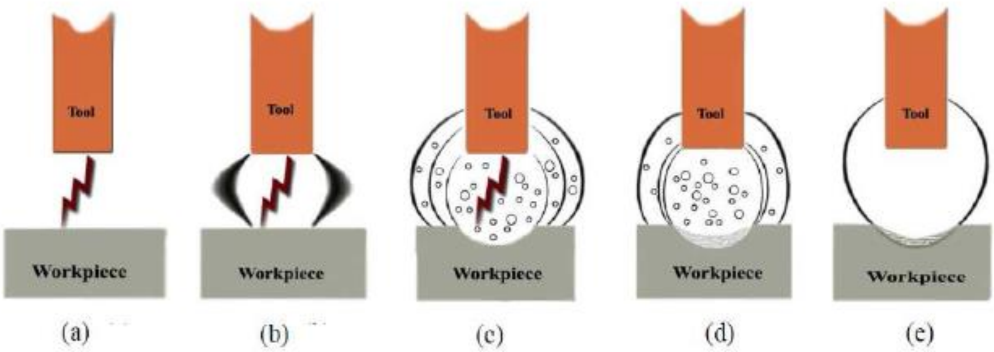

Figure 2. EDM Stages [16]

For a better understanding of the EDM principle, figure 2, can be examined.

Stage a: Electrode becomes closer enough to sparking can start.

Stage b: There is a plasma canal that occurs when the voltage falls current increases.

Stage c: Between 8000-12000°C temperature occurs thanks to the attack of ions and electrons during the discharging. Plasma canal becomes widen a little melted material area can be seen.

Stage d: Voltage and Current supplies have been disconnected. Plasma line becomes close down and material surface cools.

Stage e: Plasma canal disappears and a white layer occurs on the surface of the workpiece. Molten metal removes the dielectric flow. Little craters occurs on the surface. [2, 4, 18]

There are tons of studies about the EDM parameters that effects surface finish quality. There are around 16 parameters which affect the quality of the EDM. Also, there are combinations of parameters which is difficult identify for optimization. According to formal experiences and literature research, most effective parameters are Current (1), Tonn-Toff times (2) and materials (3). In the experiment, current (12, 16 and 20A), material removal rate, pulse on time (600,400 and 200 µs) and time interval (400, 200 and 100µs) have been examined. [8-10]

The aim of the experiment was the investigate effect of EDM parameters on PMD23 powder metallurgical tool steel during process. According to conventional applications and literature search EDM process is unnecessarily slow. With higher parametric values can improves the MRR but it is unavoidable to deform surface of the workpiece. However, thanks to parametric changes the deformation on surface can be reducible. The experiment has been done for observe effects on MRR and Ra. Also experimental results are going used to for the combination of finish and rough machining in the future commercially. There are very limited experimental works on the literature on sintered tool steels, therefore this study help to be the basis for researches. Experimentation is a key factor for the understanding the behavior of EDM and observe the parametric change during the process is essential.

2. Materials and Methods

Experimental procedure has been done by using PROMPT EDM-542 machine. Brand of the dielectric fluid was dielektrikum 358 which has 2.2 mm^2/s viscosity at 40° C and lightning point 100° C. Properties of the work material has been introduced in the next paragraph. According to literature review the parameters of the machining have been chosen for the purpose of better surface finish with the higher material removal rate. In the DOE (design of experiment) Taguchi's L27 orthogonal array has been used and results of the parameter effects are reported in results part.MS Excel, Minitab and Solidworks software's have been used for the procedure of the experiment. In figure 3 prompt machine can be seen. [11]

Figure 3. PROMPT EDM-542 Machine

In this study effects of pulse on time, time interval and current on surface roughness and material removal rate on PMD23 (AISI 1.3395) hardened tool steel has been investigated. Chemical composition of the workpiece can be seen in table 1. PMD23 steel shows almost same properties when compared to 1.3343 and these values can be seen in manufacturer's databases.[19]

Table 1. Properties of workpiece [19]

Chemical composition of PMD-23 steel (% wt)								
C	Sİ	Mn	P	S	Cr	W	Mo	V
1,29	0,26	0,26	0,027	0,02	4,04	6,42	4,87	2,79
Hardness 62 HRC								

Workpiece material has been prepared by the cad design program (Solidworks) which has 10x30x200mm dimensional features. Moreover, electrode designed with the cad program has 20x20x40mm dimensions for the machining side. Figure 4 shows the designed and finished parts for the experiment. The material of electrode was Cupro-MAX %99,99 pure copper.

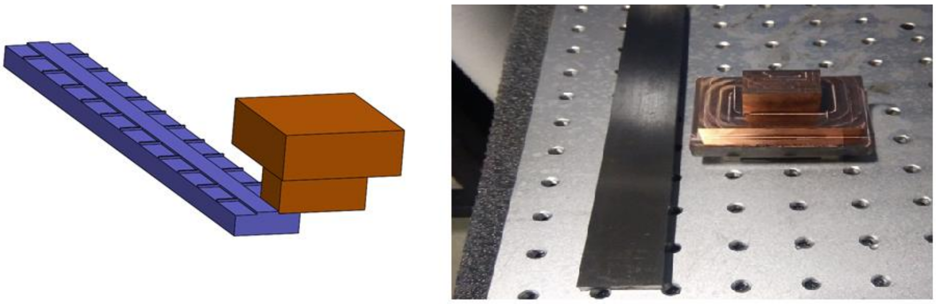

Figure 4. Cad Designed and Prepared Work piece Materials

To obtain sustainable results some parameters is to be considered stable like surface of the workpiece and surface of the electrode. The workpiece surface machined into 0,4 µm surface roughness value. During the experimental period contact surface of the electrode has been sharpened consecutively to stabilize the experimental conditions. There were 27 experiments and electrode surface has been re-machined for 27 times. Figure 5 shows surface sharpening operations.

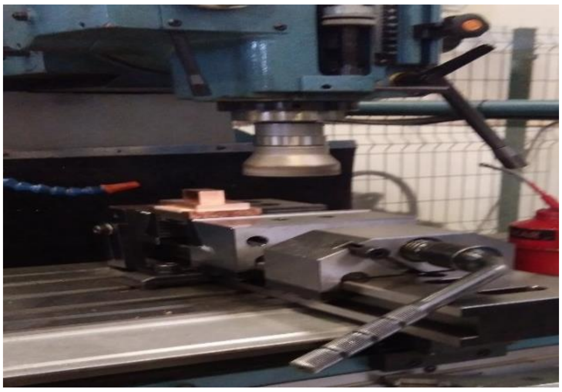

Figure 5. Sharpening the Electrode

The material removal rate of the experiment has been calculated with MRR formula. Microsoft Excel 2018 used as a calculation program and results has been reported in the experimental results section. Which can be seen in equation 1, it is basically a ratio between volume and time. [1]

$$MRR = \frac{m_1 - m_2}{\rho \, \Delta t} \quad \left(\frac{\text{mm}^3}{\text{min}} \right) \tag{1}$$

where:

- m_1 – sample weight before processing,
- m_2 – sample weight after processing,
- ρ – the density of the material,
- Δt – a time of manufacturing.

The surface roughness of the workpiece is measured by the Mititoyo SJ-201 surface roughness measurement device. Each values for the experimental results has been measured 10 times and average of them taken into account. Measurement distance and evolution length has been taken 2,5 mm. Device has 5 µm diamond Radius.

3. Results and Discussions

In the start of the experimental study has been based on the achieve higher material removal rates. In first step of the experiment there were 27 trials. Parametric values has been chosen according to firms parametric values. In the experiment different parameters of Ton-Toff and Current values applied. Main results shows that the higher current values directly increases the surface finish values. Unique results show with higher ton and toff values with higher current values gives lover surface finish as not expected. Table 2 shows the results which achieved during the experiment. Surface roughness range is between 6,9 and 12,1 µm. The material removal rate is between 17,6 and 83,1. Obtained values shows different trend when it is compared to the literature. Ra values are measured by available device and experimental funding only provided by 2D surface roughness measurement device.

Table 2. Experimental Results

Exp. No #	***Current [A]***	**Tonn** ***[µs]***	***Toff [µs]***	***Ra [µs]***	***MRR [mm3/min]***
1	12	600	400	6,9	26,4
2	12	600	200	9,1	30,3
3	12	600	100	6,7	34,3
4	12	400	400	6,3	22,9
5	12	400	200	7,3	32,3
6	12	400	100	7,1	38,2
7	12	200	400	8,1	17,6
8	12	200	200	6,8	25,5
9	12	200	100	9,2	37,7
10	16	600	400	7,8	37,3
11	16	600	200	9,0	40,8
12	16	600	100	11,6	58,8
13	16	400	400	12,1	38,0
14	16	400	200	9,0	51,9
15	16	400	100	8,8	54,0
16	16	200	400	10,5	30,2
17	16	200	200	9,8	41,9
18	16	200	100	10,4	37,8
19	20	600	400	10,1	38,8
20	20	600	200	9,0	68,4
21	20	600	100	10,7	83,1
22	20	400	400	8,8	49,5
23	20	400	200	8,0	67,5
24	20	400	100	9,8	61,4
25	20	200	400	9,6	36,4
26	20	200	200	9,2	45,1
27	20	200	100	9,1	60,6

As mentioned before the values of parameters have been chosen according to company standard. In the experimental system builded by the Taguchi L27 orthogonal array. The purpose of the Taguchi was to provide statistical analysis on the values but in this article just parametric effects have been investigated. Taguchi methods show which parameter has the highest part in the effect of the surface and material removal.

In the complete comparison the surface quality was much better with lower current values. Also, in lower values of ton times gives much better surface quality. In the experimental study it is clear when higher MRR required the surface quality becomes lower and lower. Higher parametric values create visible melted craters on the surface of the workpiece by the naked eye. The higher surface roughness is achieved in this experiment when it compared to the literature however the higher material removal rates is achieved to. Generally, EDM proses consists on 2 different operations, which are rough and fine machining. To obtain better results the combination of parameters will result more efficiently.

Thanks to Minitab and Taguchi design signal and noise ratios(S/N) of the MRR and surface roughness has been calculated. For each results the calculation is changed because in MRR higher values are expected however for surface roughness lover values are expected. Therefore, response tables have been calculated for the MRR and surface roughness. Experiment results can be seen in below.

Table 3. Response table for S/N for surface roughness (smaller is better)

Level	Current(A)	Ton(μs)	Toff
1	-17,44	-19,20	-19,22
2	-19,83	-18,53	-18,62
3	-19,41	-18,95	-18,84
Delta	2,39	0,67	0,60
Rank	1	2	3

According to results which comes for surface roughness, it is observed that shows us the main EDM parameters are current and ton, toff respectively. However, an optimization process is needed because there is not only one parameter effecting the surface but their combination and application on right side is essential in the result figures 6 and 7 these results can be seen. When current rises, the roughness rises but when ton rises roughness can be smaller. This depends on the optimal parametric combination for instance in experiment 17th the expected values become higher surprisingly. Surface roughness results can be settled by better parameters but there is need for the analyze roughness and MRR together. Each results has been carried out 3 times and average outcomes taken as result.

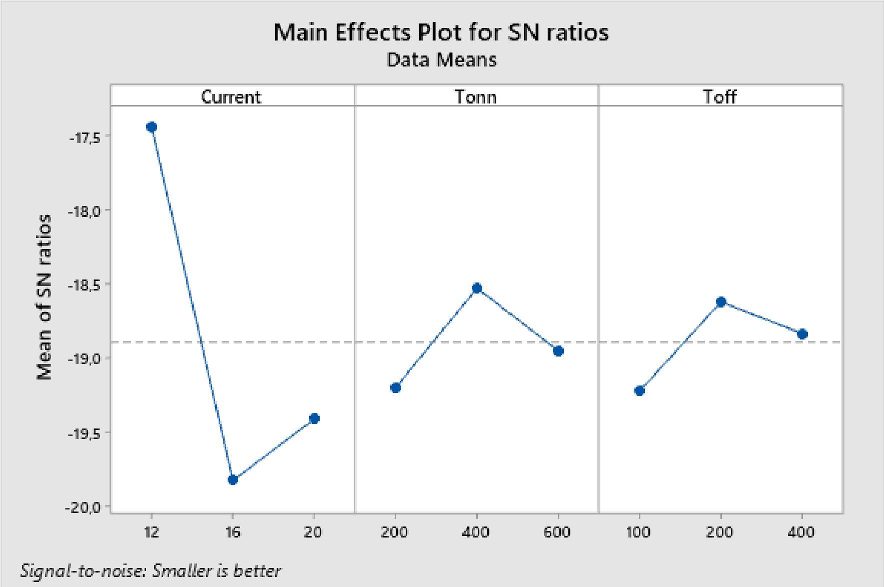

Figure 6. Optimal parameter levels for surface roughness

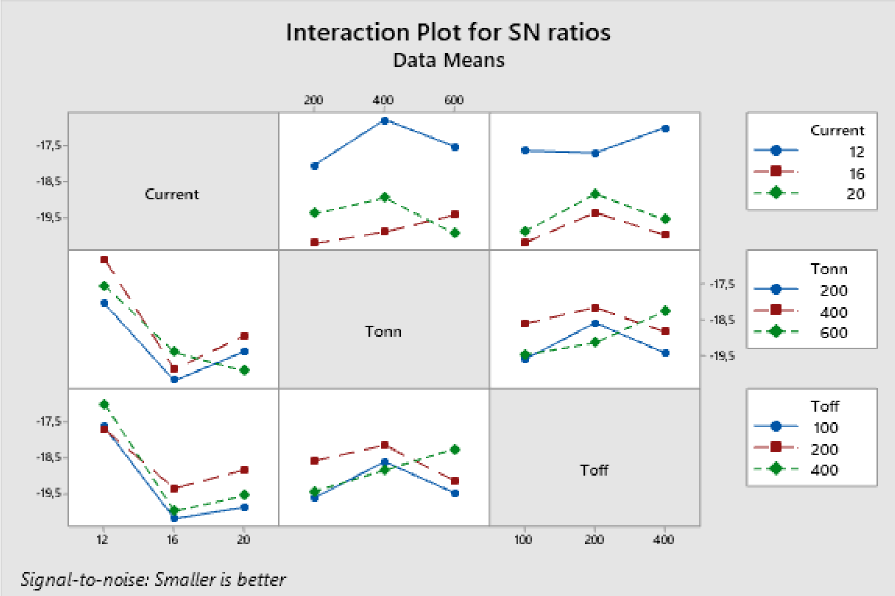

Figure 7. Optimal all effect on surface roughness

As mentioned before MRR values needs to be analyzed differently because it is evaluated values that needs to be higher. According to table 4 response values are seem different when it compared to surface roughness in the table 3, the toff values has more importance then ton values but rank of the ton values hasn't been changed. Therefore, Main effect on surface roughness is current. Higher optimized MRR values are important in EDM because it gives less machining times and economically it represents more cost effectiveness.

Table 4. Response table for S/N for MRR bigger is better

Level	Current	Ton	Toff
1	29,15	30,90	33,92
2	32,57	32,87	32,59
3	34,79	32,74	30,01
Delta	5,63	1,97	3,91
Rank	1	3	2

When parameters are compared accordingly current has rank 1, T-off has rank 2 and ton has rank 3 importance. Higher Toff values can be reducing the MRR and lover Toff vales is boosts the MRR. When it compared to surface roughness it's different. Bu same comment is acceptable hear; parameters are the most important response on the effects of roughness and MRR but there is need for the apply them together. Therefore, there is need for a combination of parameters for example in higher amperes like 20A Ton and Toff values requires to be chosen accordingly.

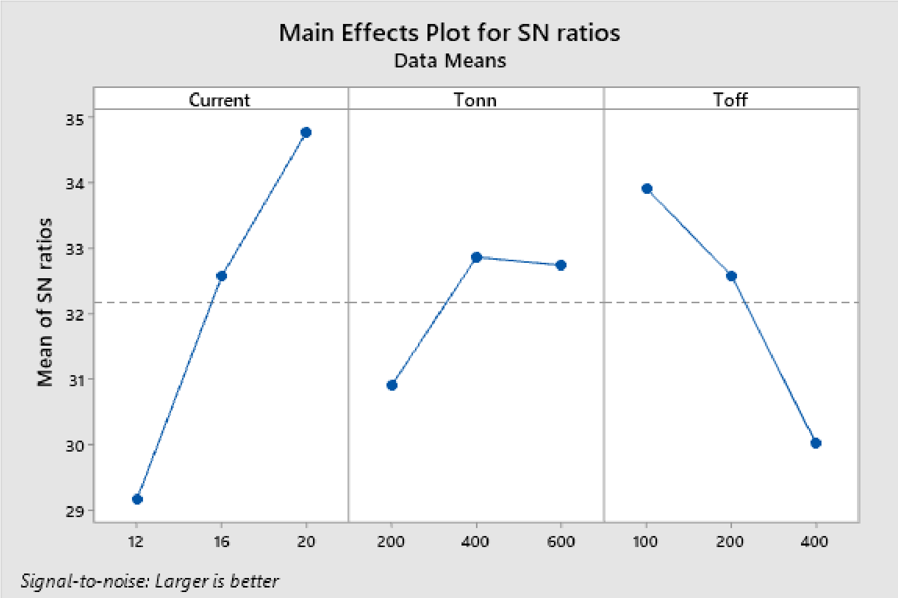

Figure 8. Optimal parameter levels for MRR

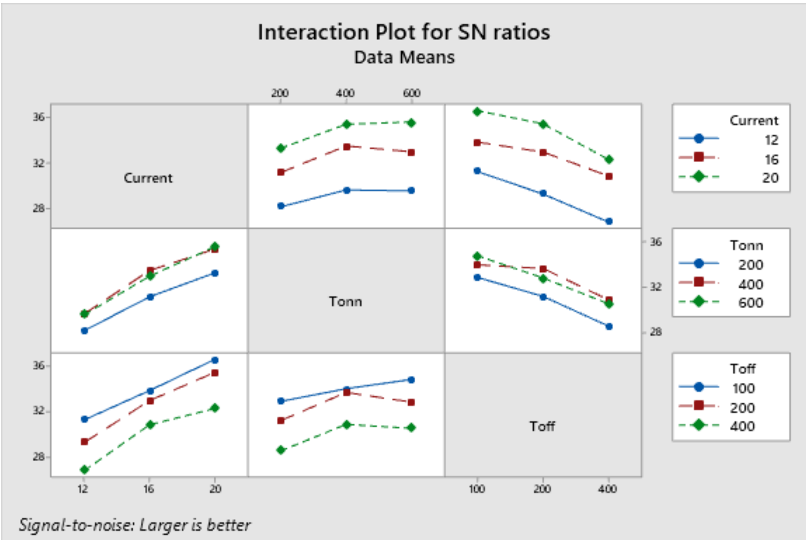

Figure 9. Optimal all effect on surface roughness

According to literature the effects on EDM parameters are very similar for example effects on surface roughness of the material is starts with the current. Results are coincident with the literature. However, the results show that raising the parameters or lowering the values are not enough to improve surface quality, there is a ratio between them which requires to be protected, generally experimental literature backgrounds are not mentioning it.For surface roughness the importance of the outcome parameters slightly changeable, when the rank compared with [2] reference results it shows the current importance is higher than ton. Another example in [5] the results shows current is higher rank Ra. It is observed that the ton and current parameters has the most important parameters for surface roughness. [1-5]

For MRR it is observed that the experimental literature reviews shows slightly different than experimental results, For instance when it compared with [4] results it MRR SN ratio graph shows almost same results with experimental results. However the rankings are different due to slight difference between parameters. These slightly difference proves that the there is a connection between the parameters Such as a ratio between them and when ton rise the toff needs to be raised accordingly. [4-13]

Observed finding of the experiment are the robust ones due to experimental noise conditions are minimized. There are very limited experimental work in literature on powder tool steels. This workout can be climb furthermore with the support of the material characterization and 3d images of the both workpiece and electrode. Also addition with other statistical DOE methods can be useful.

4. Conclusion

Electric discharge machining (EDM) plays a big role in non-traditional manufacturing methods. EDM has a great advantage for machining of hardened materials which has a complex geometries Experimental study on PMD23 (AISI 1.3395) powder metallurgical tool steel shows a quantitative experimental result for the analyses surface roughness and material removal rates. Different parametric values show different results and their effect changes for MRR and Ra differently. Outputs can be seen as follows.

→Surface roughness of the workpiece increased with the increasing ampere and ton time. Taguchi response table shows current has first, ton has second and toff has the third importance for the surface roughness. Some of these parameters are not applieble for the industry.

→According to Taguchi analysis the parameters effects changes for the MRR differently. Taguchi response table shows ampere first, toff has second and ton has the third importance for the MRR:

→High ton and toff time results with the higher surface finish values. However, these values combination can be increase the material removal rates. And combination of them results with better properties for MRR and Surface roughness.

→Increasing MRR results with the lower Ra but the combination of the parameters will provides restoration on the results. Like, higher MRR and Ra can be achieved with the optimization of the parameters.

→From different observation there is need for the differentiate finishing and rought machining steps. The combination of the parameters will result better properties.

→The wear on the electrode surface is unavoidable during the EDM proses therefore there is need for the sharpen electrode every time. Electrode surface directly effects the results.

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