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Optimization of Micro-EDM Process and its Performance Characteristic

Shivendra Raghuvanshi[1] , Sumit Kumar Singh[2] , Dr. Pankaj Agarwal[3]
[1]*M.E scholar at Samrat Ashok Technological Institute Vidisha (M.P),*
[2]*Department of mechanical engineering Sagar Institute of Research and Technology Bhopal (M.P)*
[3]*Department of mechanical engineering Samrat Ashok Technological Institute Vidisha (M.P).*

Abstract - Micro-EDM has become an important and cost-effective method of machining extremely tough and brittle electrically conductive materials. It is most widely used in process of making dies and moulds and complex sections geometry and some intricate shapes. work piece material is choosed in this experiment by using AISI 304 Stainless steel. Today's world 304 stainless steel is contributes to almost half of the world's production and the consumptions for industrial purposes. The input variable parameters are pulse on time ,current and duty cycle. The effect of variable parameters that is mentioned above upon the machining characteristics such as MRR, SR and Overcut (OC) is studied.. The tool material is copper in this experiment.

The results obtained showed that the current was the most significant parameter is followed by the pulse on time and the least significant was duty cycle for entire three responses namely MRR, Surface roughness(SR) and OC. With the increase in current and duty cycle MRR is increased but for pulse on time it increased only up to 100 micro second and then started to decrease. SR increased significantly with the increase in current; for pulse on time it increased up to 100 micro second and after that there was no significant increase; and in case of duty cycle SR increased up to 70% and then started to decrease.

Keywords— micro edm, stainless steel, MRR, Surface Roughness, OC, Taguchi method.

I. INTRODUCTION

Micro-EDM Electro discharge machining (EDM) is a known and it is most widely used nonconventional machining process for hard materials because of its ability to function on brittleness, hardness or toughness of the work piece. Using low energies, it has been successfully applied in micro-machining, for example, it is used in the mould making industry.Give higher accuracies in smaller and more complex structures and an extremely stable process. Additionally, more high-tech materials such as ceramics are used for micro parts; this presents an opportunity to apply micro EDM in that emerging material area. Process Principle of electro discharge machining process based on ablation of material through evaporation and melting. The electrical discharges take place between tool electrode and work piece which is in a dielectric medium that separates.

Micro-EDM is non- conventional machining process, where electrically conductive materials machined by using precisely controlled sparks that are occur between a work-piece and electrode in the presence of a dielectric fluid. It is uses thermoelectric energy sources for machining extremely very low machinability materials. Machining of electrically conductive material irrespective of its hardness, by the application of the thermal energy is one of prime advantages of EDM process. EDM does not make direct contact (an inter electrode gap is maintained in the process) between the work-piece and electrode, its eradicate mechanical stresses, vibration and chatter problems during machining.

II. WORKING PRINCIPLE OF MICRO-EDM

In Micro EDM process, the principle is conversion of electrical energy into thermal energy through a series of discrete sparks occurring between the conductive work-piece and tool electrode immersed in a dielectric medium and separated by small gap. Short duration discharges are generated in the liquid dielectric gap, which separates work-piece and tool. In this process electrical energy is used to generate the electrical spark and thermal energy is used for material removal. The electrode is moved towards the work piece until gap is small enough to ionized the dielectric. The dielectric flush eroded particles from gap and it is important to maintain this flushing continuously.

In this process metal is removing from the work piece due to erosion case by rapidly recurring spark discharge taking place between work piece and tool. Shown the mechanical and electrical set up and electrical circuit for electric discharge machining.A thin gap about 0.025mm is maintained between work piece and tool by the servo system. Both work piece and tool are submerged in dielectric fluid .Deionized water/ Kerosene/EDM oil is common type of liquid dielectric although gaseous dielectrics are mostly used in certain cases.

III. CHARACTERISTICS OF MICRO-EDM

MICRO-EDM specification by mechanism of process, metal removal rate and other function that shown in this table no.1

Table -1

Mechanism of process	Controlled erosion (melting and evaporation) through a series of electrics park
Spark gap	0.010- 0.500mm
Spark frequency	200 – 500kHz
Peak voltage across the gap	30- 250V
Metal removal rate(max.)	$5000mm^{3/min}$
Specific power consumption	$2\text{-}10W/mm^{3/min}$
Dielectric fluid	EDM oil, Kerosene liquid paraffin, silicon oil, de ionized water etc.
Tool material	Copper, Brass, graphite, Ag-W alloys, Cu-W alloys, Stainless steel.
MRR/TWR	0.1-10
Materials that can be machined	All conducting metals and alloys.
Shapes	Micro holes, narrow slots, blind cavities
Limitations	High specific energy consumption, non-conducting materials can't be machined.

IV. IMPORTANT PARAMETERS OF MICRO-EDM

(a) Spark on-time: The duration of time for current is allowed to flow per cycle. The Material removal is directly proportional to amount of energy applied during this on-time. This energy is really controlled by the peak current and the length of the on time.

(b) Spark off-time : The duration of time between the sparks (that is to say, on-time). This time allows the molten material to solidify and to wash out of the arc gap. This parameters is to affect the speed and the stability of the cut. Thus, if the off-time is short, it will cause sparks to be unstable.

(c) Arc gap : The Arc gap is distance between electrode and work piece during the process of micro EDM. It called as spark gap. Spark gap can be maintained by the servo System.

(d) Discharge current : Current is measured in the ampier, Allowed to per cycle. Discharge current is directly proportional to Material removal rate.

(e) Duty cycle : It is the percentage of on-time relative to total cycle time. This parameter is calculated by dividing the on-time by on-time pulse off time.

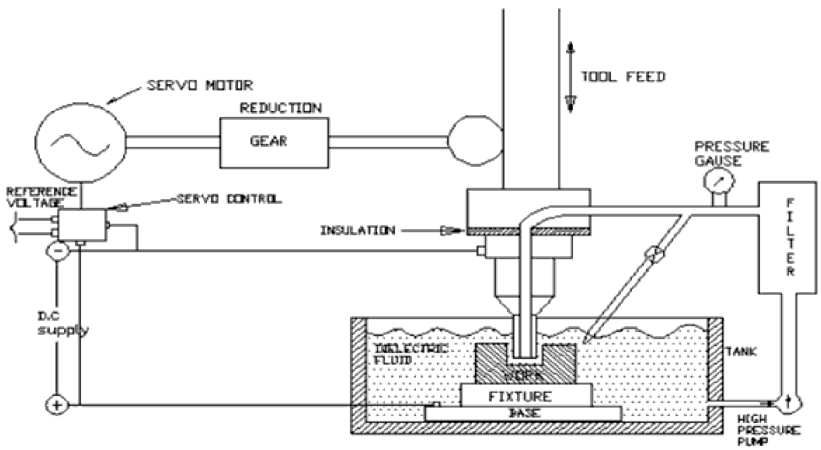
(f) Voltage : It is a potential that can measure by the volt and it is also effect to the MRR and allowed to per cycle. Voltage is given 50 V.

(g) Diameter of electrode : It is electrode of Copper-tube there are two different size diameter 4mm and 6mm in experiment. This tool is used not only as an electrode but it is also for internal flushing.

(h) Over cut – It is clearance between electrode and the work piece after the marching operation.

V. EXPERIMENTAL SETUP AND METHODOLOGY

For this experiment the whole work can be done by Micro Electric Discharge Machine, model ELECTRONICA- ELECTRAPULS PS 50ZNC with servo-head (constant gap) and positive polarity for electrode was used to conduct the experiments. Commercial grade EDM oil (specific gravity= 0.763, freezing point= 94˚C) was used as dielectric fluid. With internal flushing of 304 stainless steel tool with a pressure of 0.2 kgf/cm^2.



Basic Set-Up of Micro Electric discharge machining process

VI. PROCESS PARAMETERS OF MICRO-EDM PROCESS

Table-2

S.No.	Parameters	Range
1	Frequency	0-230KHz
2	Pulse width	1-10 s
3	Gap% of Voltage	65-100%
4	Gain	0-100
5	Pulse peak currant	45A
6	Output Voltage	70-250V
7	Dwell time	0.205
8	Polarity	+/-
9	Hole diameter	0.05-1mm
10	Spindle speed	200-1000

VII. SELECTION OF THE WORK PIECE

It is capable of machining of hard material such as the heat treated tool steels, super alloys, ceramics, carbides, composites, heat resistant steels etc. The higher carbon grades are rarely used for applications such as metal cutting tools, stamping dies etc. AISI grades of tool steel is the most commonly used scale to identify the various grades of tool steel. Individual alloys with in grade are given a numbers; for example:P20, A2, O1, D2 etc. In this experiment using AISI tool steel material this AISI 304 tool steel material is pre hardened high tensile tool steel which offers ready machine ability in hardened and tempered condition, therefore it does not require any heat treatment. Subsequent component modifications can be easily find out.

VIII. MECHANISM OF MRR

The mechanism of material removal of micro EDM process is most commonly established principle is the conversion of electrical energy into the thermal energy. During this process of machining the sparks are produced between the work piece and the tool .

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

$$MRR = \frac{W_i - W_f}{t \times \rho}$$

Where
W_i= Initial weight before machining
W_f= final weight after machining
t = machining time = 15 min
ρ is the density of AISI 304 stainless steel = 8000 kg/m3

Mechanism of Surface Roughness

The Surface Roughness is measure of the texture of the surface. It is measured in μm. If its value is high then surface is rough and if its low then surface is smooth. It is denoted by R_a. The arithmetic mean of three readings are taken as final value.

Mechanism of over cut

It is the discharged by which machined hole in work piece exceeds the electrode size and it is determined by both the initiating voltage and discharge energy. During this machining process of EDM cavity produced are larger than electrode this deference is known as Over Cut .

It becomes very important when the close tolerance components are required to produced for space application and it is also used in dies, tools and moulds for press work.

$$Overcut\ Diameter = \frac{D_i - D_o}{2}$$

Where ;

$D_i$is diameter of hole and $D_o$is diameter of tool.

IX. DESIGN OF EXPERIMENTS ANALYSIS

Genichi Taguchi developed some statistical method is used to improve the qualities of manufactures good known as the Taguchi methods. The design provides the potential and efficient method for designing a different products that can be operate consistently over the wide range of conditions. Minitab provide for both static and dynamic response of experiments. This design of experiments is used to find out the best combination of input variables in a orthogonal array.

Machining parameters and their levels:-

Table-3

Machining Parameter	**Symbol**	**Unit**	**Levels**		
			1	2	3
Current	Ip	A	2	5	8
Spark on time	Ton	μs	50	100	150
Duty cycle	T	%	60	70	80

Table Fixed Parameters and their levels:-

Table-4

SEN	**ASEN**	**Voltage**	**T_w**	**T_0**	**Flushing Pressure (kg/cm^2)**
6	3	45	0.6	0.1	0.25

X. RESULT AND DISSCUSSION

In the experiment, input parameters consider are Current (I), Spark on time (Ton), and Duty cycle (τ). Since 3 factors are select the design becomes a three level three factorial Taguchi design. L27 orthogonal array was select for experiments to be conducted.

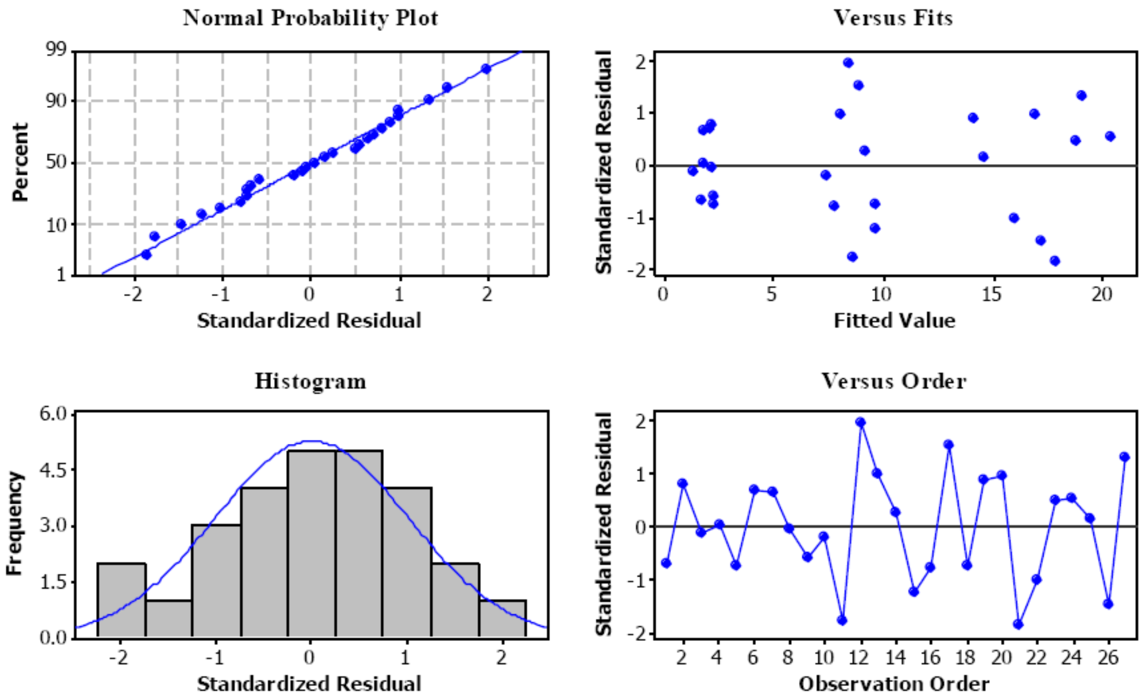
In this chapter we will discuss the results obtained, along with carried the influential parameters that affect each of the MRR, Surface Roughness and Overcut.

Observation Table-5

S.No	**Current (I_p)**	**Machinig Time (T_{on})**	**Duty cycle (τ)**	**MRR (mm3/min)**	**SR (µm)**	**OC (mm)**
1	2	50	70	1.6341	5.423	0.014
2	2	50	80	2.4165	5.876	0.019
3	2	50	90	1.4243	4.240	0.018
4	2	100	70	1.9435	4.676	0.089
5	2	100	80	2.2513	4.742	0.062
6	2	100	90	2.3870	4.320	0.074
7	2	150	70	1.9870	4.832	0.098
8	2	150	80	2.3244	4.750	0.092
9	2	150	90	2.3421	4.000	0.098
10	5	50	70	7.4687	6.010	0.102
11	5	50	80	8.4762	6.500	0.140
12	5	50	90	8.9543	6.320	0.050
13	5	100	70	8.3765	7.450	0.088
14	5	100	80	9.4367	7.410	0.154
15	5	100	90	9.6431	7.950	0.088
16	5	150	70	7.8451	6.900	0.098
17	5	150	80	9.3180	7.950	0.198
18	5	150	90	9.6080	8.000	0.186
19	8	50	70	14.5328	6.800	0.184
20	8	50	80	17.3566	7.240	0.178
21	8	50	90	17.7532	7.650	0.162
22	8	100	70	15.9321	8.976	0.190
23	8	100	80	18.9823	10.100	0.228
24	8	100	90	20.6532	10.120	0.202
25	8	150	70	14.8762	10.110	0.204
26	8	150	80	16.9984	9.790	0.226
27	8	150	90	19.6530	10.000	0.228

Analysis and Discussion of MRR

MRR increases as current increases throughout in a entire range. In case of the pulse on time, MRR first slightly increases up to 100 µs and after that decreases till 150 µs. MRR increases linearly along with increase in duty cycle within range but the magnitude increase is not large.



Main Effects Plot for MRR

Analysis of Variance for Means of MRR

Table-6

Source	DF	Seq SS	Adj MS	F	P	% cont.
Ip	2	1057.93	528.963	4893.21	0.000	96.231
Ton	2	5.06	2.529	23.39	0.000	0.4602
T	2	18.45	9.227	85.36	0.000	1.6782
Ip*Ton	4	3.10	0.774	7.16	0.009	0.282
Ip*τ	4	13.16	3.291	30.44	0.000	1.1971
Ton*τ	4	0.80	0.200	1.85	0.213	0.072
Residual Error	8	0.86	0.108			0.078
Total	26	1099.36				

Here :- S = 0.3288, R-Sq= 99.9%, R-Sq(adj) =99.7%

Response Table for Mean of MRR:
Table-7

Level		Ton	T
1	1.924	8.720	8.123
2	8.627	9.780	9.573
3	17.218	9.268	10.072

Delta	15.294	1.060	1.949
Rank	1	2	3

Table-7 shown variable sources such as pulse on time, current,duty cycle and the interactions between these three factors. Subsequently in following columns degree of freedom, Sum of squares , adjusted mean of square, Probability and distribution are calculated respectively.

Analysis and Discussion of Surface Roughness

Surface Roughness increases with the increase in current within range of experimental conditions. In case of pulse on time Surface Roughness increased up to 100µs and then increment is very slight. With respect to duty cycle, Surface Roughness first increases up to 70% and then decreases after that.

Analysis of Variance for Means of SR

Table-8

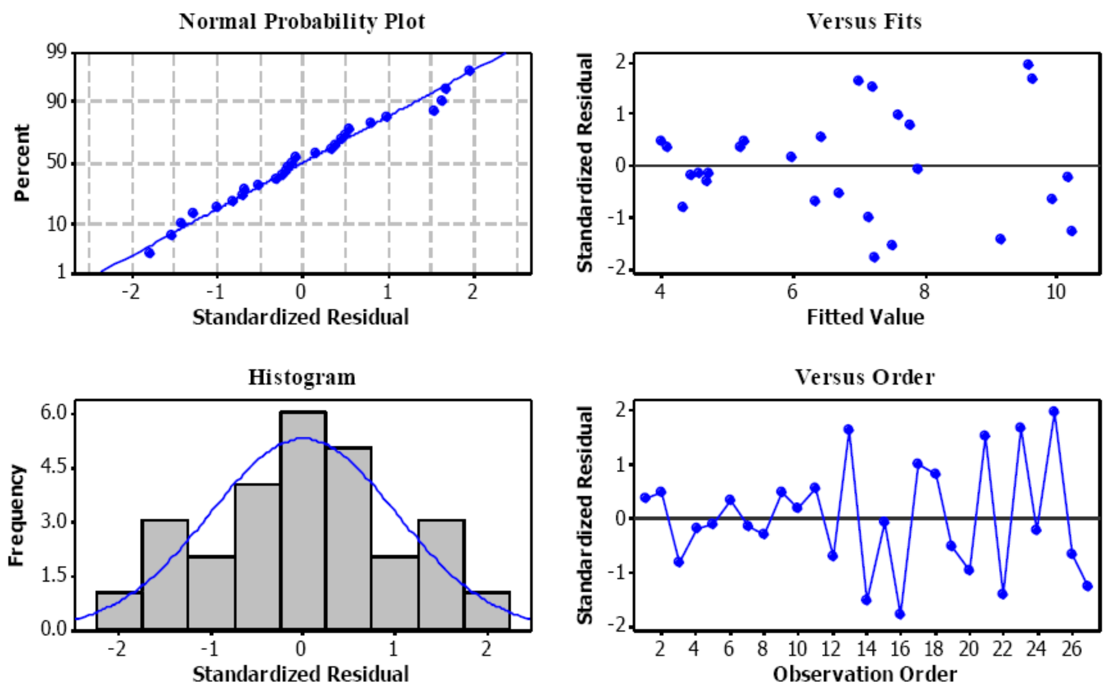
Source	DF	SeqSS	AdjMS	F	P	% cont.
Ip	2	84.121	42.0607	300.05	0.000	78.553
Ton	2	8.378	4.1890	29.88	0.000	7.8234
T	2	0.440	0.2198	1.57	0.266	0.411
Ip*Ton	4	10.873	2.7182	19.39	0.000	10.153
Ip*τ	4	1.906	0.4765	3.40	0.066	1.7798
Ton*τ	4	0.248	0.0621	0.44	0.775	0.2316
ResidualError	8	1.121	0.1402			1.0468
Total	26	107.088				

Here: - S =0.3744, R-Sq= 99.0%, R-Sq(adj) = 96.6%

Response Table for Mean of SR

Table-9

Level	Ip	Ton	τ
1	4.569	6.057	6.667
2	7.080	7.162	6.969
3	8.873	7.304	6.887
Delta	4.304	1.246	0.302
Rank	1	2	3



Residual Plots for SR

Analysis and Discussion of Overcut

The overcut increases with the increasing current within the given range of values. The OC increases linearly with the increase in Ton. But in case of τ the OC first increases up to70% and then decreases.

Analysis of Variance for Means of OC

Table-10

Source	DF	SeqSS	AdjMS	F	P	% cont.
Ip	2	0.083694	0.041847	92.43	0.000	71.787
Ton	2	0.016174	0.008087	17.86	0.001	13.873
T	2	0.002150	0.001075	2.37	0.155	1.844
Ip*Ton	4	0.003017	0.000754	1.67	0.250	2.5878
Ip*τ	4	0.004790	0.001197	2.64	0.113	4.1085
Ton*τ	4	0.003137	0.000784	1.73	0.236	2.6907
Residual Error	8	0.003622	0.000453			3.1067
Total	26	0.116585				

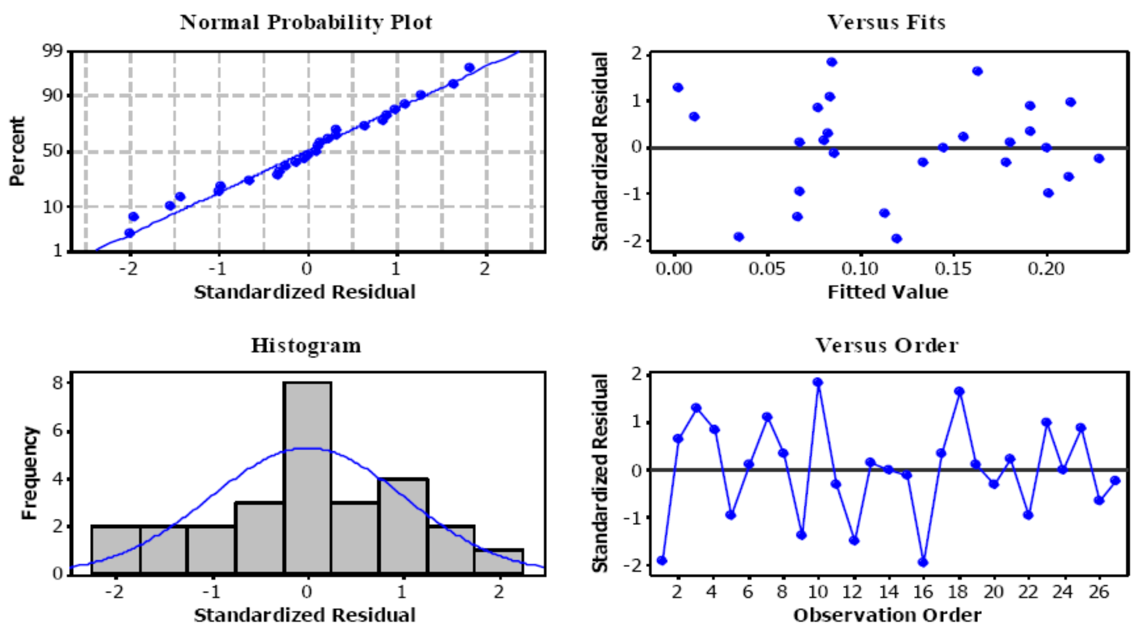
Here: -S =0.02128, R-Sq= 96.9%, R-Sq(adj) =89.9%

Response Table for Mean of OC

Table -11

Level	Ip	Ton	τ
1	0.05933	0.09367	0.11656
2	0.11856	0.12600	0.13689
3	0.19533	0.15356	0.11978
Delta	0.13600	0.05989	0.02033
Rank	1	2	3

From the ANOVA table it can be seen that current and pulse on time are the significant parameter. Also there are no significant interactions. The standard deviation of error S=0.02128 and R^2= 89.9%.
The residual plots and the interaction plots for the overcut are shown in the graphs below. From the graph it can be seen that no interactions are significant.



Residual Plots for OC

XI. CONCLUSION

In this study, experiment was conducted by the considering three variable parameters namely pulse on time, current and duty cycle. The objective was find to the Surface Roughness, Material Removal Rate and Overcut, study about the effects of variable parameters on these characteristics. The tool material taken as copper and the work piece was chosen as AISI stainless steel.
Following conclusions were drawn:

- For the MRR most significant factor was found to peak current followed by the pulse on time. MRR increased nonlinearly with increase in current. For Ton the MRR first increase till 100 µs and then it was decreased. With increase in duty cycle.
- For Surface Roughness most significant factor was again current followed by pulse on time and lastly the duty cycle. Surface Roughness increased significantly with increase in current in nonlinear

fashion. For increase in pulse on time Surface Roughness increased up to 100 µs and then there was no increase. In case of the duty cycle, SR first increase up to 70% and then it started to decrease.

- For OC most significant factor was the current followed by pulse on time and the duty cycle respectively. OC increased along with in the increase in current. For increase in pulse on time, OC is increased linearly. Finally for the duty cycle, OC increased but only up to 70% and then it started decreasing.

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