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Investigation of Process Parameters for Optimization of Surface Roughness in Finish Cut Electric Discharge Machining

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Abstract
Surface roughness has significant effect on functionality and service life of components. If surface roughness is properly controlled then, performance of the component enhances in operational applications. Surface roughness becomes key concern when intricate profiles and shapes are required to be manufactured in components. The objective of the paper is to bring up an adequate surface roughness in finish cut by optimizing process variables. If initial surface form is obtained by proper control of machining parameters then additional finishing efforts and lead time reduce a lot. In the industrial tool room survey availability of machining data is prime concern in terms of tuned process parameter for precision machining. Optimization of process parameters is essential in order to arrest surface roughness and thereby improve surface textures. Experimental investigations are performed to study the effect of pulse current, pulse on time and gap voltage on response of surface roughness, in case of ram EDM. Design of experimentation (DOE) and ANOVA are carried out for optimization of process parameters, within work interval of finish cut machining.

Keywords: Electric discharge machining (EDM), surface roughness, orthogonal array, finish cut machining.

I. INTRODUCTION

The electric discharge machining is a non-traditional manufacturing process based on electro thermal phenomenon of material erosion. A series of discrete sparks between tool electrode and workpiece removes the material in the presence of dielectric fluid. As the tool does not come in contact of workpiece hence surface texture is free of any stresses and cutting forces impressions. EDM is well suited for machining of forging dies, injection moulds and automobile parts. [1-3]

At present scenario EDM has drawn a great deal of researchers attention because of its broad industrial applications. Mohri and Saito proposed a new process of finishing machining on free form surfaces. In the process an electrode and a work were cut by machining centre, using geometrical tracing of intersections method. Powder suspended working fluid was used in finish electrical discharge machining in order to limit roughness, thereby achieve mirror like 3D surfaces. [4]

Weule and Timmermann focused on surface finishing automation in the manufacturing of dies and molds by replacing manual approach. Modern tool of honing and grinding are presented with which manual labor can be atomized with replacement of an industrial robot. Material removal theoretical model is presented for short stroke honing operation, applied on freeform surfaces. [5]

Brinksmeier et al. suggested surface roughness and form accuracy for optical applications. They studied finishing of high precision mould by newly developed abrasive polishing process and by laser polishing. The study focuses on the material removal mechanism in abrasive polishing and achieving proper surface roughness. Surface quality achieved by laser polishing was compared with abrasive flow machining. [6]

Saito and Miyoshi automated the polishing process for cavity surfaces on dies and moulds. The finishing of dies and mould is generally followed by handwork of skilled operator. An expert system is developed which acquires the knowledge of skilled machinist for mould finish operation. The established system is found useful for proper scheduling in manufacturing. [7]

Singh and et al. examined surface roughness using various machining parameters in electrical discharge machining. The effects of different tool materials were investigated for surface roughness. For higher pulse current and time, surface roughness increases more in cryogenic copper than general copper. It is found that work piece surface roughness increases due to wear rate on electrode. [8]

Improper surface textures occur during EDM process owing to the lack of availability of machinability data in terms of tuned process parameters. In the literature it is observed that the polishing process has been reported for many times but initial surface roughness information immediate after electric discharge machining is not sufficiently available. After electric discharge machining if the surface obtained itself provides proper surface roughness, then efforts required for additional finishing processes can be saved. The additional finishing like polishing, stoning and buffing may be reduced in order to save time and efforts for mould maker. Therefore, optimisation of the surface roughness in correlation with tunning of machining parameters is necessary to enhance component quality and process reliability.

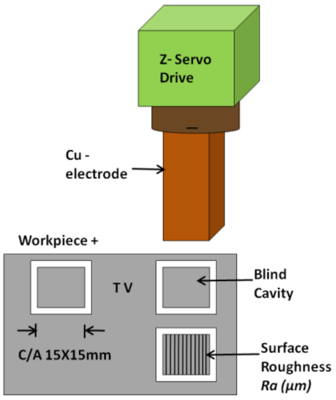


Figure1: EDM process with surface roughness

II. EDM EXPERIMENTAL PLANNING

The equipment used to perform the experiments is a die-sinking EDM machine of type Electronica E-20, which has pulse generator, as shown in fig.2. The pressure used for the dielectric fluid is 3.2 kgf/cm2, under jet flushing. The workpiece material used in experimentation is AISI D2 alloy steel which is used in the inner core and sections of the cold work dies and moulds. [1]

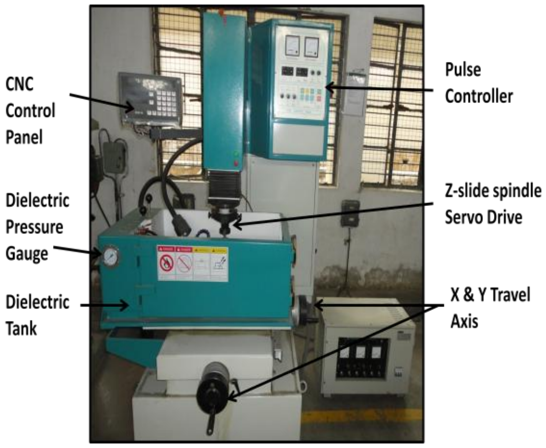


Figure2: Experimental die sink EDM

Furthermore, the copper tool is selected in a prismatic form with a transverse area of 15mm × 15mm and 50mm in height. The copper rods with 98% purity and 8.94 g/cc density were machined with good surface finish and exact dimensions as tool electrodes. Copper electrodes and workpieces were ground carefully so as to provide stable machining conditions in EDM process. [1]

2.1 Design of Experiments

The nature of variation of response with respect to a particular factor helps in deciding the levels of the factor. Though there are a large number of parameters involved in the EDM process, but in this work the level of the generator current pulse intensity (Ip), pulse time (Ton), gap voltage (Vg) have been taken into account as design factors.[1] The four level of robust L16 orthogonal array is followed for design of experiments and corresponding levels are mentioned in Table 1.

Table 1: Machining parameters with levels

Symbol	EDM machining parameters and levels				
		1	2	3	4
A (Ip)	Pulse Current (amps)	3	5	7	10
B (Ton)	Pulse-on Time (sec)	0.11	0.17	0.29	0.38
C (Vg)	Gap Voltage (volt)	130	135	140	145

2.2 Response Variable – Surface Roughness

In the electric discharge machining sparks take place from bottom and side as well. The bottom and side sparks lead to surface roughness.

Surface roughness is a measure of finely spaced surface irregularities and deviations. It is also referred as surface finish in Engineering. Roughness values are taken into consideration as initial surface finish, immediately after electric discharge machining and before polishing.

In experimentation the uniform square tool is selected. Surface roughness is measured in relation to X and Y axis and average value is mentioned in Table2. The surface roughness tester (Mitutoyo Surftest) is utilized for the measurement of cavity surface in workpiece as shown in the fig.3.

For the finish cut Ra (μm) analysis, 'lower is better' phenomenon is considered in design of experiments (DOE). The S/N ratio statistics can be obtained by evaluating largest variance in the process as,

$$\text{Ra }(\mu\text{m})\ \text{S/N Ratio} = -10\log_{10}\left(\frac{1}{n}\sum_{i=1}^{n} y_i^2\right)$$

Where yi is the ith observation of a treatment combination and n is the number of replications, which is referred here as average and means of Ra (µm) responses.

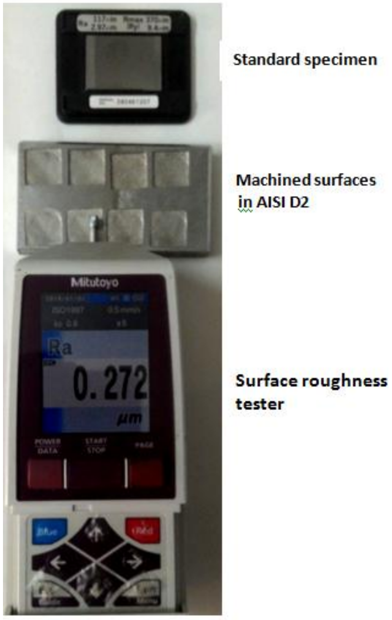


Figure3: Surface roughness testing AISI D2 sample

III. RESULTS AND ANALYSIS

The experimental results for surface roughness in finish cut machining for AISI D2 are shown in Table2. The variables considered in the experiments are current intensity (Ip), pulse on time (Ton) and gap voltage (Vg), where the behavior of each parameter significantly affects the surface roughness. Hence the array L16 having 4 numbers of levels of parameters is implemented to find out better tune up parameter with the help of Minitab17 version. [1]

Table 2: Orthogonal array L16 based experimental results for surface roughness

Ex N o.	Current Ip amps	Time Ton sec	Gap Voltage Vg volt	Avg. Ra (µm)	S/N ratio dB	Residuals
1	3	0.11	130	2.397	-7.59	0.01
2	3	0.17	135	2.79	-8.91	0.13
3	3	0.29	140	3.206	-10.11	-0.08
4	3	0.38	145	3.515	-10.91	-0.36
5	5	0.11	135	3.752	-11.48	-0.37
6	5	0.17	130	4.775	-13.57	0.04
7	5	0.29	145	4.838	-13.69	0.40
8	5	0.38	140	5.475	-14.76	0.76
9	7	0.11	140	5.651	-15.04	0.52
10	7	0.17	145	4.173	-12.40	-0.54
11	7	0.29	130	6.929	-16.81	0.07
12	7	0.38	135	5.512	-14.82	-0.76
13	10	0.11	145	6.207	-15.85	0.23
14	10	0.17	140	7.317	-17.28	-0.41
15	10	0.29	135	9.277	-19.34	0.20
16	10	0.38	130	9.775	-19.80	0.13

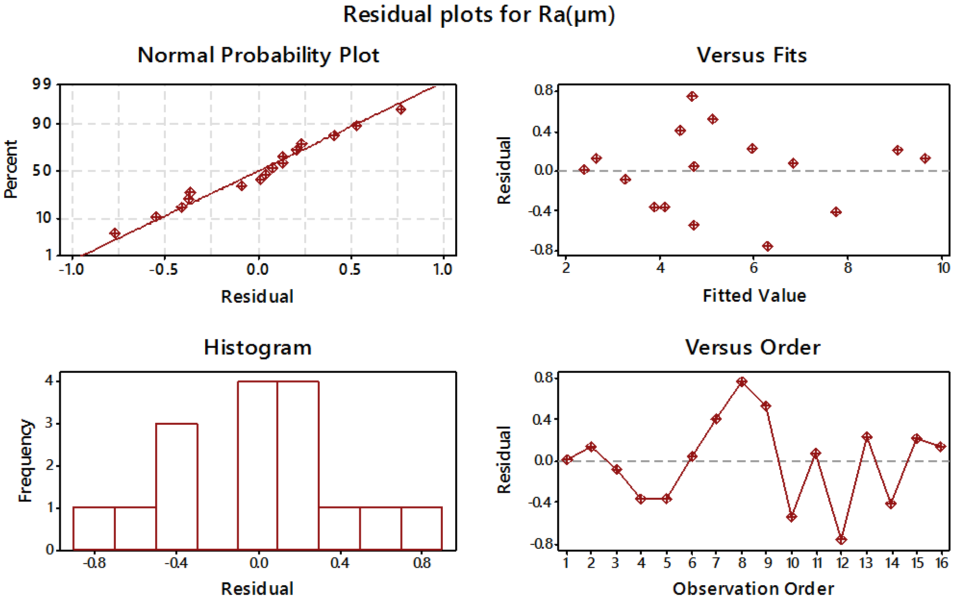


Figure4: Residual plot analysis for surface roughness

3.1 Experimental Run Adequacy through Residual Plot Analysis

Conformity of response data generated through experiments is done through the residual plot analysis for surface roughness. In the graphs of residual there are three assumptions for experimental run adequacy checking i.e. normality, constant variance and independence. All these assumptions are validated by the residual plots with intention of particular response factor, which in this case is surface roughness. Fig.4 visibly implies that Ra(µm) residuals have constant variance and independent of one another. [1]

Therefore it is concluded that the experimental data obtained through orthogonal array L16 is appropriate for surface roughness.

3.2 The Analysis of Surface Roughness

The main effects plot for surface roughness and S/N ratio are shown in fig.5&6. The S/N ratio plot for RA (µm) is followed according to 'lower the better' analysis because in the finish cut machining, lower surface roughness is preferred for dimensional accuracies. The largest spread of means for pulse current shows its importance in spark process, compared with the other variables. For the performance characteristic of surface roughness, the levels A1B1C4 including discharge current of 3amp, pulse on duration of 0.11 sec and open voltage of 145V leads to optimal tuned process parameters as shown in S/N ratio plot fig.6.

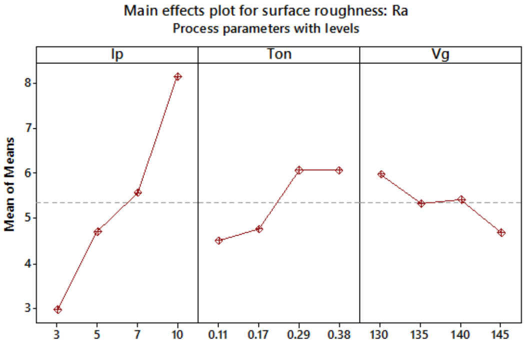
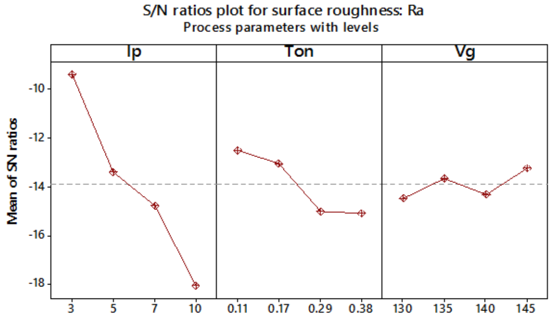


Figure5: Main effects plot for surface roughness



Signal-to-noise: Ra: Lower is better

Figure6: S/N ratios plot for surface roughness

3.3 Regression Analysis for Surface Roughness:

The regression analysis model is developed to correlate the effects of electric discharge machining parameters on the magnitude of surface roughness. The regression equation is the function of various input process variables for response of surface roughness. The two levels of interaction and second order polynomial equation are considered in the regression analysis. The regression model for surface roughness is given as,

$$\text{Surface Roughness: Ra } (\mu m) = -24 + 5.92\,Ip - 44.6\,Ton + 0.29\,Vg - 0.38\,Ip\times Ton - 0.0372\,Ip\times Vg + 0.411\,Ton\times Vg + 0.0057\,Ip^2 - 14.4\,Ton^2 - 0.00090\,Vg^2$$

3.4 Analysis of Variance for Surface Roughness

Table 3 illustrates the corresponding ANOVA results, where contributions of each machining parameter are estimated. The contributions of two level of interaction and second order of parameters are also evaluated. It can be seen that the discharge current plays vital role for the surface roughness with about 78.3% of the contribution followed by pulse on time 10.7% and gap voltage as 4%. The parametric higher order interaction of pulse current and gap voltage (Ip×Vg) is observed to have important contribution of 2.21%. The R-squared value of regression analysis model is 96.4%, which shows that the model is statistically significant.

Table 3: ANOVA for surface roughness

Ra (µm) Analysis	Seq SS	Adj SS	Seq MS	P-Value	Cont.%
Model	67.48	67.48	7.498	0.001	96.4
Ip	54.84	1.837	54.84	0.000	78.35
Ton	7.542	0.178	7.542	0.005	10.77
Vg	2.854	0.011	2.854	0.04	4.08
Ip×Ton	0.000	0.054	0.000	0.978	0.00
Ip×Vg	1.546	1.482	1.546	0.103	2.21
Ton×Vg	0.307	0.307	0.307	0.425	0.44
Ip^2	0.054	0.015	0.054	0.732	0.08
Ton^2	0.326	0.176	0.326	0.412	0.47
Vg^2	0.009	0.008	0.009	0.891	0.01
Error	2.515	2.515	0.419		3.59
Total	70.00				100

3.5 Response Surface Plot for Surface Roughness

Response surface for two variables at same time are analysed against surface roughness within the interval of finish cut machining. In the plot of Ra *Vs* Ip and Ton the levels 3amp and 0.11sec gives minimum surface roughness as shown in the fig.7. In the surface plot fig.8 it is observed that the surface roughness is minimum at spark gap voltage value130volt. In the surface plot of Ra *Vs* Ton and Vg many peaks have been observed as shown in fig.9. The highest peak values of pulse on time 0.38 sec and 140 volt are not preferred, as it leads to higher surface roughness.

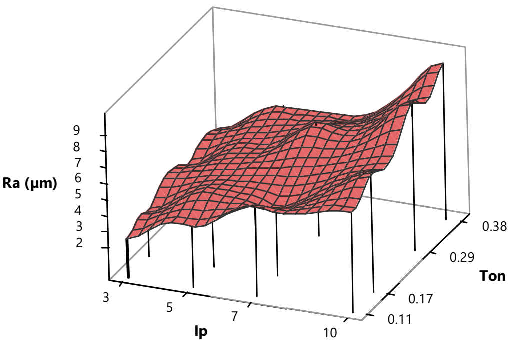


Figure7: Response surface for Ra (µm) *Vs* Ip & Ton

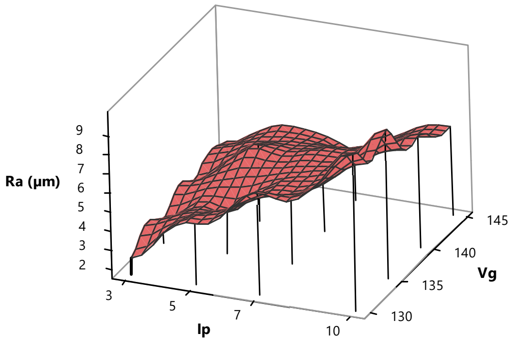


Figure8: Response surface for Ra (µm) *Vs* Ip & Vg

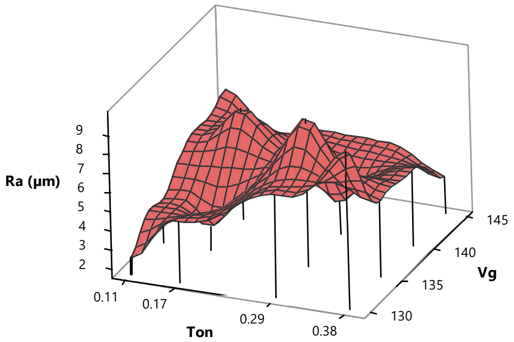


Figure9: Response Surface for Ra(µm) *Vs* Ton & Vg

IV. CONCLUSION

Implementation of finish cut machining work interval to improve the performance characteristics of surface roughness has been reported in the present work. Orthogonal array L16 experimentation and ANOVA for determining the optimal tuned process parameters has been carried out. According to response surfaces, discharge current, gap voltage and pulse duration have found a clear effect on the ram EDM performance for surface finish textures.

1) On the basis of experimental results the discharge current has been found playing significant role with about 78.3% contributions in surface roughness responses.
2) The parameter levels A1B1C4 including the discharge current 3amp, pulse duration of 0.11 sec and open voltage of 145V respectively, are the optimum favorable performance characteristic for the surface roughness
3) The surface textures obtained in experimentation array can work as comparator samples to follow particular set of machining parameter, while performing EDM operational practices in tool room.

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