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Analysis of EDM Process Parameters for Optimization of Overcut per Side using Taguchi Techniques

A. D. Urade[1], V. S. Deshpande[2]

[1]Department of Mechanical Engg., Shri Ramdeobaba College of Engineering & Management, Nagpur-440013, Maharashtra, India
[2]Department of Industrial Engg., Shri Ramdeobaba College of Engineering & Management, Nagpur-440013, Maharashtra, India

Abstract: ***The electric discharge machining is proving as highly preferred machining process for the production of dies and molds among the tool makers. Dimensional accuracy becomes key concern when intricate geometrical profiles and shapes are required to be manufactured in components. Due to the spark erosion process, the cavity dimensions produced in the dies are larger than the tool size which results into overcut per side. The requirement is lower overcut for higher dimensional accuracy. In the industrial tool room survey availability of machining data is prime concern in terms of tuned process parameter for precision machining. Optimization of dimensional deviation is essential in order to improve accuracy in designing the electrodes and arresting overcut per side. In this paper experimental investigations are carried out to study the effect of pulse current, pulse on time and gap voltage on the response of overcut per side, 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), overcut per side (OCS), orthogonal array, finish cut machining

1. 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. The high temperature electric discharges melt and vaporises material in tiny globular form which are flushed away by dielectric fluid under pressure. At the present time, EDM is a high-precision machining used for metals and metallic alloys of any hardness. This process is well suited for machining of forging dies, injection moulds and automobile parts. [1]-[3]

At present scenario EDM has drawn a great a deal of researcher's attention because of its broad industrial applications. Puertas and Luis studied the influence of the factors of intensity, pulse time and duty cycle for surface quality, metal removal rate and electrode wear. They stated that for fine finish low values of intensity and pulse time should be used. [3] Dastagiri and Hemantha Kumar investigated the effect of EDM parameter on metal removal rate and tool wear rate on surface roughness characteristics. One variable at a time was varied and its effect on metal removal rate and surface roughness observed by keeping all other entities at fixed average values. Although this analysis does not give a clear idea of the phenomena over the entire range of the input parameters, it can highlight some of the important characteristics of EDM process. [4]

Singh et al. determined best parameter setting for radial overcut. They used H-13 hot roll steel as workpiece to study various EDM parameters like peak current, gap voltage, duty cycle, polarity and retract distance. Optimum parameter were obtained using Taguchi method.[6] Chaudhary et al. studied experimental investigations to optimize dimensional deviations in wire EDM. The process variables taken were wire feed, pulse off time and servo voltage for the response variable as dimensional deviation in percentage. It is observed that servo voltage is inversely proportional to the dimensional deviation. [7]

EDM is well known for machining accurate cavities in the dies and moulds. Improper dimensional deviations 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 radial overcut has been reported for many times but overcut reporting for square or edge type geometry lacks. In die making process overcut imposes excess of lead time due to the issue of accuracy. In order to increase the machining efficiency, erosion of the workpiece must be optimised by proper control of overcut in EDM process as shown in figure1. Therefore, optimisation of the overcut per side in correlation with tunning of machining parameters would be useful to enhance the machining productivity and process reliability.

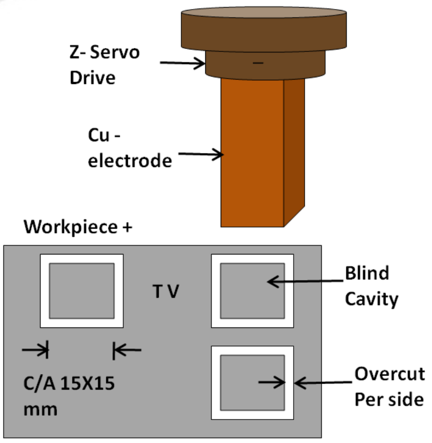

Figure 1: EDM process with overcut per side

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2. 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 figure2. The pressure used for the dielectric fluid is 3.2 kgf/cm^2, under jet flushing. [1]

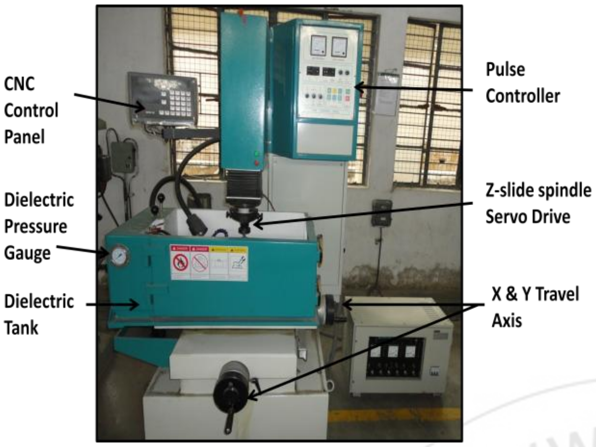

Figure 2: Experimental die sink EDM

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 tools. Furthermore, the copper tool is selected in a prismatic form with a transverse area of 15mm × 15mm and 50 mm 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 (Tp), 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

Symbols	*Machining Parameters*	*Level 1*	*Level 2*	*Level 3*	*Level 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 – Overcut per side

In the electric discharge machining sparks take place from bottom and side as well. The bottom sparks results in depth of cut whereas the side sparks lead to overcut per side. Therefore the machined area and cavity is always larger than tool dimensions which is termed as overcut per side (OCS).

The overcut per side is expressed as half of the difference between cavity dimensions (Dw) and dimension of the tool (Dt).[7] In experimentation the uniform square tool is selected and OCS is measured per side (in relation to X-axis particularly). Tool maker microscope is utilised for the measurement of cavity in workpiece and tool dimensions

$$\mathrm{OCS} = \frac{(\mathrm{Dw} - \mathrm{Dt})}{2} \qquad (1)$$

For the finish cut OCS 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,

$$\mathrm{OCS\ S/N\ Ratio} = -10\log_{10}\left(\frac{1}{n}\sum_{i=1}^{n} y_i^2\right) \qquad (2)$$

Where y_i is the i^{th} observation of a treatment combination and n is the number of replications, which is referred here as average and means of OCS response.

Table 2: Orthogonal array L16 based experimental results

Exp No.	*Pulse Current Ip amps*	*Pulse Time Ton sec*	*Gap Voltage Vg volt*	*Overcut per side OCS mm*	*S/N ratio dB*	*Residuals*
1	3	0.11	130	0.053	25.433	0.010
2	3	0.17	135	0.086	21.310	0.016
3	3	0.29	140	0.090	20.899	-0.015
4	3	0.38	145	0.109	19.251	-0.008
5	5	0.11	135	0.071	22.975	-0.038
6	5	0.17	130	0.108	19.358	-0.007
7	5	0.29	145	0.114	18.837	0.012
8	5	0.38	140	0.174	15.214	0.025
9	7	0.11	140	0.194	14.229	0.030
10	7	0.17	145	0.129	17.822	-0.010
11	7	0.29	130	0.186	14.610	0.008
12	7	0.38	135	0.159	15.954	-0.021
13	10	0.11	145	0.218	13.211	-0.017
14	10	0.17	140	0.253	11.920	0.030
15	10	0.29	135	0.179	14.967	-0.028
16	10	0.38	130	0.233	12.665	0.013

3. Results and Discussion

The experimental results for overcut per side 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 behaviour of each parameter significantly affects the overcut per side. Hence the array likes L16 having 4 numbers of levels of parameters is implemented to find out better tune up parameter with the help of Minitab17 version. [1]

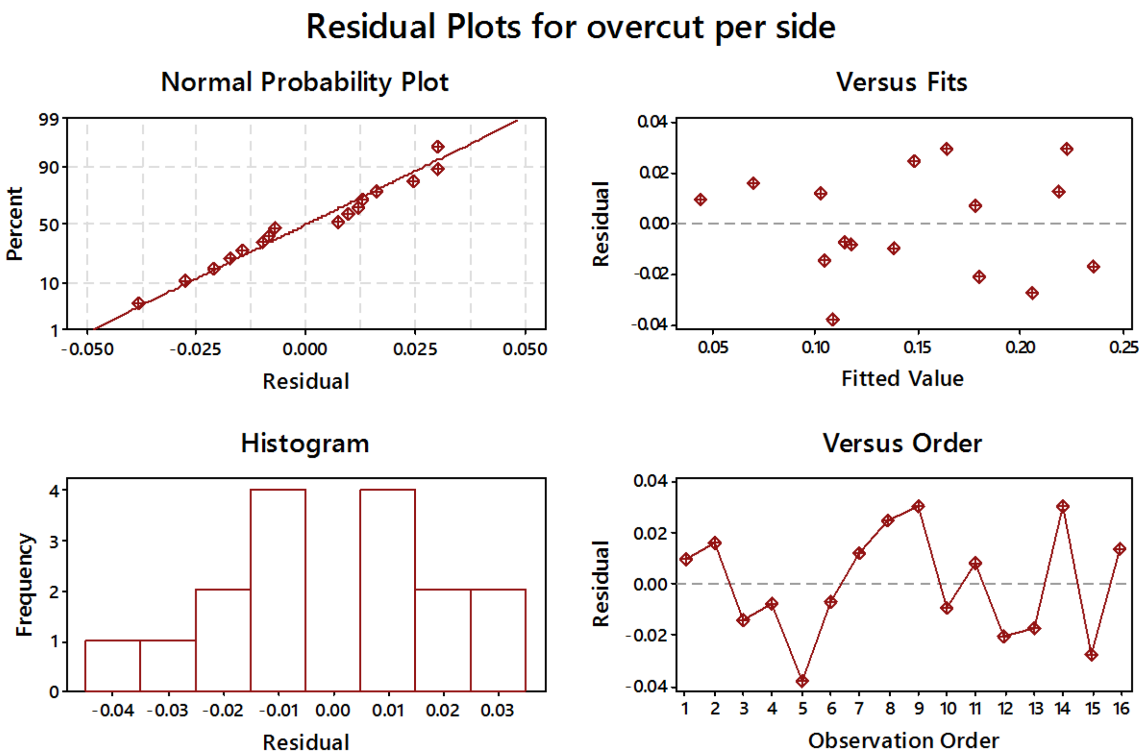

Figure 3: Residual plot analysis for overcut per side

3.1 Experimental run adequacy through residual plot analysis

Conformity of response data generated through experiments is done through the residual plot analysis for overcut per side. 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 overcut per side. Figure3 visibly implies that OCS residuals have constant variance and are independent of one another. [1]

Therefore it is concluded that the experimental data obtained through orthogonal array L16 is appropriate for overcut per side.

3.2 The analysis of overcut per side

The main effects plot for overcut per side and S/N ratio are shown in figure 4 & 5. The S/N ratio plot for OCS is followed according to 'lower the better' analysis because in the finish cut machining, lower overcut per side 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 overcut per side, the levels A1B1C2 including discharge current of 3amp, pulse on duration of 0.11 sec and open voltage of 135V leads to optimal tuned process parameters as shown in S/N ratio plot.

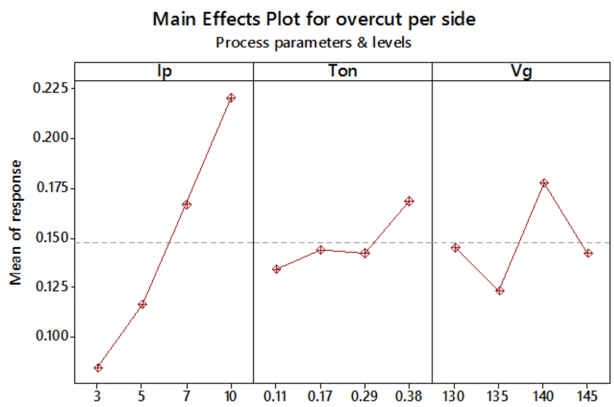

Figure 4: Main effects plot of means for overcut per side

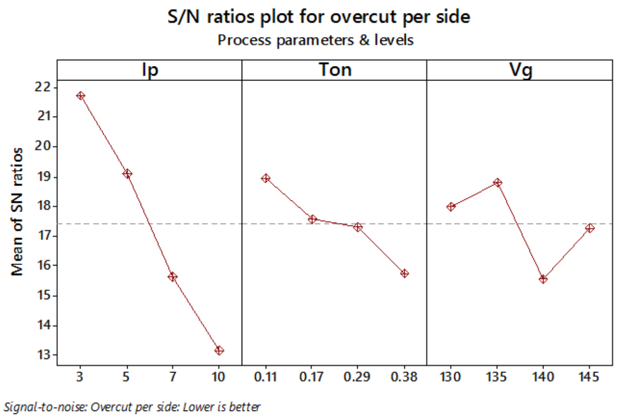

Figure 5: S/N ratios plot for overcut per side

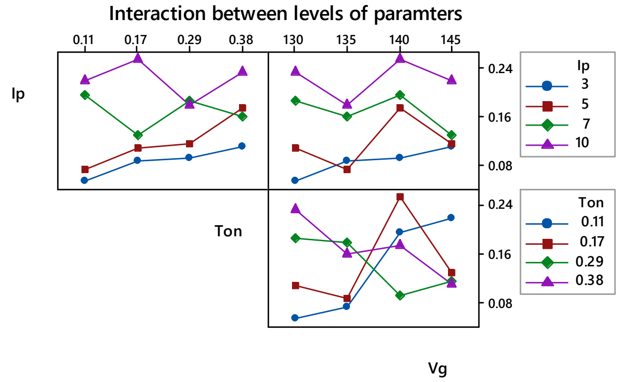

Figure 6: Interaction plot for overcut per side

The table 3 shows the means of responses for levels of parameters related to overcut per side. The pulse current is the highest ranked parameter with maximum delta difference among the levels, followed by gap voltage and pulse time. As can be seen from results the pulse current significantly dominates other factors in terms of the response variable as overcut per side.

Table 3: Means response table for overcut per side

Parameter Levels	*Pulse Current Ip (amps)*	*Pulse Time Ton (sec)*	*Gap Voltage Vg (volt)*
1	0.08467	0.13433	0.14496
2	0.11662	0.14392	0.12371
3	0.16704	0.14225	0.17787
4	0.22079	0.16863	0.14258
Delta	0.13612	0.03429	0.05417
Rank	1	3	2

3.3 Interaction plot for overcut per side

Interaction plot for overcut per side to analyse the effect of one parameter on the level of the other parameter within the machining interval are as shown in figure6. The crosses over between the connector lines indicate interactions among the levels of process variables. Parallel lines in an interaction plot indicate no interaction among levels. The interactions are observed among Ip- 7, 10 amp for spark on time 0.29 sec. In case of graph Ip-Vg interactions are observed for gap voltage145volt against the levels 5,3 amp of pulse current. In the interaction plot of Ton- Vg, heavy interactions are observed showing increase in deviations for overcut per side.

3.4 Regression analysis for overcut per side:

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

Overcut per Side (OCS) = $-3.02 + 0.075\,Ip + 2.71\,Ton + 0.0398\,Vg - 0.0935\,Ip\times Ton - 0.00028\,Ip\times Vg - 0.0171\,Ton\times Vg + 0.00020\,Ip^2 + 0.62\,Ton^2 - 0.000133\,Vg^2$

3.5 Analysis of variance for overcut per side

Table 4 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 overcut per side with about 76.7% of the contribution followed by gap voltage as 3.6%. The parametric higher order interaction of pulse current and pulse on time (Ip×Ton) is observed to have important contribution of 5.1%. The R-squared value of the regression analysis model is 88.1%, which show that the model is statistically significant.

Table 4: ANOVA for overcut per side

Source	Seq SS	Adj SS	Seq MS	F-Value	P-Value	Contri bution
Regre ssion Analysis	0.0487	0.0487	0.0054	4.93	0.033	88.1%
Ip	0.0424	0.0003	0.0424	38.63	0.001	76.7%
Ton	0.0004	0.0002	0.0004	0.40	0.549	0.8%
Vg	0.0020	0.0007	0.0020	1.80	0.228	3.6%
Ip×Ton	0.0028	0.0032	0.0028	2.57	0.160	5.1%
Ip×Vg	0.0001	0.0001	0.0001	0.06	0.814	0.1%
Ton×Vg	0.0005	0.0005	0.0005	0.49	0.512	1.0%
Ip^2	0.0000	0.0000	0.0000	0.00	0.999	0.0%

Ton^2	0.0003	0.0003	0.0003	0.26	0.627	0.5%
Vg^2	0.0002	0.0002	0.0002	0.18	0.686	0.4%
Error	0.0066	0.0066	0.0011			11.9%
Total	0.0553					100%

4. Conclusion

Implementation of finish cut EDM machining work interval to improve the performance characteristics of overcut per side 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 main effect plot it is found that discharge current, gap voltage and pulse duration have found a clear effect on the ram EDM performance for overcut per side characteristics.

1) On the basis of experimental results the discharge current has been found playing significant role with about 76.7% contributions in overcut per side responses.
2) The parameter levels A1B1C2 including the discharge current 3amp, pulse duration of 0.11 sec and open voltage of 135V respectively, are the optimum favorable performance characteristic for the overcut per side
3) Based on the experimentation conducted lower levels values than discharge current 5amp, pulse duration o.29sec may be recommended for controlling overcut in tool room EDM operational practices.

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