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Optimization of Process Parameters of EDM for Different Shape of Electrodes Using Fuzzy Logic and Doe Modelling

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Abstract: Non-conventional machining process is most growing technology for machining the high precision cut on work pieces. EDM machining is successfully cut high precise on high strength alloy materials like super alloy, Heat treated steel etc. In present research study process parameters of EDM is experimentally analysis for two different type of design of cut, which are selected from literature review. Work Piece is set as constant for this research study and heat treated before main experiments on EDM machine. Design of experiment method called "taguchi Method", is selected for this research study. Factor and Their levels are selected on the basis of literature review and industry survey. Total four factors which are following: Pulse on time, Pulse off time, PC and Press on electrode. Each factor has three levels. The selection of levels is done by pilot experiments on EDM machine. All experiments are conduct at CIPET, Jaipur at tool room. The work piece material is EN-08 but heat treated at college workshop by oil Quenching process. L9 orthogonal Array is developed for both designs of cut, first design is pentagonal cut and second cut is rectangular cut. Both cuts are same cross section but design is not same. Two response variables which are cutting time during machining and over cut from final product. Over cut is measured using micro scope available at college physics department. Analysis is done using signal to noise ratio, analysis of variance, regression modeling and fuzzy logic rules are also made for finding the importance of fully logic in this type of study. Prediction is well suited with experimental results.
Keywords: Non-conventional, EDM, CD Function, ANOVA, S/N ratio analysis, pilot experiments, Fuzzy Logic rules

I. INTRODUCTION

High precise machining is one of the regular requirements for manufacturing industry. This requirement is not fulfil by conventional machining process specially when high strength materials are used as a product. In that case non-conventional machining process is used by industry for this type of machining specially electrical discharge machining (EDM). EDM is one the most common non-conventional process for high precise machining process. In present research study the EDM machining is used for more analysis to find the role of different parameters for achieving the high precise machining. In current chapter the introduction part of EDM is present in detail as well scope of the research is also present in this chapter.

II. LITERATURE REVIEW

Yan-Cherng Lin et al [01, 2018] investigated the machining qualities of a created cross breed process of electrical discharge machining (EDM) in gas with abrasive jet machining (AJM). The investigations as to parameter improvement were planned with a L18 orthogonal array in view of Taguchi strategy. The primary process parameters, for example, machining polarity, crest current, pulse term, gas pressure, grain estimate, and servo reference voltage were picked to decide their consequences for machining execution identifying with material removal rate (MRR), anode wear rate (EWR) and surface roughness (SR) for SKD 61 apparatus steel. The test reaction esteems were exchanged to signal-to-noise (S/N) proportions, and after that the huge machining parameters related with the machining execution were inspected by analysis of variance (ANOVA). The ideal mix dimensions of the machining parameters were additionally gotten from the reaction plots of S/N proportions. The trial results demonstrate that the noteworthy machining parameters influencing the MRR were machining polarity, top current, and pulse span; top current was the huge parameter with connection to the EWR; what's more, the pinnacle current, pulse term, just as gas pressure were the huge as to the SR. In addition, The S/N proportions were improved 9.51dB, 3.44 dB and 4.52 dB at the ideal mix dimensions of machining parameters from the affirmation tests for MRR, EWR and SR, individually. Thus, the created mixture process of EDM in gas and AJM could upgrade the machining effectiveness to fit the necessities of present day producing applications. **[1]** Neelesh Singh et al [02, 2018] investigated on the impact on material removal rate (MRR) and surface roughness (SR, Ra) with various information factors which are hole voltage (Vg), crest current (Ip) and pulse on schedule (Ton) amid EDM of Inconel 601 utilizing electrolytic copper. Test work is completed utilizing Box-Behnken Design (BBD) alongside diverse mix of process parameters. Response Surface Methodology and ANOVA are utilized for associating the process parameters with the responses and to examine the critical of the inferred model. **[2]** S. Gowthaman et al [03, 2018] investigated The Monel tests are machined effectively beyond words EDM with process parameters and the impacts of every free parameter on the needy parameters are investigated utilizing multi useful Gray Relational Analysis and by Regression analysis. The accompanying ends are drawn: Through GRA, it is recognized that the Ip has a more noteworthy impact with the commitment of 82%, trailed by Toff with 12% and Ton with almost 4%. The gap voltage and the other practice part considered in the investigation are found to have least critical impacts. The streamlined machining conditions to get the satisfactory dimension of yield responses are: Pulse on Time of 307 µs, Pulse off time of 2867µs, Discharge current of 15 An and Gap voltage of 80 Volts. To approve the exploratory perceptions, demonstrating study has been performed utilizing relapse analysis. Through the got conditions, the exploratory outcomes are thought about and the mistake rate is observed to be under 3%. [**3**] E.L. Papazoglou et al [04, 2018] studied on the present experiment research means to examine the connection between's EDM parameters and machining results, for a typical and generally utilized instrument steel, to be specific AISI O1. The machining parameters, which have been utilized and changed over the test system, are the pulse current IP and the pulse-on time Ton. The material removal proportion has been determined, the surface roughness has been estimated through two regular utilized parameters Ra and Rt lastly magnifying lens perceptions were done to decide the quality and morphology of the white layer, which is a featureless layer of recast material. From the depicted research system, the accompanying ends can be drawn: The expansion of the mean machining force results a higher MRR, with the between them relationship being practically direct, while the increment of the ostensible pulse discharge vitality does not really mean a higher MRR. The MRR emphatically relies upon the mix of the machining parameters, for example Ip and Ton, for which there is an ideal mix, for the most astounding MRR and machining productivity, remembering dependably a current constraint of the current thickness. **[4]**

III. EXPERIMENTAL WORK

In present study Electrical Discharge Machine is used for finding the effect of process parameters for different shape electrodes applied in EDM Machine, The work pieces material used for this study is EN-08 which is gone through the heat treatment process to improve the strength of the work piece material. Like other research study, in present study some important process parameters are selected using local industrial survey and limitation for machine run conditions. Four process parameters are selected for this research study which are verified for range using pilot experiments and the four process parameters are pulse On time, Pulse Off Time, Peak Current and last parameter is pressure applied to electrode. The process parameters and their range for this research study is present in table 1 in coded values. The table 1 is applicable for both type of design of cut selected for this research study. First Design of cut is Pentagonal cut and second design of cut is rectangular. Both design of cut have same cross section area.

Run	T-ON (micro sec)	T-OFF (micro sec)	PC (A)	Press (bar)
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

Pilot study is performed for EDM machining for this research study and the final range for this study is present in table 2 for selective input parameters. The range is in machine units which is different from real values

Process Parameters	Symbol	Range (machine units)
Pulse on time	T-ON	50-150
Pulse off time	T-OFF	20-25
Peak PC	PC	2-6
Press	Press	0.4-0.8

In present research study, design of experiment technique called "taguchi method is" is used for making experiments on EDM machine. In present research study L9 orthogonal array is developed which is present in table 3 In this table response column is blank because it is sample table which is used data filling during experiments on EDM machine.

Run	T-ON	T-OFF	PC	Press	Response
1	50	25	3	0.5	-
2	50	27	5	0.7	-
3	50	29	7	0.9	-
4	75	25	5	0.9	-
5	75	27	7	0.5	-
6	75	29	3	0.7	-
7	100	25	7	0.7	-
8	100	27	3	0.9	-
9	100	29	5	0.5	-

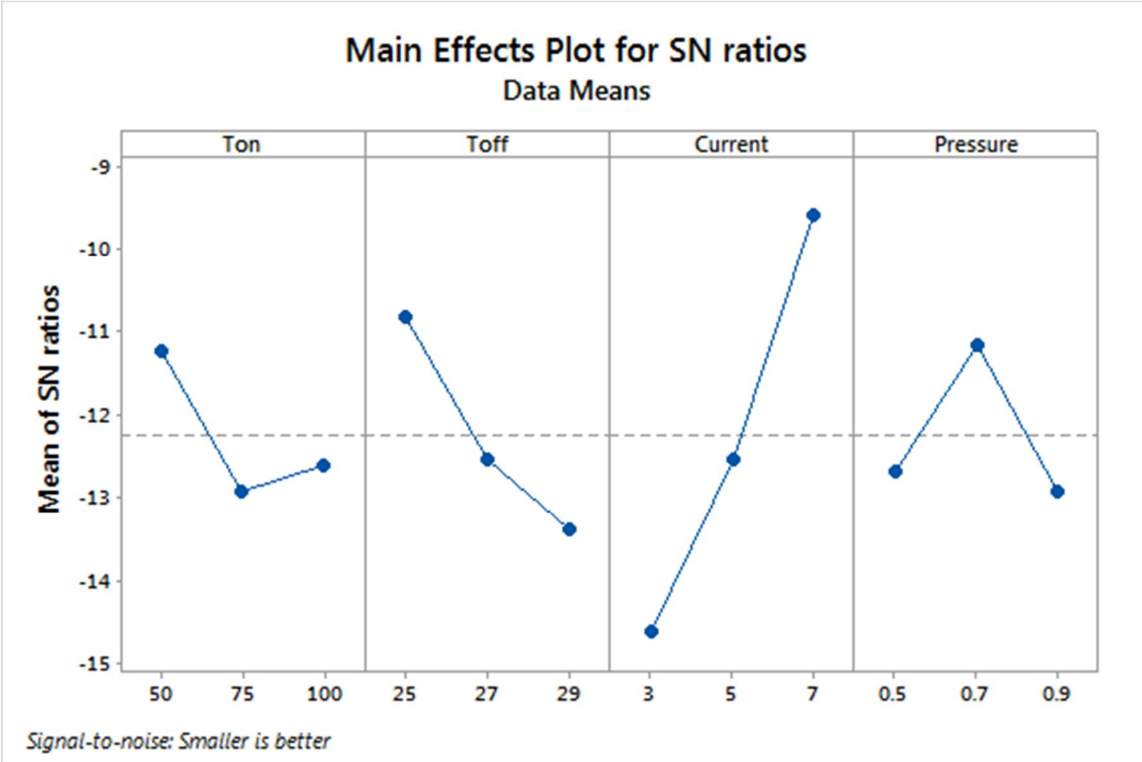
IV. RESULT & DISCUSSION

A. Signal To Noise Ratio Analysis for both Pentagonal and Rectangular Cut

Taguchi is developed a method which use to find the rank among factors fro selective response parameters and it is called as Signal to Noise ratio and in this section the S/N ratio is discussed for both type of electrode conditions. Both electrode has two response variables which are cutting time and over cut. The detailed study for S/N ratio is present in next section for both type of electrode designs.

Signal to Noise Ratio analysis for Pentagonal Cut on CT

S.No	T-ON	T-OFF	PC	Press	Cutting Time	S/N ratio
1	50	25	3	0.5	4.27	-12.606
2	50	27	5	0.7	3.43	-10.7059
3	50	29	7	0.9	3.30	-10.3703
4	75	25	5	0.9	4.20	-12.4650
5	75	27	7	0.5	3.55	-11.0046
6	75	29	3	0.7	5.84	-15.3283
7	100	25	7	0.7	2.35	-7.4214
8	100	27	3	0.9	6.25	-15.9176
9	100	29	5	0.5	5.29	-14.4691



Signal To Noise Ratio analysis for Pentagonal Cut for CT

Best Optimal Solution for CT for Pentagonal cut

Response	T-ON	T-OFF	PC	Press
Cutting Time	50	25	7	0.7

The optimal solution is find by using table 5.5, as seen in table the maximum average value of Signal to Noise ratio is always present the optimal solution, and if we find optimal solution from figure 5.1, then the optimal solution is find by using the top level of each factor from figure 5.1. By using the table 5.5, the optimal solution for cutting time for pentagonal design of electrode is A1-B1-C3-D2. The same result is present in figure 5.1 for this response variable.

The formula is following:

$$\mu_{response} = \overline{A}_{Ln} + \overline{B}_{Ln} + \overline{C}_{Ln} + \overline{D}_{Ln} - (F-1)\overline{R}$$

Here Ln represent Level number, F represent number of factors.

Predicted value for Cutting Time

$$\mu_{CT} = \overline{A}_1 + \overline{B}_1 + \overline{C}_3 + D_2 - 3\overline{R}$$

Where R is average of cutting time = 4.27

A1 is average value of factor A for level 1 is = 3.66

B1 is average value of factor B for level 1 is = 3.60

C3 is average value of factor C for level 2 is = 3.06

D2 is average value of factor C for level 3 is = 3.96

Substituting the values of various terms in the above equation,

$$\mu_{CT} = 3.66 + 3.60 + 3.06 + 3.96 - 3 * 4.27 = 1.47$$

In general the optimal solution is not available in orthogonal array and for verification of this optimal solution, extra experiments on EDM machine is required to find the error present in this optimal solution and the same results are present in table 5.7 for cutting time for pentagonal cut.

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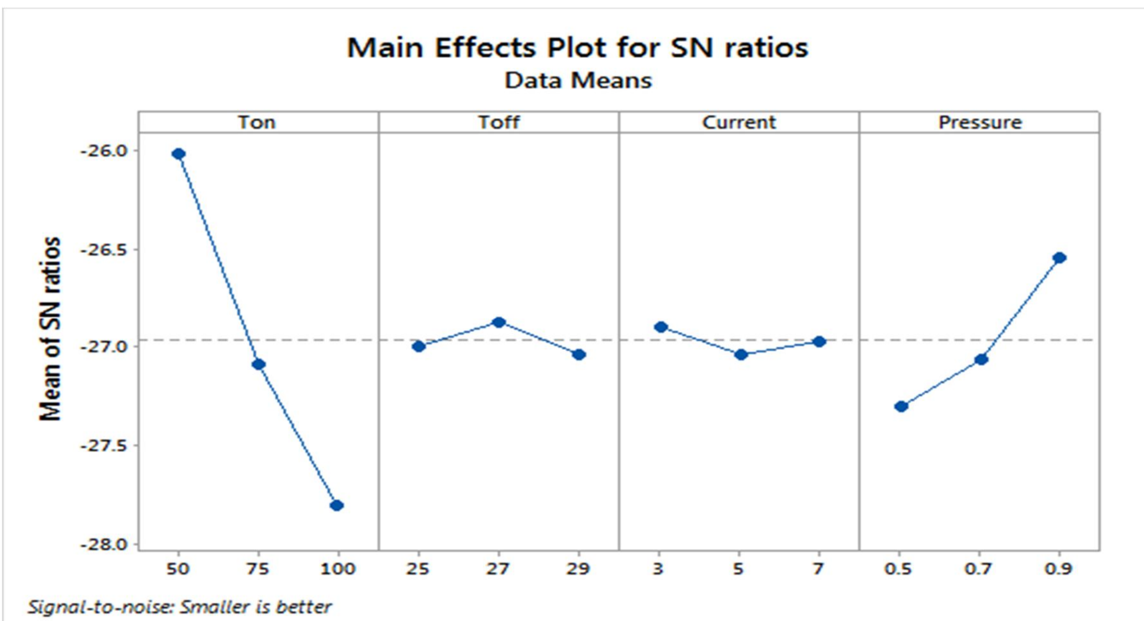
B. S/N Ratio Analysis for Over Cut (OC) for Pentagonal Cut

Over cut is second response parameter which is selected for this research work for EDM machining on EN-08 work piece material. The measured response data is present in table 5.8 for pentagonal design.

S/N ratio analysis for OC for L9 table for Pentagonal cut

S.No	T-ON	T-OFF	PC	Press	Over Cut (OC)	S/N Ratio
1	50	25	3	0.5	20.66	-26.3026
2	50	27	5	0.7	20.13	-26.0769
3	50	29	7	0.9	19.21	-25.6705
4	75	25	5	0.9	21.78	-26.7612
5	75	27	7	0.5	23.24	-27.3247
6	75	29	3	0.7	22.83	-27.1701
7	100	25	7	0.7	24.92	-27.9310
8	100	27	3	0.9	22.93	-27.2081
9	100	29	5	0.5	25.91	-28.2693



Signal To Noise ratio analysis for Pentagonal Cut for OC

Best Optimal Solution for OC for Pentagonal Cut

Response	T-ON	T-OFF	PC	Press
OC	50	27	3	0.9

The formula is following developed by Roy and Ross:

$$\mu_{response} = \overline{A}_{Ln} + \overline{B}_{Ln} + \overline{C}_{Ln} + \overline{D}_{Ln} - (F-1)\overline{R}$$

Here Ln represent Level number, F represent number of factors.

Predicted Value for OC

$$\mu_{OC} = \overline{A}_1 + \overline{B}_2 + \overline{C}_1 + D_3 - 3\overline{R}$$

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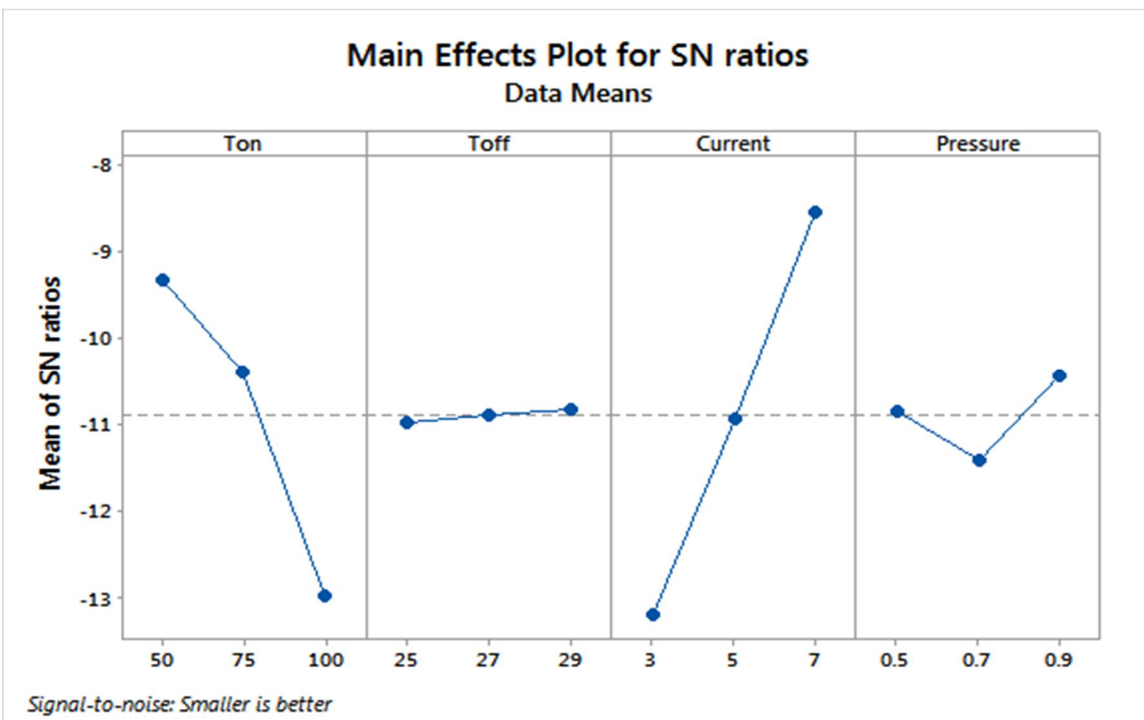
Where
R is average of cutting time = 22.40
A1 is average value of factor A for level 1 is = 20.00
B2 is average value of factor B for level 2 is = 22.10
C1 is average value of factor C for level 1 is = 22.14
D3 is average value of factor C for level 3 is = 21.30
Substituting the values of various terms in the above equation,

$$\mu_{OC} = 20.00 + 22.10 + 22.14 + 21.30 - 3 * 22.40 = 18.34$$

Signal to Noise ratio analysis for CT for Rectangular cut

S.No	T-ON	T-OFF	PC	Press	Cutting Time	S/N ratio
1	50	25	3	0.5	3.83	-11.6640
2	50	27	5	0.7	3.12	-9.8831
3	50	29	7	0.9	2.10	-6.4444
4	75	25	5	0.9	3.18	-10.0485
5	75	27	7	0.5	2.51	-7.9935
6	75	29	3	0.7	4.53	-13.1220
7	100	25	7	0.7	3.65	-11.2459
8	100	27	3	0.9	5.49	-14.7914
9	100	29	5	0.5	4.41	-12.8888



Signal to Noise Ratio Analysis for Rectangular Cut for CT

Best Optimal Solution for CT for Rectangular Cut

Response	T-ON	T-OFF	PC	Press
Cutting Time	50	29	7	0.9

The formula is following developed by Ross and Roy:

$$\mu_{response} = \overline{A}_{Ln} + \overline{B}_{Ln} + \overline{C}_{Ln} + \overline{D}_{Ln} - (F-1)\overline{R}$$

Here Ln represent Level number, F represent number of factors.
Predicted value for cutting Time for Rect cut

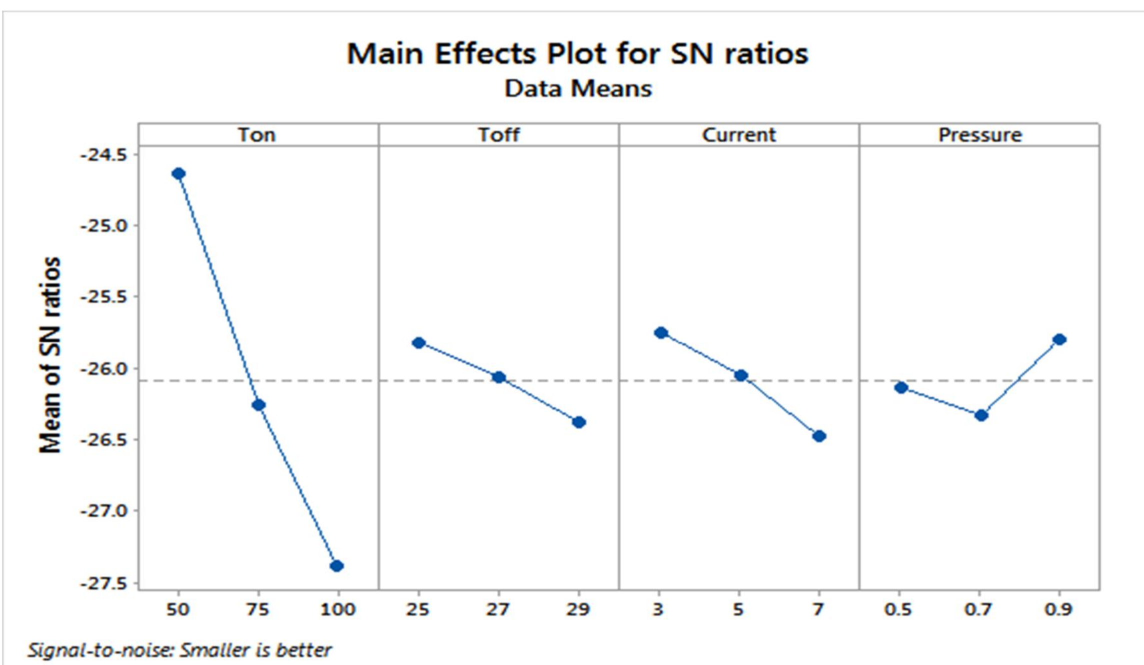
$$\mu_{CT} = \overline{A}_1 + \overline{B}_3 + \overline{C}_3 + D_3 - 3\overline{R}$$

Where R is average of cutting time = 3.64
A1 is average value of factor A for level 1 is = 3.01
B1 is average value of factor B for level 1 is = 3.55
C2 is average value of factor C for level 2 is = 3.57
D3 is average value of factor C for level 3 is = 3.59
Substituting the values of various terms in the above equation,

$$\mu_{CT} = 3.01 + 3.55 + 3.57 + 3.59 - 3 * 3.64 = 2.8$$

Signal to Noise Ratio Analysis for OC for Rectangular Cut

S.No	T-ON	T-OFF	PC	Press	Over Cut (OC)	S/N Ratio
1	50	25	3	0.5	15.98	-24.0715
2	50	27	5	0.7	17.39	-24.8060
3	50	29	7	0.9	17.82	-25.0182
4	75	25	5	0.9	19.21	-25.6705
5	75	27	7	0.5	21.54	-26.6649
6	75	29	3	0.7	21.01	-26.4485
7	100	25	7	0.7	24.38	-27.7407
8	100	27	3	0.9	21.67	-26.7172
9	100	29	5	0.5	24.24	-27.6907



Signal to Noise Ratio analysis for Rectangular Cut for OC

Best Optimal Solution for OC for Rectangular Cut

Response	T-ON	T-OFF	PC	Press
OC	50	25	3	0.9

The formula is following developed by Ross and Roy:

$$\mu_{response} = \overline{A}_{Ln} + \overline{B}_{Ln} + \overline{C}_{Ln} + \overline{D}_{Ln} - (F-1)\overline{R}$$

Here Ln represent Level number, F represent number of factors.
Predicted Value for OC for Rectangular Cut

$$\mu_{OC} = \overline{A}_1 + \overline{B}_1 + \overline{C}_1 + D_3 - 3\overline{R}$$

Where
R is average of cutting time = 22.40
A1 is average value of factor A for level 1 is = 17.06
B1 is average value of factor B for level 2 is = 19.85
C1 is average value of factor C for level 1 is = 19.55
D3 is average value of factor C for level 3 is = 19.65
Substituting the values of various terms in the above equation,

$$\mu_{OC} = 17.06 + 19.85 + 19.55 + 19.65 - 3 * 20.36 = 15.03$$

Regression Modeling
Regression Modeling equation for Cutting Time (CT) for Pentagonal Cut and Rectangular cut
Linear model regression method is applied for this research study using MINITAB software for both type of response variables.
Model Equation for Pentagonal
CT = -2.68 + 0.01927 T-ON + 0.301 T-OFF - 0.597 PC + 0.53 Press
Model Summary

S	R-sq (adj)	PRESS	R-sq (pred)
0.525608	91.68%	83.36%	63.84%

Analysis of variance of CT for Pentagonal Cut

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Regression	4	12.1766	91.68%	12.1766	3.04414	11.02	0.02
T-ON	1	1.392	10.48%	1.392	1.39202	5.04	0.088
T-OFF	1	2.172	16.35%	2.172	2.17202	7.86	0.049
PC	1	8.5443	64.33%	8.5443	8.54427	30.93	0.005
Press	1	0.0683	0.51%	0.0683	0.06827	0.25	0.645
Error	4	1.1051	8.32%	1.1051	0.27626		
Total	8	13.2816	100.00%				

Model Equation for Rectangular

CT = 2.86 + 0.03000 T-ON + 0.0317 T-OFF - 0.4658 PC + 0.017 Press

Model Summary

S	R-sq	R-sq (adj)	R-sq (pred)
0.302758	95.91%	91.83%	82.39%

Analysis of variance for CT for Rectangular Cut

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	4	8.60715	2.15179	23.48	0.005
T-ON	1	3.375	3.375	36.82	0.004
T-OFF	1	0.02407	0.02407	0.26	0.635
PC	1	5.20802	5.20802	56.82	0.002
Press	1	0.00007	0.00007	0	0.98
Error	4	0.36665	0.09166		
Total	8	8.9738			

Regression Modeling equation for OC for Pentagonal Cut and Rectanguler cut
Model Equation for Pentagonal
OC = 17.23 + 0.09173 T-ON + 0.049 T-OFF + 0.079 PC - 4.91 Press
Model Summary

S	R-sq	R-sq (adj)	R-sq (pred)
0.508963	97.93%	94.63%	84.86%

ANOVA table for OC for Pentagonal cut

Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**
Regression	4	37.5467	9.3867	36.24	0.002
T-ON	1	31.5563	31.5563	121.82	0
T-OFF	1	0.058	0.058	0.22	0.661
PC	1	0.1504	0.1504	0.58	0.489
Press	1	5.782	5.782	22.32	0.009
Error	4	1.0362	0.259		
Total	8	38.5829			

Model Equation for Rectangular cut
OC = 2.60 + 0.1273 T-ON + 0.292 T-OFF + 0.423 PC - 2.55 Press
Model Summary

S	R-sq	R-sq (adj)	R-sq (pred)
0.674574	97.42%	94.84%	84.43%

ANOVA table for OC for Rectangular cut

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	4	68.705	17.1762	37.75	0.002
T-ON	1	60.802	60.8017	133.62	0
T-OFF	1	2.042	2.0417	4.49	0.102
PC	1	4.301	4.3011	9.45	0.037
Press	1	1.561	1.5606	3.43	0.138
Error	4	1.82	0.455		
Total	8	70.525			

V. CONCLUSION

S/N ratio analysis is performed for both response CT and OC for both type of design of electrodes and the final rank identified for these response variables are present in table 6.2. The S/N ratio option “smaller is better” is selected for both response variable. As seen in table 6.2 the factor T-ON and PC (peak Current) are come as best factors for precious cutting using this machine Signal Noise ratio also help to find the optimal solution for both type of response variables for both design of electrodes and present in table 6.3 for pentagonal and Rectagular design of electrode. As seen in table the predicted values of factors for optimal solution is verified with experimental results and the error is show in the table which ie below the 20% error range. Linear regression modeling is adopted for generation of equation for these response variable CT and OC for both type of electrode designs. The generated equation are present in following section. Fuzzy Logic rules are set for both type of cut using MATLAB software the final MFs are discussed in previous chapter. The fuzzy rules are present in previous chapter.

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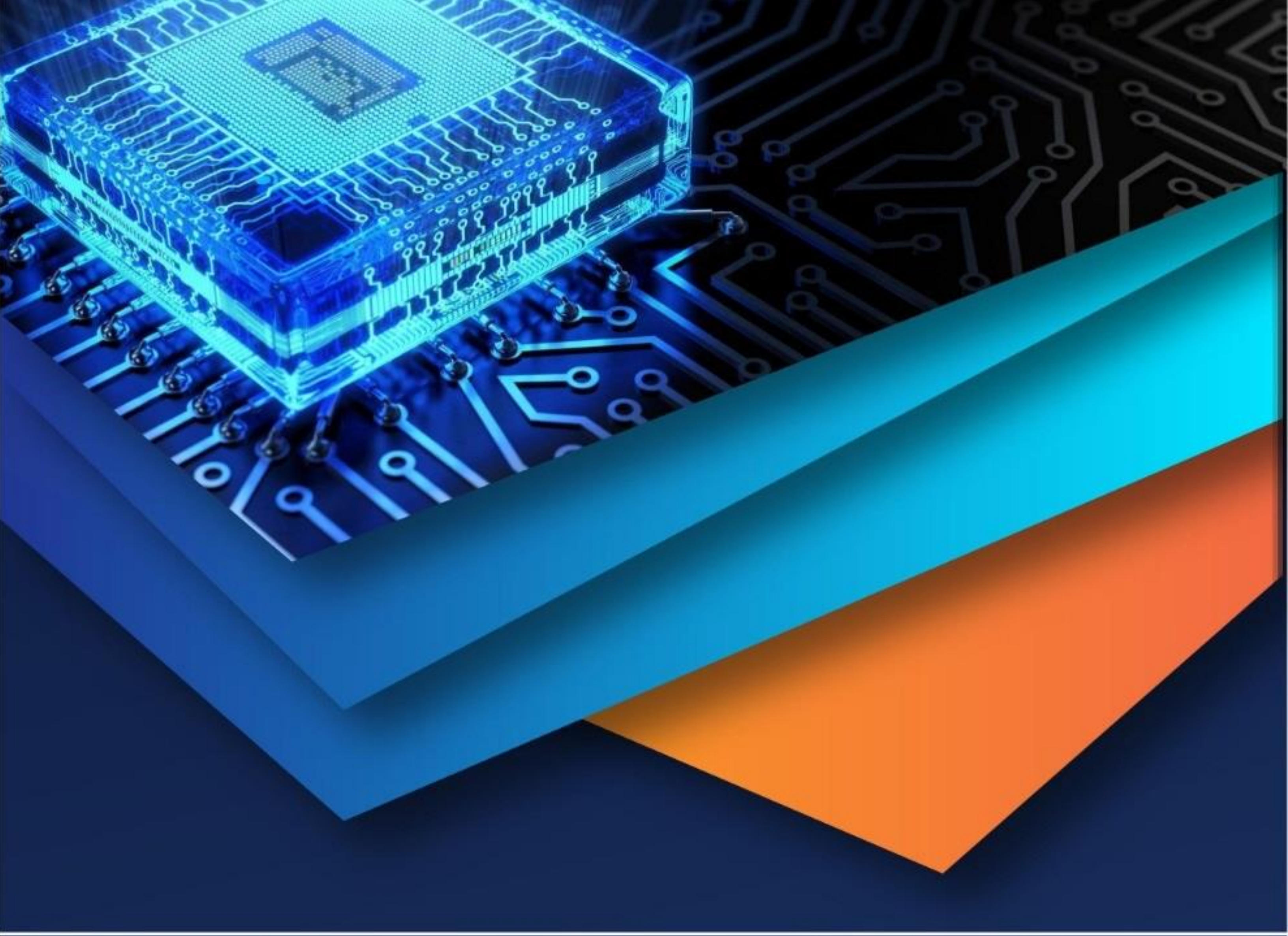

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