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Modelling and Optimization of EDM Process: A Fuzzy based Approach

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Abstract— **In this study Taguchi approach was used, which provides the design with a systematic and efficient method for conducting experimentation . The experiments are designed using L9 orthogonal array considering three process parameter such as, Current, Pulse-On Time, Pulse-Off Time, the response of the process such as Material removal rate (MRR), Tool wear rate (TWR), Surface roughness (Ra) are considered. The experimental data used in this paper is based on the research work done by Raghuraman S et.al. The analysis of various performance criteria such as, MRR, TWR, Ra, using Taguchi method and has been done. The input-output relationship modeling has been done using Fuzzy Logic. The predicted results obtained from fuzzy logic are compared with the experimental result. Moreover the multi objective optimization has been performed using fuzzy logic.**

Keywords— ***Electro Discharge Machining; Taguchi Method; Fuzzy Logic; Prediction; Optimization***

I. Introduction

Electro Discharge Machining (EDM) is non-traditional thermo electric machining process in which material removal takes place through the process of controlled spark generation between a pair of electrodes which are submerged in a dielectric medium. Use of mineral oil based dielectric liquids is the major cause of environmental concerns associated with the EDM process. Dry EDM is an environment-friendly modification of the oil EDM process in which a gaseous medium replaces the liquid dielectric. Taguchi method involves reducing the variation in a process through robust design of experiments. It aims at producing high quality and low cost product. This method was developed by Dr. Genichi Taguchi of Japan. Fuzzy logic is a form of many-valued logic which deals with reasoning that is approximate rather than fixed and exact. Fuzzy set theory provides a means for representing uncertainties and for modelling the kind of uncertainties associated with vagueness.

II. Experimental Details

The experimental data used in this paper is based on the research work done by Raghuraman S et al [1]. In their research work, optimization of EDM parameters using Taguchi method and Grey Relational Analysis for Mild Steel IS 2026 has been done.

TABLE I. EXPERIMENTAL VALUES

Exp. No.	Current(A)	Pulse ON Time(μs)	Pulse OFF Time(μs)	MRR (mm^3/min)	TWR (mm^3/min)	Ra (μm)
1	10	11	5	3.754	0.13	4.329
2	10	55	7	10.451	0.178	12.541
3	10	95	9	15.006	0.244	6.494
4	18	11	7	21.256	0.147	3.932
5	18	55	5	32.412	0.274	10.982
6	18	95	9	35.43	0.323	8.484
7	26	11	9	25.452	0.24	4.588
8	26	55	5	43.517	0.372	14.219
9	26	95	7	48.775	0.448	10.242

III. Prediction using Fuzzy Logic

Fuzzy Logic has been implemented to determine the output parameters using MATLAB software. Fuzzy Logic modelling is based on fuzzy set theory having values ranging between 0 to 1. It involves three steps: fuzzification, fuzzy inference and defuzzification. In fuzzification, membership functions are assigned for the input and the output parameters. After fuzzification, fuzzy rule base is formed. For instance, let the inputs are x_1(current), x_2(pulse on time) and x_3(pulse off time), and the outputs be y_1 (material removal rate (MRR)), y_2(tool wear rate (TWR)) and y_3(surface roughness (Ra)).

Rule n: If x1 is An and x2 is Bn and x3 is Cn, then y1 is Dn, y2 is En and y3 is Fn, where Ai, Bi, Ci, Di, Ei and Fi are the fuzzy subsets. A,B,C are the fuzzy sets of current, pulse on time and pulse off time respectively. And D, E, F are the fuzzy sets of MRR, TWR and Ra respectively. Now the rules are evaluated and the results so obtained are analyzed. This process is called fuzzy inference. The output is obtained as fuzzy variables. Conversion of fuzzy variables to absolute value is defuzzification.

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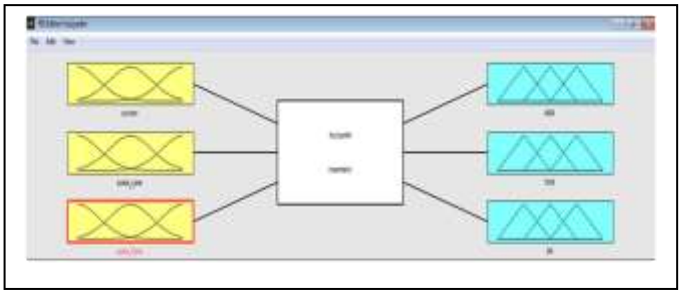

Figure 1. Input – Output relationship in Fuzzy

Fig. 1 shows the input and output relationship, where the inputs are current, pulse ON time, pulse OFF time and the outputs are MRR, TWR, Ra and they are related with the fuzzy rule.

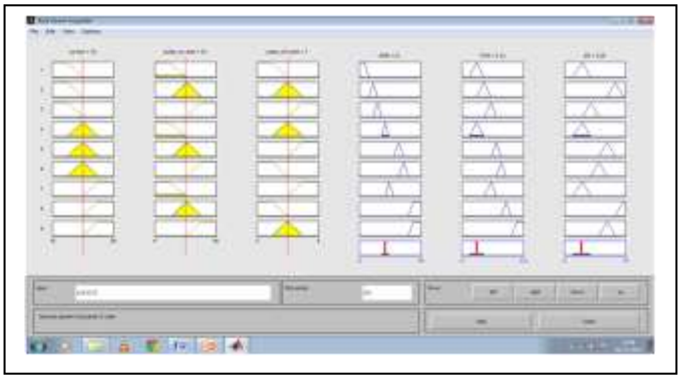

Figure 2. Rule viewer

Fig. 2 shows the rules of the fuzzy model which was used for the prediction of the output values.

A. *Comparison plots for experimental and fuzzy predicted value*

The predicted values of MRR, TWR and Ra were obtained using fuzzy logic and compared with the experimental results by plotting the graphs between the outputs and the number of experiments individually.

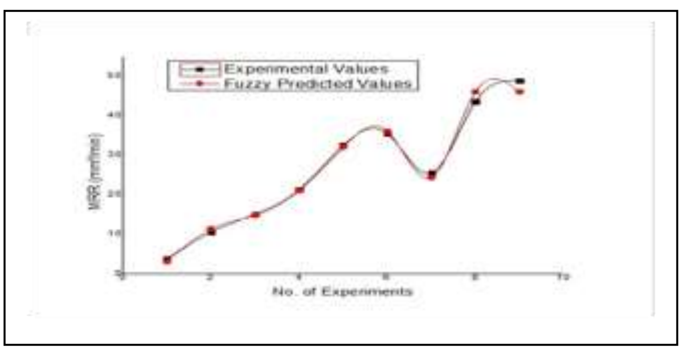

Figure 3. MRR

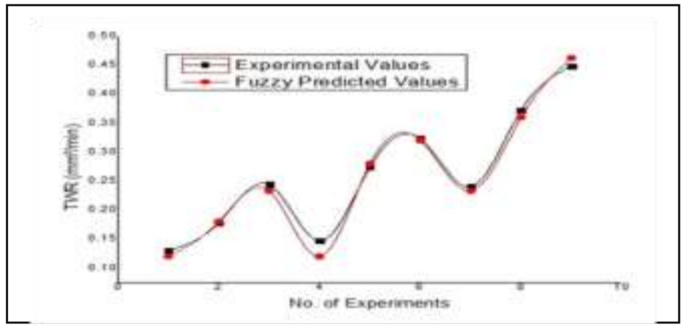

Figure 4. TWR

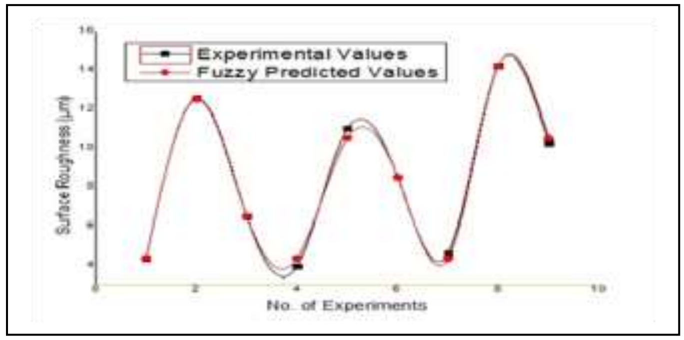

Figure 5. Ra

The fig. 3, 4 and 5 show the graphs between the number of experiments and MRR, TWR and Ra respectively. In all of the three figures, the graphs of the experimental values and the fuzzy predicted values were almost overlapping. This shows that the fuzzy predicted values can be used for future aspects.

Table II shows the comparision of the experimental result with the fuzzy predicted result for each of the parameters – MRR, TWR and Ra. The prediction error for each of the parameters was then found out to see the amount of variation between the experimental and fuzzy predicted values so as to check the accuracy of the fuzzy prediction.

The prediction error which was found using equation (1) shown below.

$$Error = \frac{|Experimental - Fuzzy|}{Experimental} \times 100\% \quad (1)$$

TABLE II. COMPARISON OF EXPERIMENTAL RESULTS WITH THE FUZZY PREDICTED RESULTS

Exp. No.	Experimental Result			Fuzzy Predicted Result			Prediction Error in %		
	MRR (mm^3/min)	*TWR (mm^3/min)*	*Ra (μm)*	*MRR (mm^3/min)*	*TWR (mm^3/min)*	*Ra (μm)*	*MRR (mm^3/min)*	*TWR (mm^3/min)*	*Ra (μm)*
1	3.754	0.13	4.329	2.98	0.12	4.33	20.61	7.6	0.23
2	10.451	0.178	12.541	11.3	0.18	12.5	8.1	1.12	0.32
3	15.006	0.244	6.494	14.7	0.233	6.5	2.04	4.51	0.09
4	21.256	0.147	3.932	21	0.12	4.33	1.2	18.36	10.12
5	32.412	0.274	10.982	32	0.28	10.5	1.27	2.19	4.38
6	35.43	0.323	8.484	36	0.32	8.5	1.61	0.93	0.18
7	25.452	0.24	4.588	24.3	0.233	4.33	4.5	2.92	1.92
8	43.517	0.372	14.219	46	0.36	14.2	5.7	3.22	0.13
9	48.775	0.448	10.242	46	0.462	10.5	5.6	3.12	2.52
Average Prediction Error							5.62	4.88	2.21
Total Average Prediction Error							4.24		

The average prediction errors for MRR, TWR and Ra were found to be 5.62%, 4.88% and 2.21% respectively. The total average prediction error was 4.24%.

IV. Optimization using Taguchi and Fuzzy Logic

In the Taguchi method, a loss function is defined to calculate the deviation between the experimental value and the desired value. The loss function is then transformed to S/N ratio. Usually, there are three categories of the performance characteristics in the analysis of the signal-to- noise ratio, i.e., the lower-the-better, the higher the-better, and the nominal-the-better. Therefore, the lower-the-better SR and TWR and the higher-the better MRR should be selected for the optimal machining result.

The S/N ratio of the lower-the-better performance characteristic:

$$\eta_{ij} = -10\log_{10}\left(\frac{1}{n}\sum_{k=1}^{n} y_{ijk}^2\right) \qquad (2)$$

The S/N ratio of the higher-the-better performance characteristic:

$$\eta_{ij} = -10\log_{10}\left(\frac{1}{n}\sum_{k=1}^{n} \frac{1}{y_{ijk}^2}\right) \qquad (3)$$

The S/N ratios for the MRR, TWR and Ra were found using the equations (2) and (3) suitably and were listed in the table III.

TABLE III. S/N RATIOS FOR THE OUTPUT PARAMETERS

Exp. No.	S/N Ratio		
	MRR	*TWR*	*Ra*
1	11.4899	17.7211	-12.7278
2	20.3832	14.9916	-21.9666
3	23.5253	12.2522	-16.2502
4	26.5496	16.6537	-11.8923
5	30.2141	11.2450	-20.8136
6	30.9874	9.8159	-18.5720
7	28.1144	12.3958	-13.2325
8	32.7732	8.5891	-23.0574
9	33.7639	6.9744	-20.2077

The S/N ratios of the output parameters were divided into three levels each and nine levels to OPI(Optimal Parametric Index) and the membership functions were accordingly assigned as shown in table IV. The OPI values for the combinations were calculated with the help of the rule base between the inputs and the output.

TABLE IV. PARAMETERS, LEVELS AND INTERVALS

Variables	Parameters	Levels	Range
Inputs	*S/N ratio of MRR*	*Low*	10 to 18.33
		Medium	14.17 to 30.83
		High	26.67 to 35
	S/N ratio of TWR	*Low*	6 to 10
		Medium	8 to 16
		High	14 to 18
	S/N ratio of Ra	*Low*	-22 to -18.33
		Medium	-20.17 to -12.83
		High	-14.67 to -11
Outputs	*OPI*	*Very Very Small (VVS)*	0 to 0.125
		Very small (VS)	0 to 0.25
		Small (S)	0.125 to 0.375
		Small Medium (SM)	0.25 to 0.5
		Medium (M)	0.375 0.625
		High Medium (HM)	0.5 to 0.75
		High (H)	0.625 to 0.875
		Very High (VH)	0.75 to 1
		Very Very High (VVH)	0.875 to 1

A fuzzy based relation was formed between the S/N ratios of the output parameters and OPI using MATLAB. OPI is defined to find the optimal level of the input parameters. It was set to the range of 0 to 1.

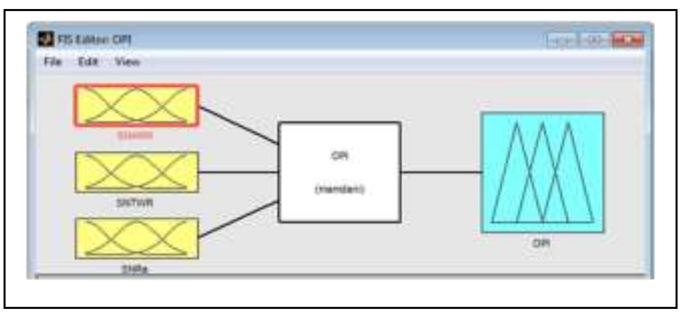

Figure 6. Fuzzy relation

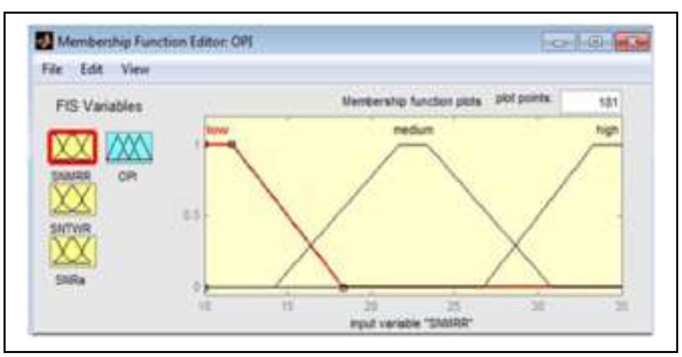

Figure 7. Membership function of S/N ratio of MRR

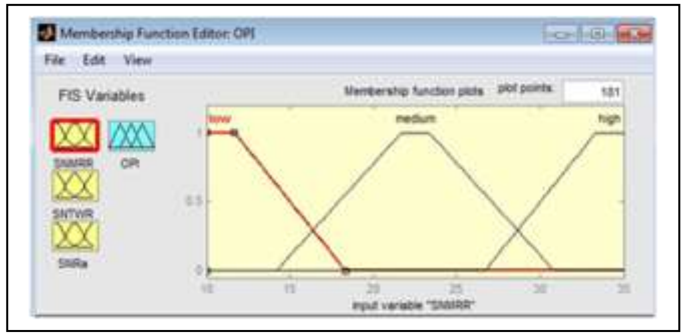

Figure 8. Membership function of S/N ratio of TWR

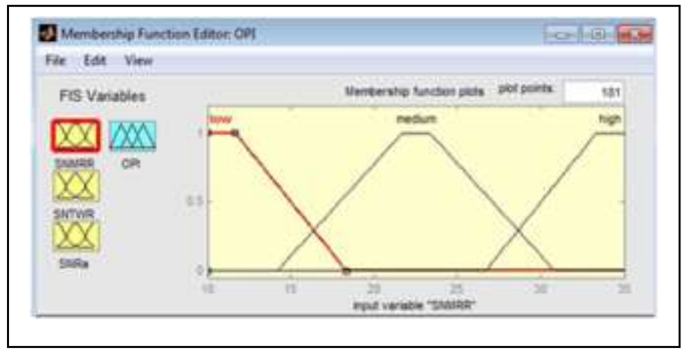

Figure 9. Membership function of S/N ratio of Ra

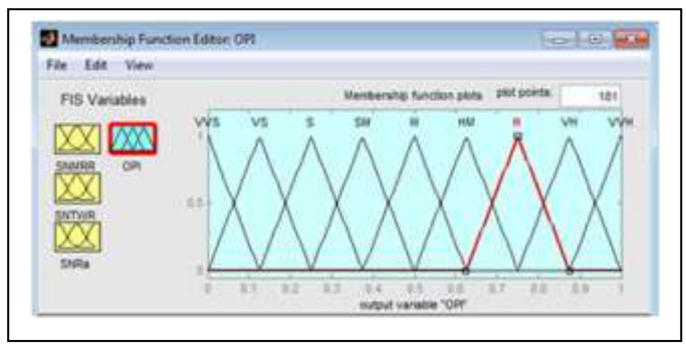

Figure 10. Membership function for OPI

Figure 11. Fuzzy output

Fig. 6 shows the relationship between S/N ratios of MRR, TWR, Ra with OPI. Fig. 7, 8, 9 and 10 show the membership functions of the S/N ratios of MRR, TWR, Ra and OPI according to their levels and range respectively. Fig. 11 shows the rules for this fuzzy model which was used to find out the values of OPI. These values were listed in table V as shown below.

TABLE V. RESULTS OF OPI

Experiment No.	OPI
1	0.0427
2	0.5
3	0.5
4	0.5
5	0.955
6	0.942
7	0.375
8	0.945
9	0.5
Mean	0.5844

The mean of the OPI for the machining parameters at levels 1, 2 and 3 can be calculated by averaging the optimal performance indexes for the respective experiments (Table I). The overall mean was found to be 0.5844.

TABLE VI. OPTIMAL PERFORMANCE INDEX (OPI)

Machining Parameters	**OPI**		
	Level 1	***Level 2***	***Level 3***
Current	0.3475	0.799	0.6066
Pulse ON Time	0.3059	0.8	0.6473
Pulse OFF Time	0.6475	0.5	0.6056

OPI should be high for better machining. The graphs for current, pulse ON time and pulse OFF time were plotted against OPI at their three levels as shown in Fig. 12.

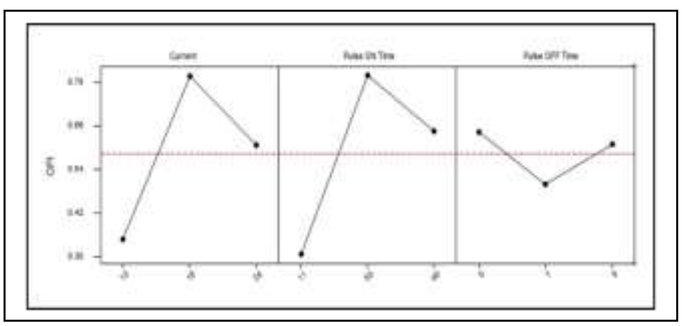

Figure 12. OPI graph

The above graph shows that OPI value is highest at level 2 for current and pulse ON time and highest at level 1 for pulse OFF time.

V. Conclusion

The experiment was designed using Taguchi method and fuzzy logics were applied to it for the prediction and optimization of machining parameters.

The predicted results obtained from fuzzy logic are compared with experimental result. The average prediction errors were found to be 5.62% for MRR, 4.88% for TWR and 2.21% for Ra. And the total average prediction error was 4.24%.

The combination of machining parameters for optimal performance was found to be level 2 for current(18 A), level 2 for pulse ON time(55 µs) and level 1 for pulse OFF time(5 µs).

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