Optimization of Operating Parameters for EDM Process based on the Taguchi Method

Madhuri Pradhan, R. K. Bhoi, S. Rana

*Abstract— **In this paper the complexity of electrical discharge machining process which is very difficult to determine optimal cutting parameters for improving cutting performance has been reported. Optimization of operating parameters is an important step in machining, particularly for operating unconventional machining procedure like EDM. A suitable selection of machining parameters for the electrical discharge machining process relies heavily on the operators' technologies and experience because of their numerous and diverse range. Machining parameters tables provided by the machine tool builder cannot meet the operators' requirements, since for an arbitrary desired machining time for a particular job, they do not provide the optimal machining conditions. An approach to determine parameters setting is proposed. Based on the Taguchi parameter design method and the analysis of variance, the significant factors affecting the machining performance such as crater diameter,recsat layer,grain size,haz for a hole machined by EDM process, are determined.***

Index Terms—complexity, Optimization, EDM, significant factors.

I. INTRODUCTION

Electrical Discharge Machining (EDM) was first introduced in the 1940's as a crude device used to cut broken machining tools from expensive in-process parts. Since that time EDM has become a sophisticated and indispensable technology, revolutionizing the tool, die, and mold making industries, and making significant inroads into the production of highly accurate, intricate and difficult to machine production parts. In electrical discharge machining, it is important to select machining parameters for achieving optimal machining performance. Usually, the desired machining parameters are determined based on experience or handbook values. However, this does not ensure that the selected machining parameters result in optimal or near optimal machining performance for that particular electrical discharge machine and environment. In earlier work to solve this task, Lin, Wang, Yan, Tarng [2] used the Taguchi method with fuzzy logic as an efficient approach to determine the optimal machining parameters in the electrical discharge machining process. The Taguchi method can optimize performance characteristics through the settings of process parameters and reduce the sensitivity of the system performance to sources of variation.

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As a result, the Taguchi method has become a powerful tool in the design of experiment methods [2]. However, most published Taguchi applications to date have been concerned with the optimization of a single performance characteristic. Handling the more demanding multiple performance characteristics is still an interesting research problem [2]. By means of orthogonal array with the grey relational analysis the optimization procedure for determining the optimal machining parameters with the multiple performance characteristics in the EDM ISSN: 0975-5462 6880 A.Thillaivannan et. al. / International Journal of Engineering Science and Technology Vol. 2(12), 2010, 6880-6888 process can be greatly simplified [3]. As a result, the method developed in this study is very suitable for practical use in a machine shop. In the past decade, neural networks have been shown to be the highly flexible modeling tools with capabilities on learning the mathematical mapping between input variables and output features for nonlinear systems [6]. Also, the superior performances of neural networks for modeling machining processes have been published elsewhere. In these, multi-layer Perceptions based on back-propagation (BP) technique have been employed for monitoring and modeling the reported processes. Wang, Gelgele, Yi Wang, Yuan and Fang developed a hybrid artificial neural network and genetic algorithm methodology for modeling and optimization of electro-discharge machining [7]. The hybridization approach is aimed not only at exploiting the strong capabilities of the two tools, but also at solving manufacturing problems that are not amenable for modeling using traditional methods. Based on an experimental data, the model was tested with satisfactory results. The developed methodology with the model is highly beneficial to manufacturing industries, such as aerospace, automobile and tool making industries. A better process model is established based on neural networks by comparing the predictions from different models under the effect of change of polarity between the electrode and the work materials in the EDM process. Initially, pertinent process variables affecting the MRR, namely the polarity of the electrode, the discharge time, the peak current, and the materials of both the tool and the workpiece, were screened by making use of Taguchi method on design of experiments [8]. The DOE experimental data were later used for training the various process models. Finally, more experimental verification on the established process models was conducted, and comparisons among the models, including a statistical process model, were analyzed.

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II. Problem Formulation

2.1. Design Variables

The formulation of an optimization problem begins with identifying the underlying design variables, which are primarily varied during the optimization process. In this paper current and pulse width are considered as design variables.

2.2. Constraints

The constraints represent some functional relationship among the design variables and other design satisfying certain physical phenomenon and certain resource are greater than or equal to, a resource value. In this paper, recast layer, haz, crater dameter and grain size of the EDM hole are considered as constraints.

2.3 Objective function

The objective function can be of two kinds. Either the objective function is to be minimized or it has to be maximized. In this paper, minimization of total machining time is considered as objective function.

III. Experimental Equipment and Design

An EDM machine, developed by SPARKONIX (I) LTD. was used as the experimental machine. The work material, electrode and the other machining conditions were as follows (1) Workpiece (anode), Stainless Steel 340C; (2) Electrode (cathode), Tungsten Ø 1.6mm; (3) Dielectric fluid, Kerosene; (4) Workpiece height, 50mm; (5) Workpiece length, 100mm. A total of two machining parameters (current and feed) were chosen for the controlling factors and each parameters have levels as shown in Table 1.

Process parameters and their levels.

Experimental layout using an 16 orthogonal array and data of multiple performance characteristics

Expt. no	Current (amp)	Pulsewidth (μsec)	Dutycycle (%age)	Gap voltage (volt)	Initial wg. of w/p (gm)	Final wg. Of w/p (gm)	Time taken for1mm depth	MRR
1	8	100	10	40	125.8356	124.8733	13	0.07404
2	8	200	10	40	124.8729	123.8164	14	0.07546
3	8	300	10	40	123.8164	122.7840	18	0.057
4	8	400	10	40	122.7852	121.8480	16	0.0585
5	4	200	10	40	125.8130	124.7918	42	0.0243
6	8	200	10	40	124.8729	123.8164	14	0.0754
7	12	200	10	40	124.7918	123.7614	8	0.1288
8	16	200	10	40	123.7614	122.7258	16	0.0647

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A.Thillaivannan et. al. / International Journal of Engineering Science and Technology Vol. 2(12), 2010, 6880-6888 .The machining results after the EDM process under the designed machining conditions are evaluated in terms of the following measured machining performance: (1) total machining time (min); (2) oversize (mm); (3) taper (mm).

IV. Solution Methodology

Taguchi Method is a new engineering design optimization methodology that improves the quality of existing products and processes and simultaneously reduces their costs very rapidly, with minimum engineering resources and development man-hours. The Taguchi Method achieves this by making the product or process performance "insensitive" to variations in factors such as materials, manufacturing equipment, workmanship and
operating conditions.

4.1 Taguchi Method

Experimental design methods [9] were developed originally by Fisher [10]. However, classical experimental design methods are too complex and not easy to use. Furthermore, a large number of experiments have to be carried out as the number of the process parameters increases. To solve this important task, the Taguchi method uses a special design of orthogonal array to study the entire parameter space with only a small number of experiments. The experimental results are then transformed into a signal-to-noise (S/N) ratio. The S/N ratio can be used to measure the deviation of the performance characteristics from the desired values.Usually, there are three categories of performance characteristics in the analysis of the S/N ratio: the lower-thebetter, the higher-the-better, and the nominal-the-better. Regardless of the category of the performance characteristic, a larger S/N ratio corresponds to better performance characteristic. Therefore, the optimal level of the process parameters is the level with the highest S/N ratio. Furthermore, a statistical analysis of variance (ANOVA) is performed to identify the process parameters that are statistically significant. The optimal combination of the process parameters can then be predicted based on the above analysis.

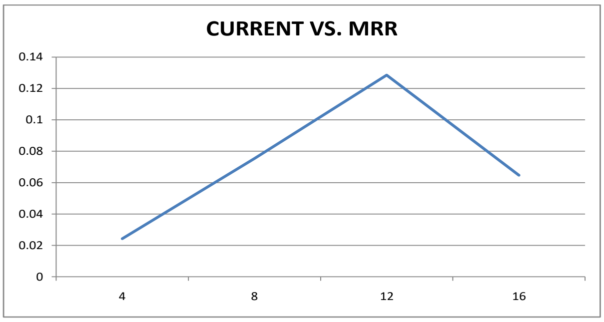

Figure A

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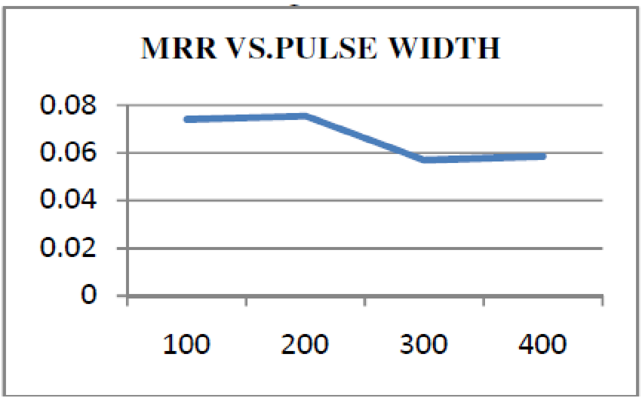

Figure B

Expt. No.	Pulse Width P.W.	Current in ampere	crater Diameter (µm)	Heat Affected Zone (µm)	Recast layer(µm)	Grain size(µm)
1	1	1	482.9054	237.625	93.78	237.625
2	1	2	446.2567	174.66	38.23	174.66
3	2	3	439.2367	245.5	29.27	245.5
4	2	4	494.71	278.625	28.88	278.625
5	3	1	446.9894	448.425	53.26	448.428
6	3	2	425.9	237.625	38.23	174.44
7	4	3	509.3938	215.5	36.045	215.5
8	4	4	482.1646	348.125	56.525	348.125

After that, individually Taguchi method was applied for each performance characteristic for optimization.
Taguchi method is applied for crater diameter

Expt. No.	Pulse Width	No. of Pulse	Spatter Diameter	Square	S/N Ratio
1	1	1	482.9054	233197.6	-53.6772
2	1	2	446.2567	199145	-52.9917
3	2	3	439.2367	192928.9	-52.854
4	2	4	494.71	244738	-53.887
5	3	1	446.9894	199799.5	-53.0059
6	3	2	425.9	181390.8	-52.5862
7	4	3	509.3938	259482	-54.1411
8	4	4	482.1646	232482.7	-53.6639

Here respective pulse width and current, crater diameter values were obtained and that is shown in table 4.3. After that, Average crater diameter calculated (considering the pulse width

ÞA1=1/2(482.9054+446.2567)=464.581 pulsewidth 100µs)

ÞA2=1/2(439.2367+494.71)=466.973 (pulse width – 200 µs)

þA3=1/2(446.9894+425.5)=436.2447 (pulse width-300µs)

(pulse width 400 µs)

ÞA4=1/2(509.3938+482.1646)=495.77

Then in this average value, found the highest and lowest values and calculated the difference between them

Maximum – Minimum = 495.7792-436.2447=59.534

Average crater diameter calculated (considering the current)

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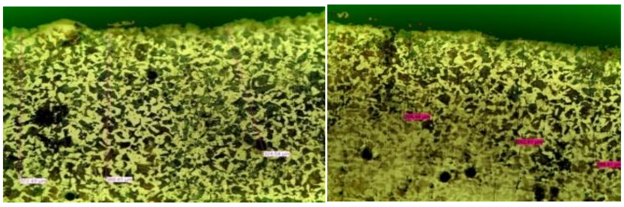
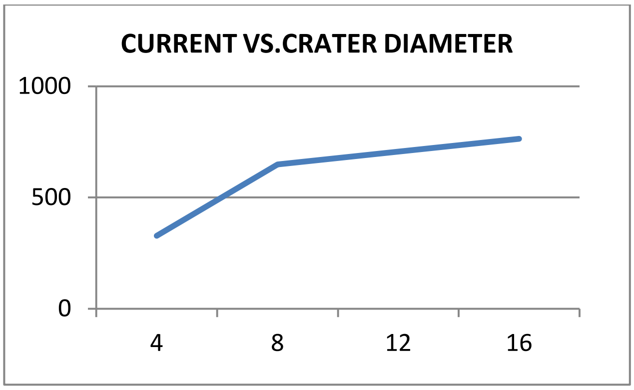
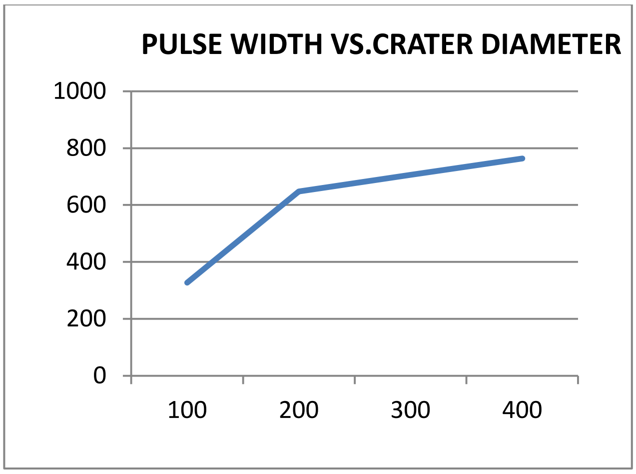
þB1=1/2(482.9054+439.2367)= 461.071 (current – 4)
þB2=1/2(446.9894+509.3938)=478.191 (current-8)
þB3=1/2(446.2567+494.71)= 470.4833 (current-12)
þB4=1/2(425.5+482.1646)= 453.8323 (current-16)
Maximum – Minimum = 470.482-453.832=24.3587
Here þA2 and þB3 having low values, so that (1200-8) combination considered for optimization of haz. For both the difference, the highest difference was the effective for the optimization of Spatter diameter.



View of haz





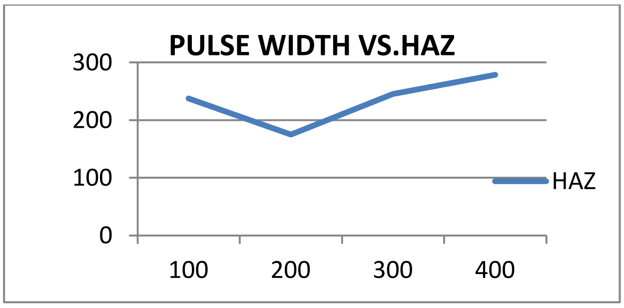
Activation Functions

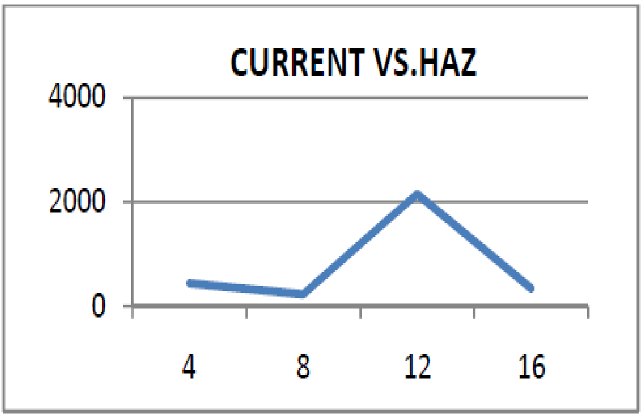
After getting the graph of average spatter diameter with respect to pulse width and current. Then signal-to –noise ratio was evaluated by considering the static problem of spatter diameter and this should be a minimum value, so that the lower the better formula was applied.

Lower is Better $S/N_{LB} = -10\log\left(\frac{1}{n}\sum_{i=1}^{n} y_i^{2}\right)$

In the above table 4.3 y_i^2 was the square of each data of spatter diameter and that was calculated. Then signal to noise ratio for the spatter diameter was calculated as above the Equation (4.4). After getting the signal-to-noise ratio. Average signal – to-noise ratio calculated (considering the pulse width)

ÞA11=-1/2(-53.6772-52.991)=-53.334 (pulse width – 100 µs)
ÞA12=-1/2(-52.854-53.887)=-53.370 (pulse width – 200 µs)
ÞA13=1/2(-53.005-52.586)=-52.795 (pulse width-300µs)
ÞA14=1/2(-54.141-53.663)=-53.902 (pulse width-400µs)
Then is this signal to noise ratio average value, found the highest and lowest values and calculated the difference between them.
Maximum – Minimum = -53.334+53.902=0.5315
Average signal to noise ratio (considering the current)
þ11=1/2(-53.677-52.854)=-53.260 (current-4)
þ12=1/2(-53.005-54.141)=-53.573 (current–8)
þ13=1/2(-52.991-53.887)=-53.439 (current-12)
þ14=1/2(-52.586-53.663)=-53.124 (current=16)
Then difference was calculated by the highest and lowest values of that average values.
Maximum – Minimum = -53.124+53.573=0.449
Here þA12 and þ B 13 having high values. So that (1200-8) combination was best for optimization. High values suggest the effective parameter i.e current was effective than other pulse width for





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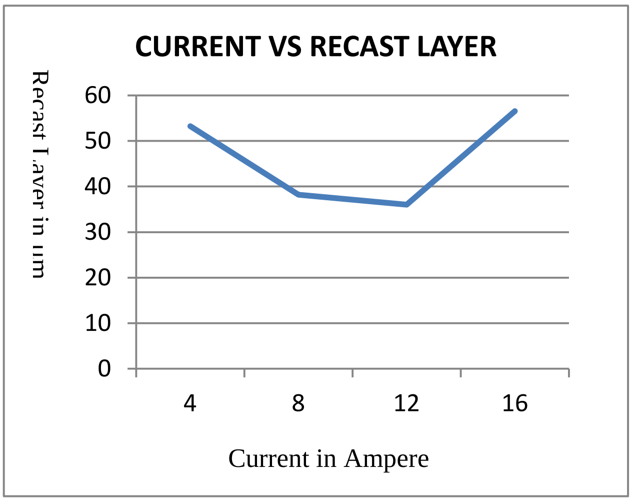
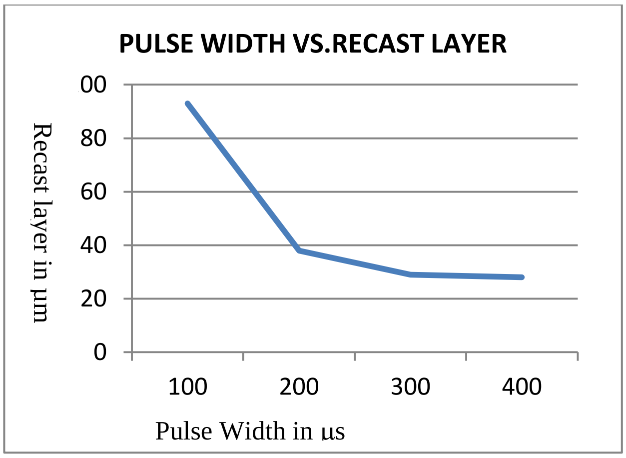
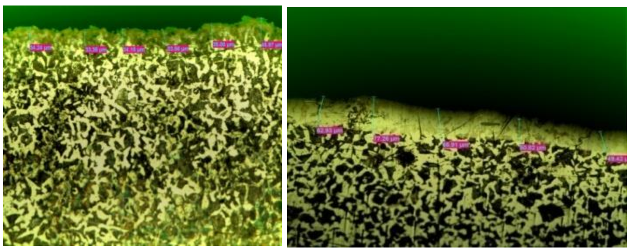
Average signal to noise ratio HAZ VS PULSE WIDTH

Average signals to noise ratio haz Vs both pulse width, current. Similarly Taguchi method is applied in other parameters Heat Affected Zone and recast layer.

Expt No.	Pulse Width	current	Recast layer	Square	S/N Haz
1	1	1	93.78	8794.6884	-39.442
2	1	2	38.23	796.93.29	-31.068
3	2	3	29.27	856.7329	-28.079
4	2	4	28.88	834.0544	-27.1707
5	3	1	53.26	2836.627	-31.5177
6	3	2	38.23	1461.5329	-31.068
7	4	3	36.45	1328.6025	-9.596
8	4	4	56.52	3194.5104	-8.4911







Respective pulse width and current. Recast layer were obtained in the above table 4.9 After that,

Average Recast Layer (considering the pulse width)

þA1 = 1/2 (93.78+38.23) =66.005 (pulse width – 100)

(pulse width –200)

þA2=1/2(29.27+28.88)=29.075

(pulse width –300)

þA3=1/2(53.26+38.23)=45.745

þA4=1/2(36.45+56.52)=46.485 (pulse width- 400)

Then in this average value, found the highest and lowest values and calculated the difference between them.

Maximum – Minimum = 53.76-40.123 = 13.637

Average Recast Layer (considering the CURRENT)

þB1=1/2(93.78+29.27)=61.525 (current 4)

þB2=1/2(53.26+36.45)=44.855

þB3=1/2(38.23+28.88)=33.555

þB4=1/2(38.23+56.52)=47.375

Here þA2 and þB2 having low values. So that (1200-A) was the best combination for optimization of the recast layer. High values of difference suggest the effective parameter i.e. current was effective than pulse width for optimization i.e. shown in table 4.7

After getting the graph of average recast layer with respect to pulse width and current. Then signal to noise ratio was evaluated by considering the static problem of recast layer, and this should be a minimum value, so that the lower the better formula was applied.

Lower is Better

$$S/N_{LB} = -10\log\left(\frac{1}{n}\sum_{i=1}^{n} y_i^2 ....(4.4\right)$$

In the above table 4.6 y_i^2 was the square of each data of recast layer and that was calculated. Then Signal to noise ratio for the recast layer was calculated as above the Equation (4.4) After getting the signal to noise ratio.

Average signal to noise ratio (considering the pulse width)

(pulse width – 100 µs)

þA11=1/2(-39.442-31.068)=-35.255

(pulse

þA12=1/2(-28.079-27.170)= -27.624

width – 200 µs)

pulse width – 300

þA13=1/2(-31.517-31.068)=-31.292

µs)

þA14=1/2(-9.596-8.491)= -9.043 (pulse width 400µs)

Then in this signal to noise ratio average value, found the highest and lowest values and calculated the difference between them.

Maximum – Minimum = -9.043+35.255= 26.211

Average signal to noise ratio (considering the current)

þA11=1/2(-39.442-28.079)= -33.7605 (current-4)

þA12=1/2(-31.517-9.596)=-20.556 (current 8)

þA13=1/2(-31.068-27.170)=-29.119 (current 12)

þA14=1/2(-31.068-8.491)= -19.779 (current 16)

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Then difference was calculated by the highest and lowest values of that average values.
Maximum – Minimum = -19.779+33.760= 13.981
Then find out the highest value of average signal to noise ratio recast layer. Here þA12 and þB12 having high values. So that (1200-A) combination was best. Also calculated the difference between high and low average signal to noise ratio recast layer. High values suggest the effective parameter i.e. current was effective than pulse width.

Taguchi method is applied for grain size

Average grain size (considering the pulse width)

þA1=1/2(285.535+390.833)=338.184 (PULSE 100)

þA2=1/2(245.391+258.666)=252.028 (pulse 200)

þA3=1/2(493.648+390.833)=442.240 (pulse 300)

þA4=1/2(328.898+550.87)= 439.884 (pulse 400)

Then difference was calculated by the highest and lowest values of that average values.
Maximum – Minimum = 442.240-252.028= 190.212
Then find out the lowest value of average grain size. Here þA2 and þB3 having low values. So that (1200-8) was the best combination for optimization of grain size. Also calculate the difference between high and low average grain size. High values suggest the effective parameter i.e. pulse width was effective than no of pulse i.e. shown in table 4.10
After getting the graph of average Taper angle with respect to pulse width and no of pulse. Then signal to noise ratio was evaluated by considering the static problem of Taper angle and this should be a minimum value, so that the lower the better formula was applied.

Lower is Better $S/N_{LB} = -10\log\left(\frac{1}{n}\sum_{i=1}^{n} y_i^{2}\right)$

In the above table 4.9 y_i^2 was the square of each data of taper angle and that was calculated. Then signal to noise ratio for the taper angle was calculated as above the Equation (4.4).
After getting the signal to noise ratio
Average signal to noise ratio (considering the pulse width)

(pulse – 100 μs)

þB11=1/2(-49.1075-51.259)=-50.183

(pulse – 200 μs)

þB12=1/2(-46.547-46.213)=-46.38

þB13=1/2(-50.858-51.259)= -51.058 (PULSE 300)

(pulse – 400 μs)

þB14=1/2(-44.320-45.790)=-45.055

Then in this average value, found the highest and lowest values and calculated the difference between them.
Maximum – Minimum =-45.055+51.058=6.003
Average signal to noise ratio (considering the currrent)

(current 4)

þb11=1/2(-49.1075-46.547)=-47.827

þb12=1/2(-50.858-44.320)= -47.589 (current 8)

(current 12)

þb13=1/2(-51.259-46.213)=-48.736

þb14=1/2(-51.259-45.790)=-48.524 (current 16)

Then difference was calculated by the highest and lowest values of that average values.
Maximum – Minimum =0.909
Then found out the highest value of average signal to noise ratio grain size. Here þA12 and þB13 having high values. So that, (1200-8) was the best combination for optimization. Also calculate the difference between high and low average signal to noise ratio grain size. High values suggest the effective parameter i.e. pulse width was effective than no of pulse.

for average s/n of grain size.

AVG S/N of Taper Angle (μm)	Pulse Width (μs)	Current (amp)
Level – 1	-50.183	-47.827
Level – 2	-46.38	-45.589
Level – 3	-51.058	-48.736
Max-Min	-45.055	-48.524
Rank	1	2

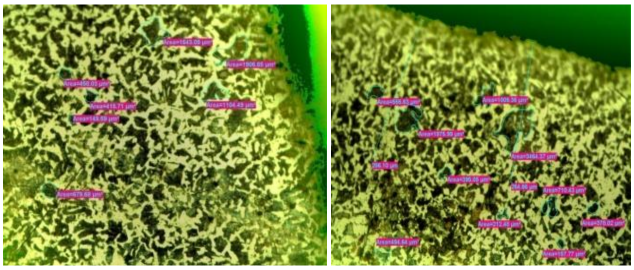


Fig. A

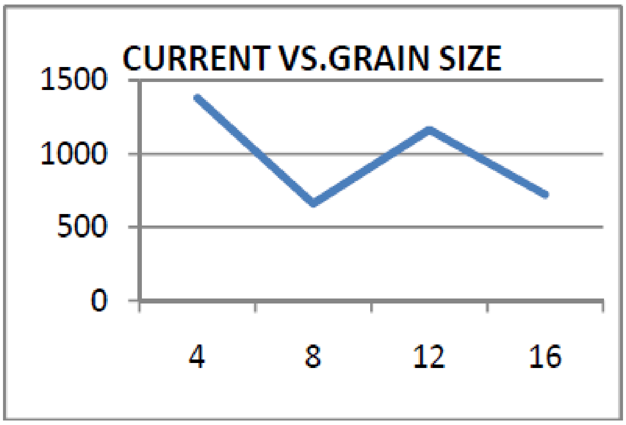
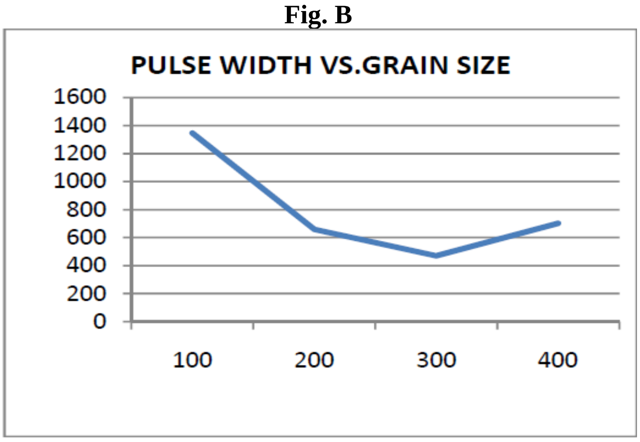


Fig. B



V. Results and Discussion

5.1 Taguchi Method

5.1.1 Orthogonal Array

The result of L8 OA from Table 3, shows that the optimal machining parameters are the ***current at level***

2 (i.e. 2 A) and ***pulse width(i.e.100µs)***based on the minimum S/N ratio.
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5.1.2 ANOVA:

The result of ANOVA for both total machining time and S/N ratio from Table 4 and Table 5, whose % contribution is *92.874* and *95.611* respectively, shows that the parameter ***current*** is the most significant factor that affect the performance characteristic.

5.1.3 Graphs:

The graphs for the total machining time Vs S/N ratio for both the parameters current (Fig 3) and pulse width (Fig 4) are plotted.

VI. Conclusion

In this paper a practical method of optimizing cutting parameters for electrical discharge machining under the minimum total machining time based on Taguchi method is presented. This methodology is not only time saving and cost effective but also efficient and precise in determining the machining parameters. It is found that current has a significant influence on the total machining time. As a result, the performance characteristic total machining time can be improved through this approach. In addition, in this paper a feedforward-backpropagation neural network is developed for getting the parameters i.e. current and feed for a required total machining time, oversize and taper of a hole to be machined by EDM, which are given as inputs. The collected experimental data are used for training and testing the network. The results are presented in the previous section. In the future, the methodology presented in this work could be applied to different machining conditions such as different work material, electrode etc. so as to build a CAPP expert system of EDM with the goal of automation.
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