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Surface Finish Improvement of a Mold in Die Sinking EDM Process

KEYWORDS: EDM, Taguchi Method, Surface Roughness, Optimization

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ABSTRACT *In this research work effort is made to optimize the response (i.e. surface roughness) of die sinking EDM process. The input variable parameters are spark gap, sparking area, current duration and current off time. To design the experiments Taguchi method, which is one of the proven techniques of DOE is used. The responses obtained after the experiments are used to find the optimum combination of factors and their levels to get the best output. This best combination is achieved using Taguchi Method. Also the interactions between various factors are highlighted to understand the inter-dependability between each other. A multiple linear regression analysis technique has been used to formulate the relation between the factors and their response to develop a mathematical model.*

1. Introduction

In 1770, the English scientist, Priestley, first detected the erosive effect of electrical discharges on metals. During research (to eliminate erosive effects on electrical contacts) the Soviet scientists, Lazarenko and Lazarenko (1940), decided to exploit the destructive effect of an electrical discharge and developed a controlled method of metal machining. In 1943, they announced the construction of the first Spark Erosion machine. The spark generator used in 1943, known as the Lazarenko circuit, has been employed over many years in power supplies for EDM machines and an improved version is being used in many current applications.

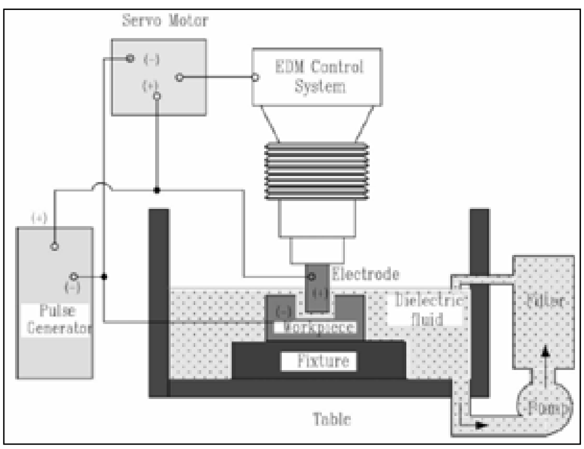

Figure (1) Typical Setup for EDM

The basic principle in EDM is the conversion of electrical energy into thermal energy through a series of discrete electrical discharges occurring between the electrode and workpiece immersed in the dielectric fluid. The insulating effect of the dielectric is important in avoiding electrolysis of the electrodes during the EDM process. The spark is initiated at the point of smallest inter-electrode gap by a high voltage, overcoming the dielectric breakdown strength of the small gap. At this stage, erosion of both the electrodes takes place. After each discharge, the capacitor is recharged from the DC source through a resistor and the spark that follows is transferred to the next narrowest gap. The cumulative effect of a succession of sparks spread over the entire workpiece surface leads to its erosion to a shape which is approximately complementary to that of the tool

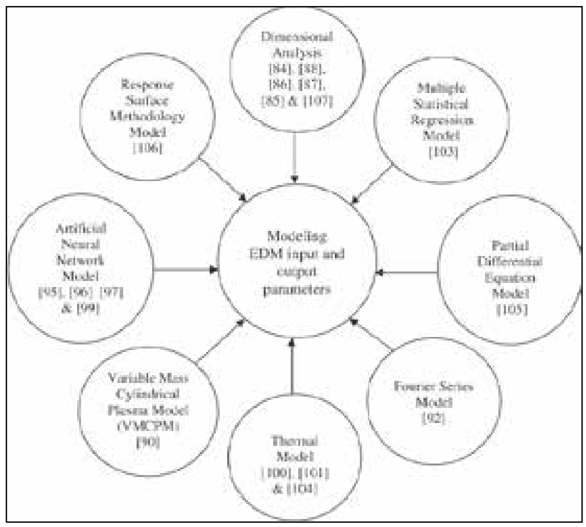

Figure (2) Modeling of EDM process

Abbas et. al. [1], in their paper reviews the research trends in EDM on ultrasonic vibration, dry EDM machining, EDM with powder additives, EDM in water and modelling technique in predicting EDM performances.

2. Experimental Design Procedure

Experiments are carried out by researchers or engineers in all fields of study to compare the effects of several conditions or to discover something new. If an experiment is to be performed more efficiently, then a scientific approach to planning it must be considered. The statistical design of experiments is the process of planning experiments so that appropriate data will be collected, the minimum number of experiments will be performed to acquire the necessary technical information, and suitable statistical methods will be used to analyze the collected data. The statistical approach to experimental design is necessary if we wish to draw meaningful conclusions from the data. Thus, there are two aspects of any experimental design: the design ofthe experiment and the statistical analysis of the collected data. They are closely related, since the method of statistical analysis depends on the design employed.

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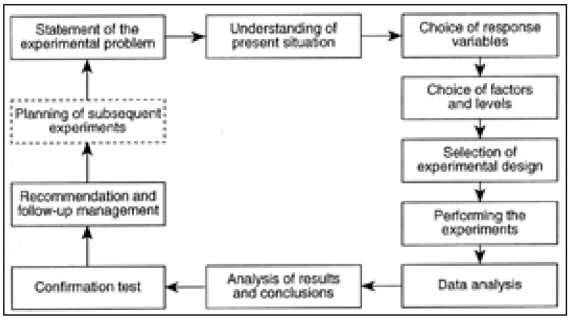

Figure (3) outline of experimental design procedure

3. Experimental Planning (Taguchi Method)

The main purpose of the Taguchi method, developed by Dr. Genechi Taguchi from Japan in 1952, is to (1) find controllable factors and levels during product design or process improvement, (2) acquire the best factor level combination through orthogonal array design laboratories, and (3) reduce quality loss and costs.

Taguchi method is a powerful tool for the design of high quality systems. It provides simple, efficient and systematic approach to optimize designs for performance, quality and cost. Taguchi method is an efficient method for designing process that operates consistently and optimally over a variety of conditions. To determine the best design it requires the use of a strategically designed experiment [6]. Taguchi approach to design of experiments in easy to adopt and apply for users with limited knowledge of statistics, hence gained wide popularity in the engineering and scientific community.

The major steps of implementing the Taguchi method are: (1) to identify the factors/interactions, (2) to identify the levels of each factor, (3) to select an appropriate orthogonal array (OA), (4) to assign the factors/interactions to columns of the OA, (5) to conduct the experiments, (6) to analyse the data and determine the optimal levels, and (7) to conduct the confirmation experiment.

Table 1: Process Parameters

Sr. No.	Factor			Level		
				1	2	3
1	A	Spark Gap	Per side	0.11	0.22	0.33
2	B	Sparking Area	cm^2	0.5	1	2
3	C	Current Off Time	µs	25	50	100
4	D	Spark Duration	µs	25	50	100
Response		Surface Finish	µm	Y		

Orthogonal arrays which are frequently used is that of three-level standard orthogonal arrays. The symbol for this group is

$$L_{3^m}\left(3^{(3^m-1)/2}\right)$$

Where,

m= a positive integer which is greater than 1

3^m = the number of experimental runs.

$$\frac{(3^m-1)}{2} = \text{the number 6 columns in the orthogonal array}$$

The three-level standard orthogonal arrays most often used are L_9 (3^4) and L27 (3^{13}), which are simply expressed as L_9 and L_{27}. L_9 is the simple three-level orthogonal array, and is shown in Table

The columns of L9are generated as follows. Columns 1 and 2 are the fundamental columns which are given as (0 0 0 1 1 1 2 2 2) and (0 1 2 0 1 2 0 1 2), respectively. The other columns are generated by these fundamental columns according to the following formula:

Number in the column of basic mark xy = (that of basic mark x +that of basic mark y) (mod3).

For example, column 3 is generated from columns 1 and 2 by summing the values in columns 1 and 2. But if the sum is equal to 3, then it becomes 0, and if the sum is equal to 4, then it becomes 1 and so on. The basic mark of column 4 began as a2b, which means that column 4 is generated by calculating.

(2′ (number in column 1) + (Number in column 2)) (mod3).

Table 2: L9 (3^4) orthogonal array

Experiment number	Column number			
	1	2	3	4
1	0	0	0	0
2	0	1	1	1
3	0	2	2	2
4	1	0	1	2
5	1	1	2	0
6	1	2	0	1
7	2	0	2	1
8	2	1	0	2
9	2	2	1	0
Basic mark	a	B	Ab	ab^2

From the factor combinations i.e. 3^4 experiments it is found that the L_9 orthogonal array is the best suitable options (refer table 3).

Table 3: Test combinations for L_9

Test	Factor						A_1			A_2			A_3		
	A	B	C	D			B_1	B_2	B_3	B_1	B_2	B_3	B_1	B_2	B_3
T_1	1	1	1	1		D_1									
T_2	1	2	2	2	C_1	D_2									
T_3	1	3	3	3		D_3									
T_4	2	1	2	3		D_1									
T_5	2	2	3	1	C_2	D_2									
T_6	2	3	1	2		D_3									
T_7	3	1	3	2		D_1									
T_8	3	2	1	3	C_3	D_2									
T_9	3	3	2	1		D_3									

4. Machine setup

Figure (4) machine setup

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The experiments were carried out on a standard EDM machine; model ROBOFORM 550 of Agie Charmillers with straight polarity. AISI H13 Hot die Steel (specimens 32mm × 31mm × 24mm) hardened to 52-54 HRC was used as work piece material with commercial grade EDM 30 as the dielectric fluid and Copper electrode.

MITUTOYO SJ-201 - Surface roughness Tester is used for SR measurement.

Figure (5) Surface roughness Tester

5. Results and Discussion
Table 4: Observation

Test	Factor				Response				Mean Response	S/N Ratio
	A	B	C	D	Y_1	Y_2	Y_3	Y_4	Y	
T_1	1	1	1	1	5.67	5.45	5.65	5.61	5.595	-14.957
T_2	1	2	2	2	4.89	4.93	4.87	4.88	4.8925	-13.791
T_3	1	3	3	3	3.16	3.15	3.16	3.14	3.1525	-9.9731
T_4	2	1	2	3	3.43	3.39	3.41	3.43	3.415	-10.668
T_5	2	2	3	1	3.27	3.29	3.27	3.28	3.2775	-10.311
T_6	2	3	1	2	3.38	3.40	3.39	3.41	3.395	-10.617
T_7	3	1	3	2	4.25	4.24	4.26	4.25	4.25	-12.568
T_8	3	2	1	3	4.14	4.09	4.13	4.10	4.115	-12.288
T_9	3	3	2	1	5.23	5.13	5.09	5.16	5.1525	-14.241

SA_1=5.595+4.8925+3.1525=13.6125
SA_2=3.415+3.2775+3.395=10.0875
SA_3=4.25+4.115+5.1525=13.5175
A_1=13.6125/3=4.5466
A_2=10.0875/3=3.3625
A_3=13.5175/3=4.5058

Similarly calculating the mean change in surface finish under the conditions B_1, B_2, B_3 , C_1, C_2, C_3,

D_1, D_2, D_3 (Refer Table 5)

Table 5: Mean Change and S/N Ratio for Individual Factors

Factor	Total Result	Mean Change	S/N Ratio
A_1	54.56	4.546667	-12.907
A_2	40.35	3.3625	-10.5319
A_3	54.07	4.505833	-13.032
B_1	13.26	4.42	-12.7309
B_2	12.285	4.095	-12.1297
B_3	11.7	3.9	-11.6103
C_1	13.105	4.368333	-12.6205
C_2	13.46	4.486667	-12.8998
C_3	10.68	3.56	-10.9506
D_1	14.025	4.675	-13.1696
D_2	12.5375	4.179167	-12.3251
D_3	10.6825	3.560833	-10.9762

From the calculated result of Mean Change and S/N Ratio Mean effect of individual factor such as A1, A2, etc. are plotted and shown in figure and figure respectively.

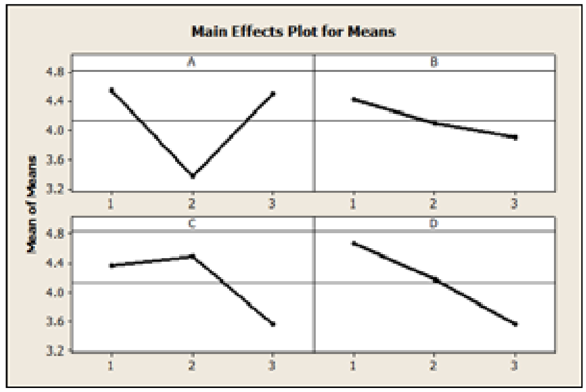

Figure (6) Main Effect Plot for Means (Refer table 5)

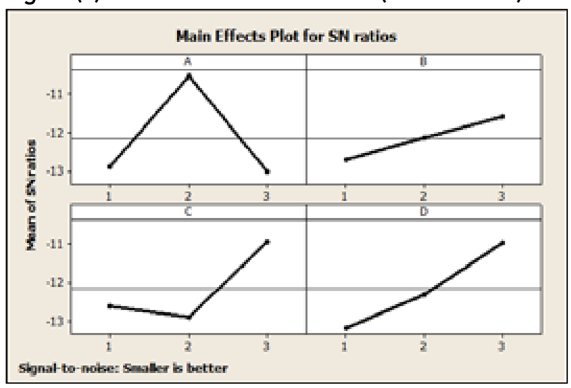

Figure (7) Main Effect Plot for S/N Ratio (Refer table 5)

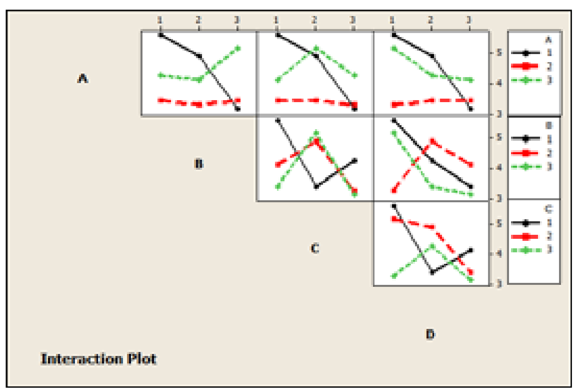

Figure (8) Interaction plot for factor A, B, C & D
(A: B, A: C, A: D, B: C, B: D, C: D)

The relative magnitude of the effect of different factors can be obtained by the decomposition of variance, called analysis of variance (ANOVA).

Table 6: ANOVA Table

Source	DOF	SS	V	F	P (%)
A	4	10.8445	2.71112	1107.773	41.502
B	4	1.6562	0.41405	169.1817	6.3383
C	4	6.10446	1.52611	623.5746	23.362
D	4	7.47821	1.86955	763.9039	28.619
e	19	0.0465	0.00244		0.1779
Total	36				100

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Test No. 54 of full factorial results exhibits the optimum response of surface finish i.e. the predicted value of the surface finish is 1.968 µm.

To validate the predicted result obtained from Taguchi method (using MINITAB™) it is necessary to conduct the verification run. After conducting the experiment for optimum combination obtained i.e. $A_2B_3C_3D_3$ (i.e. Spark Gap 0.22 per side, Sparking Area 2 cm^2, Current off time 100 µs, Spark Duration 100 µs)value of surface roughness is 2.03 µm, which shows a close correlation with predicted value.

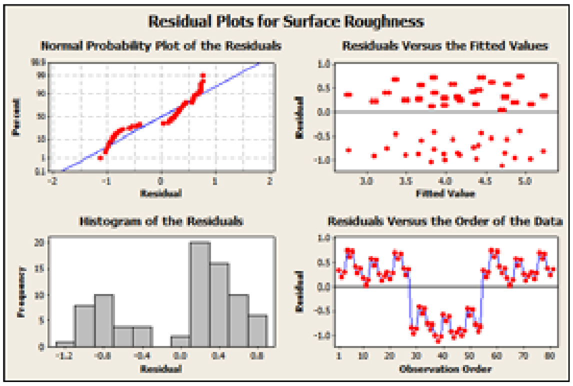

Figure (9) Residual plot for Surface Roughness

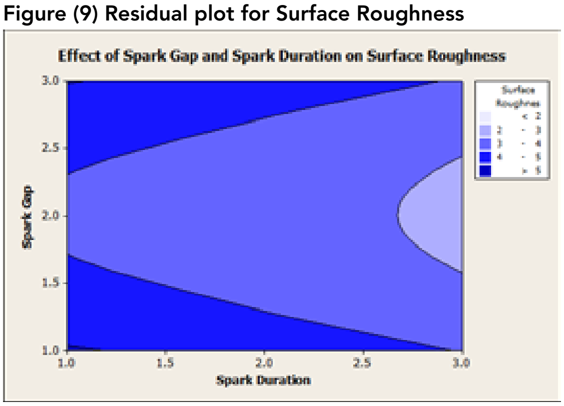

Figure (10) Effect of spark gap and spark duration on surface roughness

6. Conclusions

1) A_2 (Spark gap), B_3 (Sparking area), C_3 (Current off time), D_3 (spark duration) gives the optimum surface finish.
2) Predicated value of surface finish is 1.96 µm
3) Multiple linear regression analysis equation obtained from the set of experiments conducted and predicated result is, Surface Roughness = 6.10 × (0.186 Spark Gap) × (0.325 Sparking Area) - (0.0119 Current off Time) × (0.0145 Spark Duration)
4) From the interaction plot (refer figure 8) it is observed that each factor and its levels strongly interacted with each other.

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