Improving the Quality of Groove in Electro Chemical Machining (ECM) Process by Taguchi Method

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Abstract

This research presents a study of relationship between Electro Chemical Machining (ECM) parameters and groove depth and groove Ratio. Design of Experiment (DOE) by gomplete randomized and Taguchi method has been applied to investigate the optimal combinations of process parameters to the targets: 10 micron of groove depth and 1 of groove ratio. Signal-to-noise(S/N) ratio was determined to know the level of importance of the parameters. The results were confirmed experimentally at 95% confidence interval. Based on ANOVA, 10 amperes of current with 10 pulses, duty factor is 40% and gap factor is 50 micron was found to be significant for best groove depth and groove ratio.

***Keywords**:* ECM, Design of Experiment, Taguchi, Groove depth, Groove ratio.

1. Introduction

A conventional electrochemical machining (ECM) tool are used to form a specific groove pattern on a workpiece, such as a pattern of dynamic pressure grooves on a hydrodynamic bearing for use in a hard disk storage device .More specifically, in such a bearing, a rotation shaft, which includes a flange, is fitted in a hollow sleeve in which radial and thrust dynamic pressure grooves are formed. The radial dynamic pressure groove is formed on a surface that is oriented in a radial sleeve direction, and the thrust dynamic pressure groove is formed on a surface, such as that of a step formed in the sleeve, that is oriented in an axial sleeve direction. Lubricant oil fills the minute spaces between the external circumference of the rotation shaft and inner circumference of the sleeve. Defects of Electro Chemical Machining for sleeve groove manufacturing process are out of the specification of groove depth and groove ratio. Therefore, it is important to optimize the processes parameters suitably to groove depth and groove ratio which are the key performance index of the quality. In this study, the study was considered only thrust for optimum parameters as shown in Fig.1.

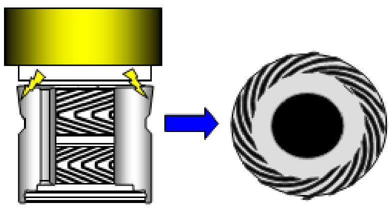

Fig.1 Thrust for grooves on a bearing

2. Experimental design approach

The Taguchi technique is a methodology for designing high quality system, was developed by Taguchi [1].This method uses a special design of orthogonal arrays to study the entire parameter space with small number of experiments only. In this study, four parameters were used as control factors and each parameter was designed to have three levels (Table 1). The experimental design was according to an L18 array based on Taguchi method (Table 2) [2-3]. To obtain the estimates of S/N ratio and the average response, analysis was performed on the responses for each run of experiment (3 times replication). Science it is required that "Nominal-the-Best" has been used. The S/N ratio for target is the best is shown as follows: [4-5]

$$S/N_{\tau} = 10\log\left(\frac{\overline{y}_i^{\,2}}{S_i^{\,2}}\right) \qquad (1)$$

Where y is the performance characteristic and S is variance of sample.

Table. 1 Factors and levels

Factor / Level	Level 1	Level 2	Level 3	unit
Current (A)	8	9	10	A
Pulse (B)	10	15	20	pulse
Duty cycle (C)	20	30	40	%
Gap (D)	40	50	60	μm

3. Results and discussion

The Taguchi method uses S/N ratio instead of the average value to interpret the trial results data into a value for the evaluation characteristic in the optimum setting analysis [1-3]

Table. 2 Orthogonal array of Taguchi L_{18}

Exp.No	Parameters			
	A	B	C	D
	CC	Pulse	Duty	Gap
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	1	2
5	2	2	2	3
6	2	3	3	1
7	3	1	2	1
8	3	2	3	2
9	3	3	1	3
10	1	1	3	3
11	1	2	1	1
12	1	3	2	2
13	2	1	2	3
14	2	2	3	1
15	2	3	1	2
16	3	1	3	2
17	3	2	1	3
18	3	3	2	1

3.1 Groove Depth

Table. 3 Average S/N of groove depth

Factor	A	B	C	D
	CC	Pulse	Duty	Gap
Level 1	50.83	51.43	51.09	54.85
Level 2	54.55	51.48	52.51	54.79
Level 3	55.36	57.82	57.15	51.09
Effect	4.53	6.39	6.06	3.76
Rank	3	1	2	4

By applying Eq.1, the S/N values for each experiment of L18 was calculated in Table3. It can be concluded that factor B, C, A and D affect to groove depth respectively.

Table. 4 Average groove depth

Factor	A	B	C	D
	CC	Pulse	Duty	Gap
Level 1	9.681	7.144	7.031	11.710
Level 2	10.856	10.619	10.606	10.537
Level 3	11.205	13.978	14.105	9.495
Effect	1.524	6.834	7.074	2.215
Rank	4	2	1	3

Table 4 shows average groove depth. The highest effect is the level that gives the highest value. The average values were C, B, D and A respectively. So factor D (Gap) is optimum value due to it affected to average depth groove with the least S/N value. Fig.2 and Fig.3 show main effects plot of S/N ratio and means of groove depth respectively.

3.2 Groove ratio

Table. 5 Average S/N of groove ratio

Factor	A	B	C	D
	CC	Pulse	Duty	Gap
Level 1	43.32	44.55	43.57	45.12
Level 2	42.37	41.83	40.91	42.59
Level 3	44.69	44.01	45.90	42.67
Effect	2.31	2.71	4.99	2.52
Rank	4	2	1	3

Table. 6 Average groove ratio

Factor	A	B	C	D
	CC	Pulse	Duty	Gap
Level 1	1.1922	1.1778	1.1589	1.2806
Level 2	1.1356	1.1383	1.1478	1.1950
Level 3	1.1211	1.1328	1.1422	0.9733
Effect	0.0711	0.0450	0.0167	0.3072
Rank	2	3	4	1

Table 5 shows average S/N ratio of groove ratio . The highest followed with the lowest were C, B, D and A respectively. And Table 6 depicts the average of groove ratio. The most effective parameters on the groove ratio are found as follows; D, A, B and C. The gap (D) is a strong function for developing a process model.

Based on the results of the main effects plot of S/N ratio of groove depth in Fig.2, it can be considered with factors A,B and C that give the highest of mean effect plot of S/N ratio. The optimal parameters for groove depth was obtained the CC (A) at Level 3 (Max S/N = 55.36),the pulse (B) at Level 3 (Max S/N = 57.82) and the duty (C) at Level 3 (Max S/N = 57.15). And, the results of the main effects plot of S/N ratio of the groove ratio in Fig.4. It can be considered with factors A,B and C that give the highest of mean effect plot of S/N ratio. The optimal parameters for groove depth was obtained the CC (A) at Level 3 (Max S/N = 44.69), the pulse (B) at Level 1 (Max S/N = 44.55) and the duty (C) at Level 3 (Max S/N = 45.90). Fig.4 and Fig.5 show main effects plot of S/N ratio and means of groove ratio respectively.

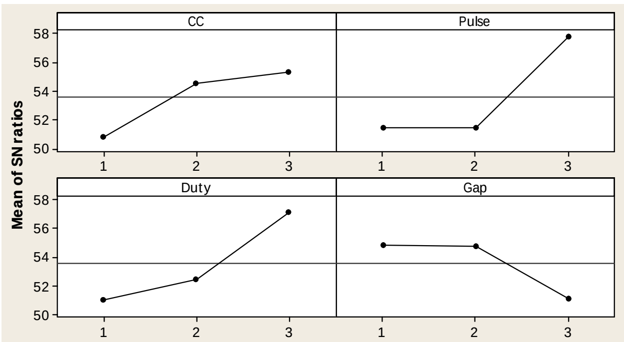

Fig. 2 Main effects plot of S/N ratio of groove depth

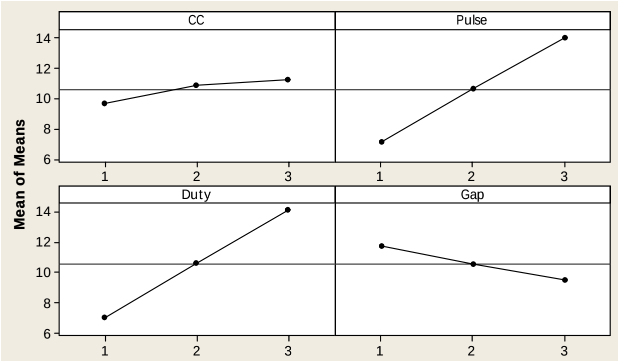

Fig. 3 Main effects plot for means of groove depth

From the above results, the pulse (B) gave optimal factor for groove depth at Level 3 but gave optimal groove ratio at Level 1.

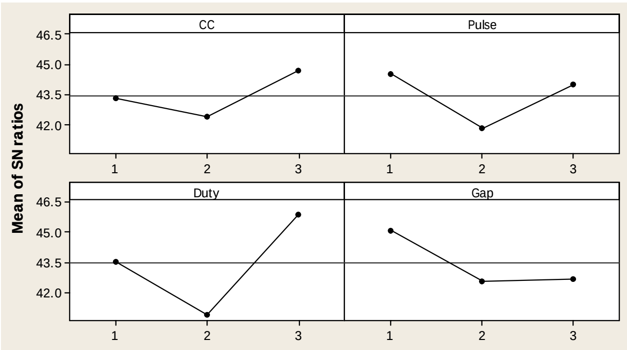

Fig. 4 Main effects plot of S/N ratio of groove ratio

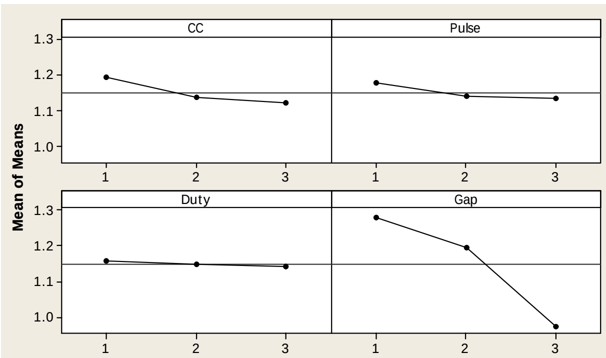

Fig. 5 Main effects plot for means of groove ratio

So, the result should be considered in Table 2 for Exp.No.16 (A=3,B=1 and C=3) that gives the groove depth at the nearest value(10). Thus, we selected Level 1 for the pulse (B).

Factor D (gap)

The gap (D) can be calculated for optimal average groove depth at 10 µm and groove ratio at 1 that shown in the equation.

$$\therefore \hat{\mu}_y = \bar{T} + \hat{\alpha} + \hat{\xi} + \hat{\varphi} \tag{2}$$

$$\therefore \hat{\mu}_y = \bar{T} + (\bar{C}_3 - \bar{T}) + (\bar{B}_1 - \bar{T}) + (\bar{D}_? - \bar{T}) \tag{3}$$

$\bar{T}$ = the sum average of groove depth

$$\bar{T} = \frac{(\bar{C}_1 + \bar{C}_2 + \bar{C}_3) + (\bar{B}_1 + \bar{B}_2 + \bar{B}_3)}{6}$$

$$\bar{T} = \frac{31.741 + 31.742}{6} = 10.58$$

$\bar{C}_3$ and $\bar{B}_1$ from Table 4

$$\therefore 10 \;=\; \bar{C}_3 + \bar{B}_1 + \bar{D}_? - 2\bar{T}$$

$$= \; 14.105 + 7.144 + \bar{D}_? - 2(10.58)$$

$$\bar{D}_? \;=\; 9.912$$

From the Table 4, $\bar{D}$ at Level 3 gives 9.495 that gives the nearest of 9.912.

D for the average groove ratio

$$\bar{T} = \frac{(\bar{C}_1 + \bar{C}_2 + \bar{C}_3) + (\bar{B}_1 + \bar{B}_2 + \bar{B}_3)}{6}$$

$$\bar{T} = \frac{3.4489 + 3.4489}{6} = 1.15$$

$\bar{T}$ = the sum average of groove ratio

$\bar{C}_3$ and $\bar{B}_1$ from Table 6

$$\therefore 1 \;=\; \bar{C}_3 + \bar{B}_1 + \bar{D}_? - 2\bar{T}$$

$$= \; 1.1422 + 1.1778 + \bar{D}_? - 2(1.15)$$

$$\bar{D}_? \;=\; 0.979$$

From the Table 6, D at Level 3 gives 0.9733 that gives the nearest of 0.979. Thus, D at level 3 was selected for the study.

3.3 Regression Analysis

Multiple linear regression equations were modeled for a relationship between process parameters in order to evaluate groove depth and groove ratio. Model for multiple regression equation is

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \ldots + \beta_k X_k + \varepsilon \quad ..(4)$$

where, y is dependent parameter, $x_1, x_2, \ldots x_k$, are independent parameters, β's are regression parameters and ε is residue. Regression equations, formulated for groove depth and groove ratio are

Depth = - 11.6 + 0.762xCC + 0.683x Pulse + 0.354xDuty - 0.111xGap ....(5)

Ratio = 2.33 - 0.0356xCC - 0.00450xPulse - 0.00083xDuty - 0.0154xGap……….(6)

The ten experiments were carried out for checking the equation. The average of groove depth's result is higher than the actual value (error 3.5 %). Similarly at the average of groove ratio's result is lower than that actual value (error 2.8 %).

4. Conclusion

From signal-to-noise (S/N) ratio results, the optimum parameters for groove depth and groove ratio are current at Level 3 (10 A), pulse at Level 1 (10 pulses), duty cycle at Level 3 (40%) and gap at Level 3 (60 µm).

5. Acknowledgements

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6. References

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