CASE 44

Quality Improvement of an Electrodeposited Process for Magnet Production

Abstract: In a conventional development process of electrodeposition, improvement has been focused mainly on pinholes as one of the quality characteristics. However, in our research, we regarded a function of coating formation in the electrodeposition process as an input and output of energy. By reducing the variability in coating thickness on each side and minimizing the difference in coating thickness in both sides of a magnet, we aimed to minimize pinholes as a quality characteristic.

1. Introduction

The magnet for motors is electrodeposited to prevent it from releasing dust and from becoming rusty. There are coating methods other than electrodeposition: for example, spraying and plating. One of the major advantages of electrodeposition is its good "throwing power," which enables us to obtain uniform coating thickness even on a complicated shape. However, since the rare-earth-bonded magnet used is compression molded from metal powder, it has plenty of hollow holes inside. Therefore, when its coating is baked, gas frequently comes out of the inside, leading to the development of tiny pinholes, ranging in diameter from a few micrometers to a few dozen on the coat.

To electrodeposit a magnet, water-soluble resin made primarily of epoxy resin is used. After charging the magnet negatively and the electrode positively by applying voltage in its solution, we can obtain water electrolysis, which raises the pH of the solution, with hydrogen generated around the magnet. On the other hand, since the coating material in the solution is charged positively, it is attracted by the magnet and consequently condensed and educed on the surface of the magnet due to alkali.

The coating thus formed on the surface has many minute holes generated by O_2 gas. Because of current flowing through these holes, new coatings are reduced continuously. This is regarded as a growing coating process. The educed coatings per se have high resistance. As the coatings develop, the number of holes for O_2 gas decreases and a smaller amount of current flows. Therefore, since the current tends to flow from a high-resistance area to a low-resistance area, it forms new coatings in areas where coatings are not well developed. This phenomenon, throwing power, is peculiar to electrodeposition.

2. Generic Function and Measurement Characteristics

In a conventional electrodeposition development process, improvement has focused mainly on pinholes as one quality characteristic. However, in our research, we regarded a function of coating formation in the electrodeposition process as an input and output of energy.

Most magnets are ring-shaped and have electrode terminals on the outer circumference. Therefore, electrical current flows less easily in the inner circumference. In addition, because of the circulation of the coating solution, the inner side is

Taguchi's Quality Engineering Handbook. Genichi Taguchi, Subir Chowdhury and Yuin Wu

Table 1
Signal and noise factors

Signal Factor:	M_1	M_2	M_3
Coulomb value	2	3	4
Noise Factor:	N_1	N_2	
1: measured side	Outer side	Inner side	
2: deterioration of solution	Yes	No	
3. coating thickness	Maximum	Minimum	

disadvantageous. That is, coating forms differently on the outer and inner circumferences. As a result, on the inner side, where a thinner coating develops, a defect related to pinholes occurs more often than on the outer side. By reducing the variability in coating thickness on each side and minimizing the difference in coating thickness on both sides of a magnet, we aimed to minimize pinholes as a quality characteristic.

As Table 1 shows, after setting a Coulomb value as an integral of current to a signal factor, we conducted an analysis based on dynamic characteristics by measuring coating thickness with a β-ray thickness measuring instrument. As the noise factor, we used a compounded factor consisting of coating thickness on both the outer and inner sides of a magnet, maximum and minimum thickness on each side, and deterioration of solution. Figure 1 outlines the experimentation on electrodeposition. A beaker was considered an easy experimental device as a downscale of the mass-production line.

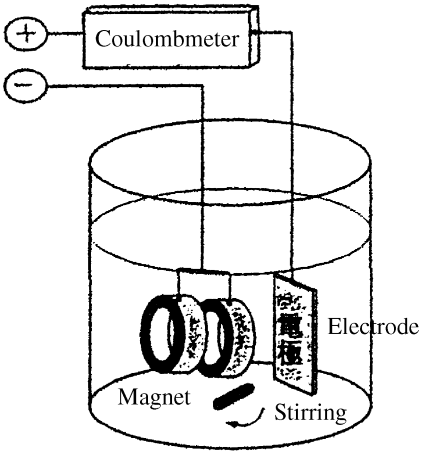

Figure 1
Experimental device

Setting up two ring-shaped magnets at the same time, we measured each. Next, using magnets that were longer than their outer diameter, we attempted to simulate the situation of our mass-production line (producing tubular magnets).

3. Calculation of SN Ratio

Table 2 shows data examples of experiment 1 in an L_{18} orthogonal array. Using these data we computed the SN ratios and sensitivities as follows.

Total variation:

$$S_T = 9.5^2 + 9.3^2 + \cdots + 13.6^2 + 14.5^2 = 2188.01 \qquad (f = 12) \tag{1}$$

Linear equations:

$$L_1 = (2)(9.5 + 9.3) + \cdots + (4)(21.1 + 20.6) = 291.7$$

$$L_2 = (2)(6.7 + 6.7) + \cdots + (4)(13.6 + 14.5) = 204.0 \tag{2}$$

Effective divider:

$$r = 2^2 + 3^2 + 4^2 = 29 \tag{3}$$

Variation of proportional term:

Table 2
Data of experiment 1 on coating thickness (μm)

	M_1 (2)		M_2 (3)		M_3 (4)	
N_1	9.5	9.3	14.6	14.5	21.1	20.6
N_2	6.7	6.7	10.7	10.9	13.6	14.5

$$S_\beta = \frac{(L_1 + L_2)^2}{(2)(2r)} = \frac{(291.7 + 204.0)^2}{(2)(2)(29)}$$

$$= 21{,}18.26 \qquad (f = 1) \tag{4}$$

Variation of differences between proportional terms:

$$S_{N\beta} = \frac{L_1^2 + L_2^2}{2r} - S_\beta$$

$$= \frac{291.7^2 + 204.0^2}{(2)(29)} - 2118.26$$

$$= 66.31 \qquad (f = 1) \tag{5}$$

Error variation:

$$S_e = S_T - S_\beta - S_{N\beta} = 2188.01 - 2118.26 - 66.31$$

$$= 3.44 \qquad (f = 10) \tag{6}$$

Error variance:

$$V_e = \frac{S_e}{(2)(2)(3) - 2} = \frac{3.44}{10} = 0.34 \tag{7}$$

Total error variance:

$$V_N = \frac{S_T - S_\beta}{(2)(2)(3) - 1}$$

$$= \frac{2188.01 - 2118.26}{11} = 6.34 \tag{8}$$

SN ratio:

$$\eta = 10 \log \frac{(1/4r)(S_\beta - V_e)}{V_N}$$

$$= 10 \log \frac{[1/(4)(29)](2118.26 - 0.34)}{6.34}$$

$$= 4.59 \text{ dB} \tag{9}$$

Sensitivity:

$$S = 10 \log \frac{1}{4r}(S_\beta - V_e)$$

$$= 10 \log \frac{1}{(4)(29)}(2118.26 - 0.34)$$

$$= 12.61 \text{ dB} \tag{10}$$

Table 3
Control factors and levels

	Level		
Signal	1	2	3
A: distance between electrodes	Far	Close	—
B: temperature	Low	Mid[a]	High
e: —	—	—	—
C: NV value	Small	Mid[a]	Large
D: amount of ash	Small	Mid[a]	Large
E: amount of solvent	Small	Mid[a]	Large
F: flow of solution	Small	Mid	High
G: voltage (V)	115	175	235

[a] Current level.

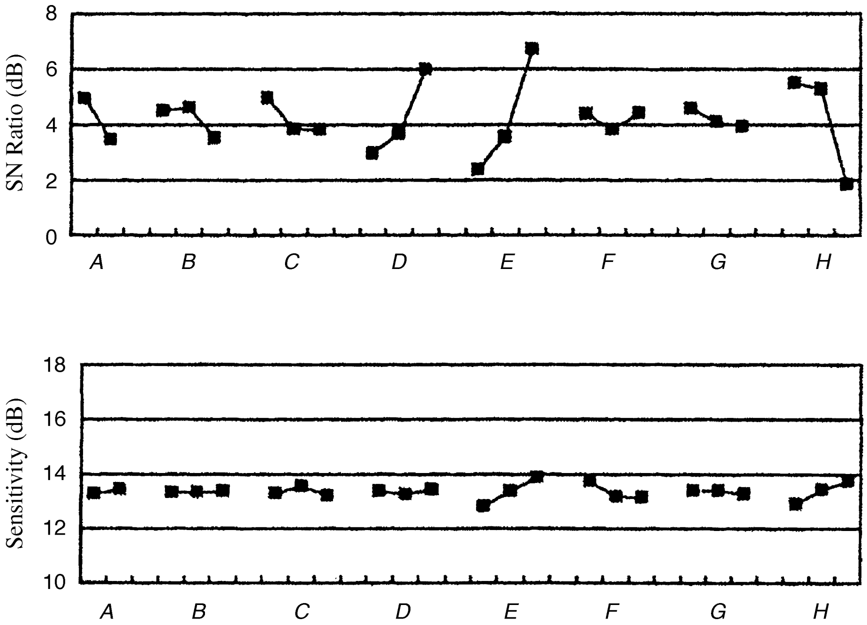

Figure 2
Response graphs

4. Optimal Configuration and Confirmatory Experiment

Table 3 shows the control factors selected. All seven factors were selected based on our existing technical knowledge. Figure 2 shows the response graphs for the SN ratio and sensitivity. Table 4 and Figure 3 show estimations of the SN ratio and sensitivity and results obtained from the confirmatory experiment.

Looking at these results, we can see good reproducibility in gains. In addition, comparing the results with our technical knowledge, many of them are regarded as quite reasonable. While the linearity between a Coulomb value and coating thickness had been fairly good under the current configuration, the SN ratio was improved under the optimal configuration. Because of a reduced difference in coating thickness between the outer and inner circumferences, pinhole defects are expected to decrease. On the other hand, the sensitivity is never improved. Since this research focused more on quality improvement without major changes in the

Table 4
Results of estimation and confirmatory experiment

	SN Ratio		Sensitivity	
Configuration	**Estimation**	**Confirmation**	**Estimation**	**Confirmation**
Optimal	8.49	11.70	13.95	14.28
Current	3.01	7.42	13.27	14.16
Gain	5.48	4.28	0.68	0.12

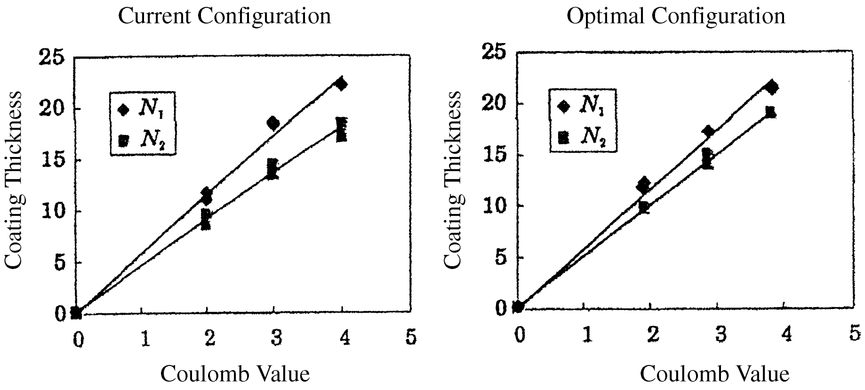

Figure 3
Results of confirmatory experiment

existing production line, we have not chosen factors that influence sensitivity significantly.

As a result of deploying the optimal configuration obtained in this research, we have succeeded in slashing the number of pinhole-related defects remarkably, by 90%. On the other hand, by stabilizing the coating thickness, we have also enhanced the dimensional accuracy of products.

Reference

Hayato Shirai and Yukihiko Shiobara, 1999. Quality improvement of electro-deposited magnets. *Quality Engineering,* Vol. 7, No. 1, pp. 38–42.

This case study is contributed by Hayato Shirai.