CASE 19

Minimizing Variation in Pot Core Transformer Processing

Abstract: This study addressed a transformer processing problem involving inductance changes. Due to inductance falling out of the ranges calculated, much time and expense were involved in an attempt to rectify the problem. In this L_{16} experiment it was determined that by adjusting the level settings of seven of these factors, average inductance could be reduced by 90%. Annual losses attributed to this product were reduced to 28% per power supply model.

1. Introduction

The objective of this study was to minimize inductance variation from transformer to transformer after processing. The inductance should be within calculated limits. A ferrite pot core transformer (Figure 1) was the subject of the experiment.

Manufacturing specifications are determined as follows:

$$L = N^2 \frac{A_L}{1 \times 10^6} \tag{1}$$

where L is in millihenries, N is the number of primary turns, and A_L is in inductance factor from the core manufacturer's data sheets (specified with a tolerance). Initial out-of-tolerance inductance indicates an incorrect number of primary turns or incorrect core material. Large drops in inductance after processing indicate separated or cracked cores. This results in high magnetizing currents and flatter hysteresis loops. The present distribution of transformer inductance is shown in Figure 2, where 8.2% of the products are below the lower specification limit.

2. Factors and Experimental Layout

The brainstorming group consisted of representatives from quality, product design, and manufacturing. A total of 12 people attended the brainstorming session, which lasted two hours. The transformer process flow diagram, with factors and measurements steps, is shown in Figure 3. The group originally discussed 14 possible factors, but this was reduced to nine controllable and two noise factors (Table 1). From Table 1 it was decided to select two orthogonal arrays, one for controllable factors and another for noise factors. An L_{16} orthogonal array was modified by using a linear graph (Figure 4) and multilevel arrangement to yield an L_{16} (8×2^8) array. A standard L_4 (2) orthogonal array was selected for the noise factors. Since available production time for the experiment was minimal, it was decided to process two transformers per experiment. The experiment layout is shown in Table 2.

3. Results of Experiment

A regular analysis was conducted using inner and outer orthogonal array concepts. This analysis identified the most significant factors and interactions between noise and control factors. The following equation was the basis for variation calculations:

$$S_T = \sum_{i=1}^{n} y_i^2 - \text{CF} \tag{2}$$

Nominal-the-best SN ratio analysis was also done.

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

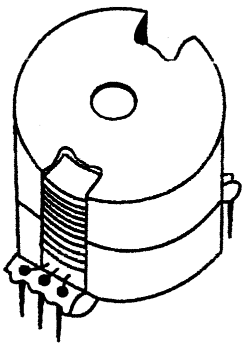

Figure 1
Pot core transformer

This type of analysis is more sensitive than regular analysis because (among other advantages) it provides robustness against all sources of noise, not necessarily only the noise factors controlled. The SN ratio nominal-the-best equations for Table 2 are as follows:

$$\eta = 10 \log \frac{1}{n} \frac{S_m - V_e}{V_e} \tag{3}$$

$$S_m = \frac{T^2}{n} \tag{4}$$

$$V_e = \frac{\sum_{i=1}^{n} (y_i - \bar{y})^2}{n - 1} \tag{5}$$

For run 1:

$$S_m = \frac{(9.44 + 10.21 + 9.54 + 9.73)^2}{4} = 378.70$$

$$V_e = \frac{(9.44 - 9.73)^2 + (10.21 - 9.73)^2 + (9.54 - 9.73)^2 + (9.73 - 9.73)^2}{4 - 1} = 0.117$$

$$\eta = 10 \log \frac{1}{4} \left(\frac{378.70 - 0.117}{0.117} \right) = 29.08 \text{ dB}$$

4. Optimization and Estimation

Optimum levels were determined from the response graphs (Figure 5) and Table 3. A trade-off between interaction with noise factors, main effects, and SN ratio was considered to determine how a confirmation experiment should be conducted. The SN ratio determines the best factor levels for robustness against noise factors. The higher the SN ratio, the more robust the level setting is to noise.

Regular analysis determined that the best factor levels were L_2, B_1, C_1, D_1, E_1, and F_2. Factor G had a conflict between interactions with noise. Level G_1 is optimum for robustness against noise factor Y; G_2 is optimum for robustness against noise factor X.

SN ratio analysis identified levels, L_2, L_4, L_6, B_2, C_1, D_2, F_1, G_2, H_1, and A_2 as best. Factor levels of L, B, D, and F were in conflict between regular analysis and SN ratio analysis. This conflict is not unusual, since SN ratio analysis considers the variability of the quality characteristic due to all sources of noise,

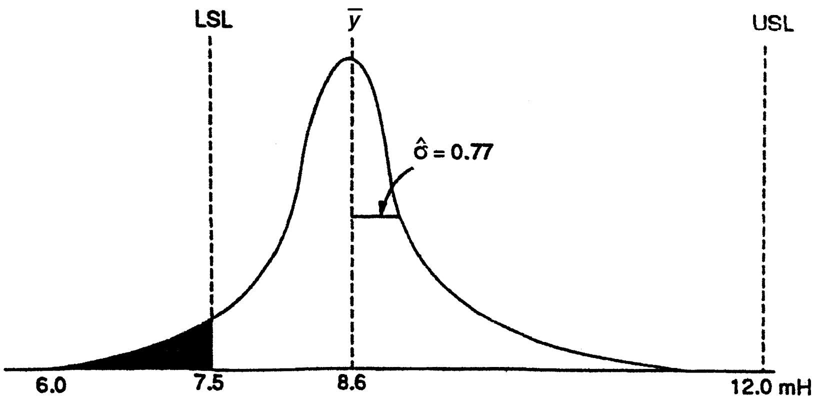

Figure 2
Present PS6501 auxiliary distribution curve

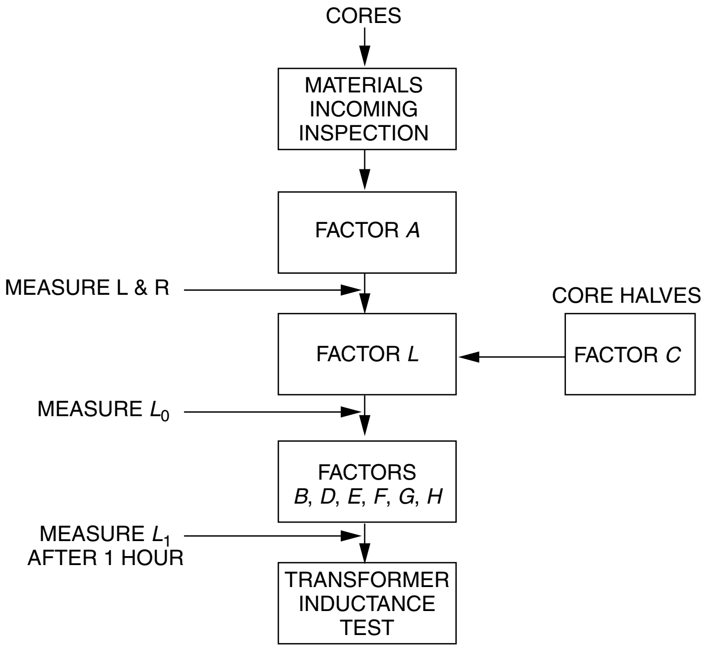

Figure 3
Transformer process

Table 1
Factors and levels

Factor	1	2	3	4	5	6	7	8
A	Level 1	Level 2						
B	Level 1	Level 2						
C	Level 1	Level 2						
D	Level 1	Level 2						
E	Level 1	Level 2						
F	Level 1	Level 2						
G	Level 1	Level 2						
H	Level 1	Level 2						
L	Level 1	Level 2	Level 3	Level 4	Level 5	Level 6	Level 7	Level 8

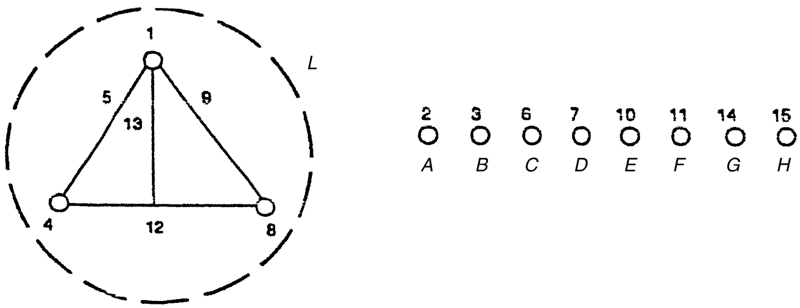

Figure 4
Linear Graph

Table 2
Orthogonal array

Exp.	X	Y	Z
1	1	1	1
2	1	2	2
3	2	1	2
4	2	2	1

Array	*L*	*A*	*B*	*C*	*D*	*E*	*F*	*G*	*H*	Data				*T*	SN[a]
1	1	1	1	1	1	1	1	1	1	9.44	10.21	9.54	9.73	38.92	29.08
2	2	1	1	1	1	2	2	2	2	9.07	9.68	8.82	8.84	36.41	11.42
3	3	1	1	2	2	1	1	2	2	8.41	7.23	8.87	8.17	32.68	21.42
4	4	1	1	2	2	2	2	1	1	10.20	10.48	10.62	11.08	42.38	29.20
5	1	2	2	2	2	2	2	2	2	9.56	8.39	8.85	7.87	34.67	21.64
6	2	2	2	2	2	1	1	1	1	9.08	9.18	9.30	8.94	36.50	35.59
7	3	2	2	1	1	2	2	1	1	9.30	8.11	9.43	9.04	35.88	23.55
8	4	2	2	1	1	1	1	2	2	9.72	9.83	9.92	9.85	39.32	41.40
9	5	1	2	1	2	1	2	1	2	9.10	8.88	9.43	10.08	37.49	25.07
10	6	1	2	1	2	2	1	2	1	9.63	9.77	9.90	9.73	39.03	38.82
11	7	1	2	2	1	1	2	2	1	9.94	9.17	10.40	9.15	38.66	23.96
12	8	1	2	2	1	2	1	1	2	9.63	7.85	9.52	7.87	34.87	18.87
13	5	1	2	2	1	2	1	2	1	10.11	8.52	9.84	7.83	36.30	18.46
14	6	2	1	2	1	1	2	1	2	9.89	10.65	10.19	10.71	41.44	28.49
15	7	2	1	1	2	2	1	1	2	10.20	9.87	10.87	10.73	41.67	27.00
16	8	2	1	1	2	1	2	2	1	8.72	8.94	9.14	8.91	35.71	34.24

[a] SN ratio nominal-the-best equations are given in Section 3.

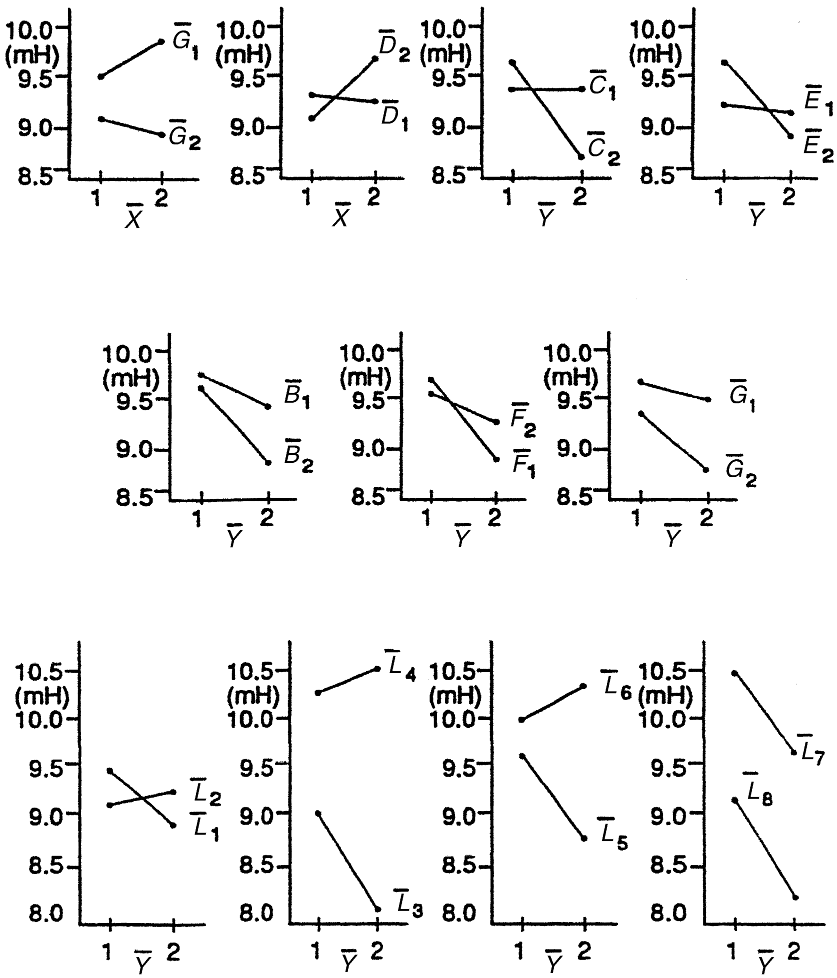

Figure 5
Response graphs

not just the noise factors controlled in the experiment. A confirmation experiment (Table 4) was designed to identify the optimum setting for the conflicting factors.

As a result of the confirmation experiment, optimum factor levels L_4, B_1, C_1, E_1, F_2, G_1, D_1, A_2, and H_1 were selected for production and cost reasons. The process average equation for each combination of noise factor is

$$\hat{u} = \overline{YL} + \overline{YB} + \overline{YC} + \overline{YE} + \overline{YF} + \overline{YG} + \overline{XD} + \overline{XG} - \overline{G} - 5\overline{Y} - \overline{X} \qquad (6)$$

The inductance results at optimum levels for each combination of noise factors is

$$\hat{u}x_1 y_1 = 10.01 \text{ mH}$$

$$\hat{u}x_1 y_2 = 11.40 \text{ mH}$$

Table 3
Summary table

Factor		Regular Analysis					
		Interaction with Noise Factor					
		Y		X			
		1	2	1	2	Main Effect	SN $-10 \log \eta$
L	1	9.35	9.05	—	—	9.20	6.11
	2	9.06	9.16	—	—	9.11	12.13
	3	9.00	8.14	—	—	8.57	3.86
	4	10.12	10.31	—	—	10.21	15.21
	5	9.62	8.83	—	—	9.22	2.47
	6	9.90	10.21	—	—	10.06	13.61
	7	10.35	9.73	—	—	10.04	5.45
	8	9.25	8.39	—	—	8.82	7.69
B	1	9.62	9.47	—	—	9.55	—
	2	9.54	8.98	—	—	9.26	—
C	1	9.51	9.51	—	—	9.51	11.25
	2	9.65	8.94	—	—	9.30	5.38
D	1	—	—	9.44	9.92	—	6.90
	2	—	—	9.23	9.53	—	9.72
E	1	9.44	9.35	—	—	—	10.48
	2	9.72	9.10	—	—	—	6.14
F	1	9.62	9.08	—	—	—	9.44
	2	9.54	9.37	—	—	—	7.18
G	1	9.73	9.59	9.51	9.82	9.66	—
	2	9.43	8.87	9.17	9.13	9.15	—
H	1	—	—	—	—	—	9.60
	2	—	—	—	—	—	7.02
A	1	—	—	—	—	—	—
	2	—	—	—	—	—	—

$$\hat{u}x_2y_1 = 10.17 \text{ mH}$$

$$\hat{u}x_2y_2 = 11.56 \text{ mH}$$

Table 4
Confirmation experiment

Exp.	Level								
	L	*C*	*E*	*D*	*H*	*A*	*B*	*F*	*G*
1	4	1	1	2	1	2	1	2	1
2	6	1	1	2	1	2	1	2	1
3	2	1	1	2	1	2	1	2	1
4	Best	1	1	2	1	2	2	1	2

5. Confirmation and Improvement in Quality

Average values obtained in the experiment were confirmed at the levels predicted. The mean inductance was influenced by the factors exactly as predicted.

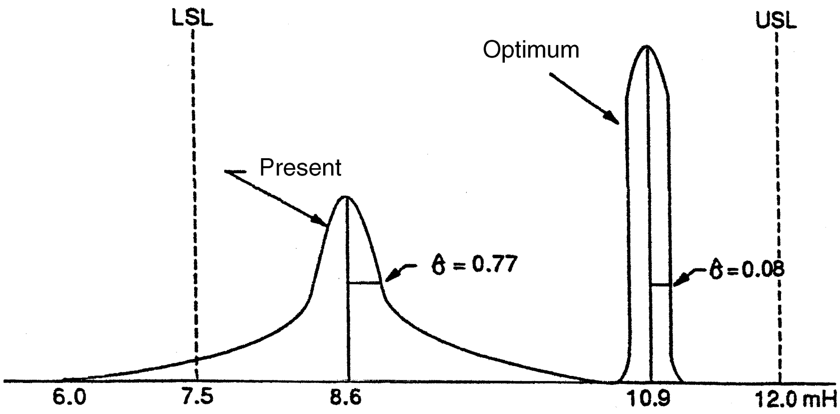

Figure 6
Comparison of transformer inductance distributions

The confirmation experiment variation was calculated from only two samples; therefore, more data should be obtained to determine the actual inductance distribution. The variation exhibited in the experiment falls within the range predicted in the analysis, although at the upper limit of the confidence interval.

Implementing the new factor levels will improve the capability of the process. A comparison of transformer inductance distributions is shown in Figure 6. Engineering and assembling time will not be wasted on questions regarding out-of-specification transformers. Scrap transformers and production delays will be eliminated.

Savings using the conventional method were calculated to be about 28% annually. This calculation considers yearly production volume, rejection percentage, cost of scrap, and engineering and assembly time. If costing information, specification limits, and target value are valid, savings calculated by the quality loss function (QLF) will be reflected in real life. In this case, the annual savings calculated by the QLF are 30.60%. After a more extensive confirmation/production run, the mean can be adjusted to the target value. This will increase savings due to minimizing loss due to quality to 99.67% annually (when the quality loss after optimization is compared to the quality loss before optimization).

This case study is contributed by Gerard Pfaff.