CASE 37

Optimization of a Wave Soldering Process

Abstract: In optimizing manufacturing conditions for soldering, quality characteristics such as bridges or no-solder joints are traditionally measured for evaluation. By using the characteristics of current and voltage as an ultimate objective function of soldering, we optimized manufacturing conditions in the automated soldering process.

1. Introduction

For optimization of manufacturing conditions in the automated soldering process, it is important to make the process robust not only to the products of current-level density but also to those with high density, to arrange conditions for manufacturing various types of motherboards without adjustment. The process studied is outlined in Figure 1.

In optimizing manufacturing conditions for soldering, quality characteristics such as bridges or no-solder joints are traditionally measured for evaluation. Soldering is used to join a land pattern printed on the board to a lead of an electronic part (Figure 2). Defects called *no-solder* indicate that the two parts are not joined completely; *bridge* is the name given to the defect of unwanted joints.

In one print board, some portions need considerable energy for soldering and others need less energy. This manufacturing process provides the same amount of energy to each portion. Our technical objective is to solder circuit boards evenly no matter how much energy is needed. In addition, ideally, the amount of current flowing in solder is proportional not only to its area but also to the corresponding voltage. Therefore, by using the characteristics of current and voltage as an ultimate objective function of soldering, we optimize manufacturing conditions in the automated soldering process.

2. SN Ratio for Current and Voltage Characteristics

For calculating the SN ratio (Table 1), we set up a sectional area of solder, M^*, to a three-level signal factor for a production-related signal, and voltage to a four-level signal factor for a soldering-function-related signal. We measured continuously the current corresponding to the incrementing voltage.

As the noise factor, we separated the factor levels to those needing a lot of energy for soldering and those needing little, then compounded them. For experimentation, we designed and fabricated test pieces. A test piece had a certain cross-sectional area and a compounded noise factor condition. Based on the data in Table 2, we proceeded with our calculation of the SN ratio for the voltage and current characteristics as follows.

Total variation

$$S_T = 18^2 + 16^2 + \cdots + 178^2 = 241{,}073 \qquad (f = 24) \tag{1}$$

Linear equations:

$$L_1 = (5)(15)(18) + \cdots + (20)(62)(192) = 796{,}540 \tag{2}$$

$$L_2 = 737{,}770 \tag{3}$$

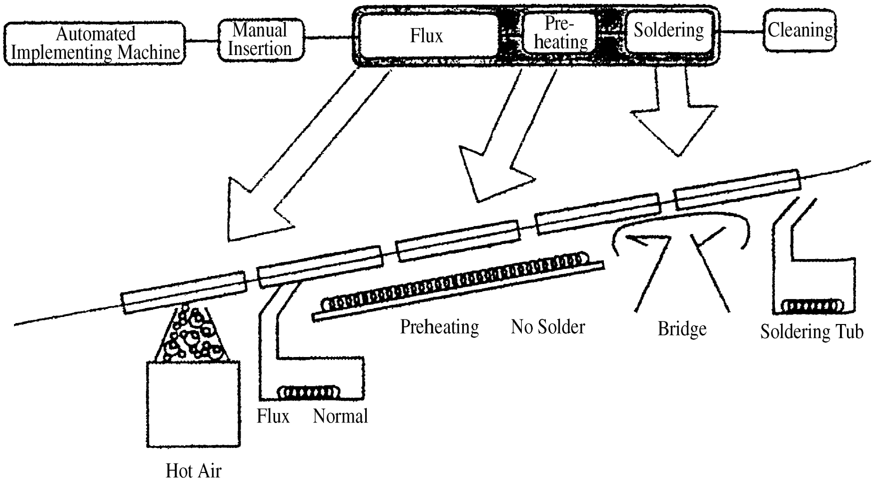

Figure 1
Automated soldering process

Effective divider:

$$r = [(5)(15)]^2 + [(5)(50)]^2 + [(5)(62)]^2 + \cdots + [(20)(62)]^2 = 4{,}926{,}750 \quad (4)$$

Variation of proportional term:

$$S_\beta = \frac{(L_1 + L_2)^2}{2r} = 238{,}910.76 \qquad (f_\beta = 1) \quad (5)$$

Variation due to proportional terms:

$$S_{N\beta} = \frac{L_1^2 + L_2^2}{r} - S_\beta = 350.53 \qquad (f_{N\beta} = 1) \quad (6)$$

Error variation:

$$S_e = S_T - S_\beta - S_{N\beta} = 1811.71 \qquad (f_e = 22) \quad (7)$$

Error variance:

$$V_e = \frac{S_e}{f_e} = \frac{1811.71}{22} = 82.35 \quad (8)$$

Total error variance:

$$V_N = \frac{S_{N\beta} + S_e}{1 + 22} = \frac{350.53 + 1811.71}{23} = 94.01 \quad (9)$$

SN ratio:

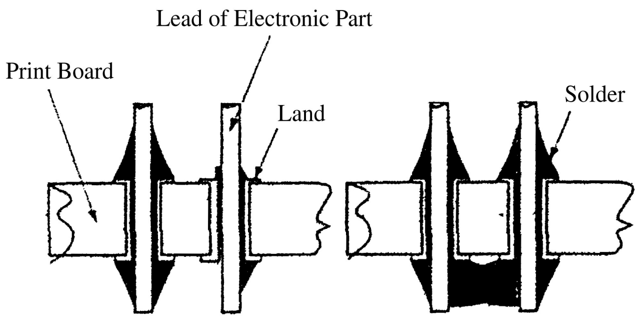

Figure 2
No-solder and bridge

Table 1
Signal and noise factors

Factor	Level 1	Level 2	Level 3	Level 4
Signal factors				
Sectional area M^* ($\times 10^{-1}$ mm^2)	15	50	62	—
Voltage M (mV)	5	10	15	20
Noise factor				
Energy demand	Much N_1		Little N_2	
Pattern interval of motherboard	Narrow		Wide	
Number of motherboard layers	Many		One	

Table 2
Current data (dB $\times$ 10^{-2} A)

Sectional Area:		M_1^* (15)		M_2^* (50)		M_3^* (62)	
	Noise:	N_1	N_2	N_1	N_2	N_1	N_2
Voltage	M_1 (5)	18	16	44	42	61	55
	M_2 (10)	33	28	84	79	118	105
	M_3 (15)	44	38	116	112	163	145
	M_4 (20)	52	47	143	138	192	178

Table 3
Control factors and levels

Control Factor	Level 1	Level 2	Level 3
A: amount of flux air flow	1.5	Current	—
B: specific gravity of flux	−0.01	Current	+0.01
C: opening of flux air knife	Fully closed	Half closed	Fully open
D: distance between solder and board	Close	Mid	Far
E: wave height	Low	Mid	High
F: solder temperature	Low	Mid	High
G: preheating temperature	Low	Mid	High
H: conveyor speed	Slow	Mid	Fast

$$\eta = 10 \log \frac{(1/2r)(S_\beta - V_e)}{V_N} = -35.89 \text{ dB} \quad (10)$$

Sensitivity:

$$S = 10 \log \frac{1}{2r}(S_\beta - V_e) = -16.16 \text{ dB} \quad (11)$$

3. Optimal Configuration and Confirmatory Experiment

As control factors we chose several production-related variables (Table 3), and allocated them to an L_{18} orthogonal array. Since three control factors, solder temperature, preheating temperature, and conveyor speed, are energy-related factors, mutual interaction between them is assumed to exist. In other words, if we set the levels of these factors independently, we cannot provide adequate energy to each factor–level combination (Figure 3). Thus, as a result of studying levels along energy contours, we used a sliding-level method (Figure 4 and Table 4). According to the result in the L_{18} orthogonal array, we calculated an SN ratio and sensitivity for each experiment. Their response graphs are shown in Figure 5.

Table 5 shows the estimates of the SN ratio under the current and optimal configurations. The fact that the gains in the confirmatory experiment were consistent with those estimated demonstrates success in our experimental process. Next, we calculated the gains obtained by the loss function. Assuming that the resulting social loss when the function reaches its limitation, A_0, is 50,000 yen, we have

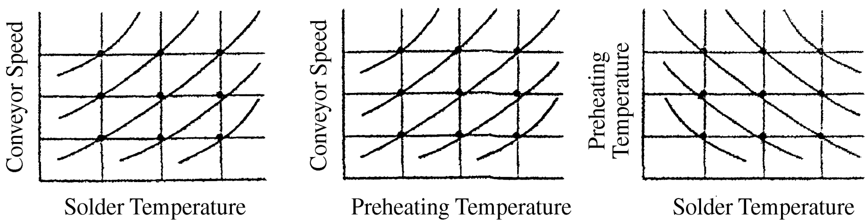

Figure 3
Energy balance by combination of solder temperature, conveyor speed, and preheating temperature

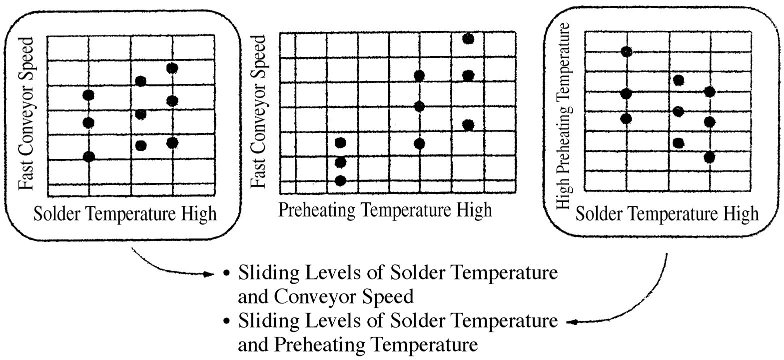

Figure 4
Selection of values at factor levels for soldering by sliding-level method

Table 4
Relative factor levels for solder temperature

Solder Temperature	Conveyor Speed			Preheating Temperature		
	G_1 Slow	G_2 Mid	G_3 Fast	G_1 Low	G_2 Mid	G_3 High
F_1: low	0.63	0.9	1.125	90	120	160
F_2: mid	0.7	1.0	1.25	70	100	130
F_3: high	0.742	1.06	1.325	40	90	120

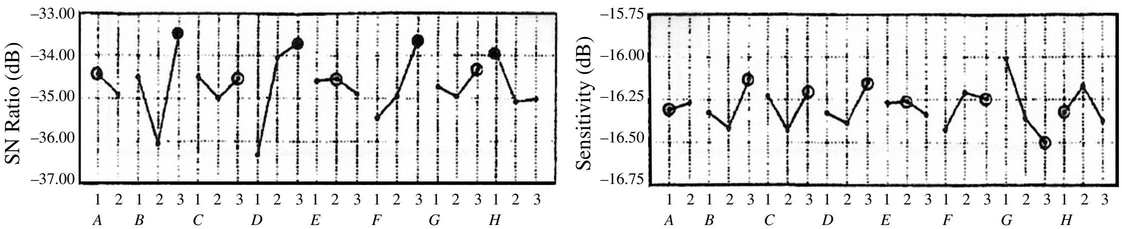

Figure 5
Response graphs

$$L_0 = k\sigma^2 = \frac{50{,}000}{(60.2^2)(2951.9)(3000)} = 122.2 \text{ million yen} \qquad (12)$$

$$L_1 = k\sigma_1^2 = \frac{50{,}000}{(60.2^2)(935.4)(3000)} = 38.7 \text{ million yen} \qquad (13)$$

Thus, our improvement will result in a benefit of $L_0 - L_1 = 83.5$ million yen/month.

Table 5
Results of confirmatory experiment

	Configuration		
	Optimal	Current	Gain
Estimation	−30.70	−36.09	5.39
Confirmation	−29.71	−34.70	4.99

Reference

Shinichi Kazashi and Isamu Miyazaki, 1993. Process optimization of wave soldering by parameter design. *Quality Engineering,* Vol. 1, No. 3, pp. 22–32.

This case study is contributed by Shinichi Kazashi.