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REDUCTION OF DEFECTS IN WAVE SOLDERING PROCESS

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Key Words

Tuner; Uncontrollable factor; Dry solder; Oxidized PCB; Shorting; Orthogonal array.

Introduction

A company is engaged in manufacturing tuners for use in color televisions. Electronic circuits are assembled on printed circuit boards (PCBs). The bare PCB is first dip soldered, and after passing through assembly lines, they are wave soldered. This method of automatic wave soldering is preferred over hand soldering because it offers a higher rate of production along with a uniform quality of solder. A high rate of production is achieved because of simultaneous soldering of all joints on the board and simultaneous soldering of more than one board. A uniform quality of solder is achieved because soldering takes place under nearly identical conditions. The two major defects noticed are shorting and dry solder.

Background

One study on optimization of process parameters was conducted some time earlier with respect to a certain design of tuners. Since the design of the PCB has been changed, it had been expressed by the shop-floor people that the quality of soldering was poor in spite of maintaining the optimum levels. In fact, around 60–70 dry-solder defects and 10–15 shorting defects were observed per 10 tuners. To rectify these defects, six workers had to be engaged to keep up with the current rate of production. Because rework was expensive, to avoid the recurrence of the defects, frequent adjustment of process parameters had to be made on a trial-and-error basis by the concerned production personnel. Thus, there was a need to study the process and to arrive again at the optimum conditions of the process parameters under the changed scenario.

Objective

The aim of this study was to arrive at suitable levels of the process parameters involved in the wave soldering process so as to minimize the incidence of defects.

Approach

Study of Existing Process

In the conventional method, the production person used to make a number of trials by changing the process parameters that he/she suspected to be an influence. In practice, this type of trial-and-error approach usually takes a long time to arrive at a reasonably satisfactory level of performance.

The main drawback of the approach is the lack of insight into possible interactive effects of different parameters and therefore varying only one parameter at a time while trying to keep others at a constant level may not lead to best levels of the parameters. Thus, a systematic and scientific experimental approach was necessary and the same was adopted to get a comprehensive picture for the factors/interactions affecting the quality of wave soldering and thereby to arrive at a suitable combination of the process parameters.

Experiment

After discussions with the concerned technical personnel of the wave soldering process, the following factors and levels were chosen.

Controllable Factors

The controllable factors are presented in Table 1. Suspected interactions are A × B, D × E, D × G, and F × G.

Uncontrollable Factor

The PCB quality was taken as an uncontrollable factor and kept in the outer array. It had two levels:

1. Nonoxidized PCBs, where the PCB pack was opened and chip-mounted within 2 days
2. Oxidized PCBs, where the PCB pack was opened for 3–10 days and then chip-mounted.

In usual practice, the PCBs used to be opened and sent to the chip-mounting process. The time varied anywhere between 2 and 10 days to get them chip-mounted. The personnel expressed serious concern that the PCBs might be oxidized during this period, and as a result, the quality of soldering was poor. Because this variation of time was not easily controllable, PCB quality was treated as a noise factor, with the above two levels.

Table 1. Controllable Factors

CODE	FACTOR	LEVEL 1	LEVEL 2	UNIT
A	Flux specific gravity	0.80	0.78	—
B	Foam pressure	0.20	0.15	kg/cm^2
C	Blower heater temperature	215	210	°C
D	Preheater temperature	80	75	°C.
E	Solder bath temperature	230	225	°C
F	Wave height	11.5	11.0	mm
G	Conveyor speed	1.75	1.65	m/min
H	Direction of PCB	Existing	Reverse	—
I	Jig height	High	Low	—

Experimental Design and Response

Because there are nine factors and four interactions had to be studied, the experiment was designed using an L_{16} orthogonal array layout. The defects recorded as response are dry solder and shorting. Table 2 shows the experimental layout and Table 3 shows the data on the number of defects under each experimental combination.

Analysis

To facilitate the analysis of data on the number of defects, they are first transformed into $\sqrt{(x)}$, where x is the number of defects in 10 tuner cards under each experimental condition. Because the quality of PCBs had been considered as an uncontrollable factor, the data at both levels of the uncontrollable factor were involved in combining into a single statistics of performance measure $Z(y_1, y_2)$ calculated as follows:

$$Z(y_1, y_2) = -10 \log_{10} \sum y_i^2/n;$$

here, $i = 1, 2$, $n = 2$, $y_i = \sqrt{(x_i)}$, and x_i is the number of defects in 10 cards at the ith level of the uncontrollable factor. Maximization of $Z(y_1, y_2)$ helps reduce the average and variability together. Thus, Z is taken as the analytical response in our experiment.

The value of the statistics of performance measure $Z(y_1, y_2)$ was evaluated for each of the 16 experimental combinations of the controllable factors. The experimental data thus transformed were analyzed using analysis of variance and are shown in Tables 4 and 5 for dry solder and shorting defects, respectively.

From Tables 4 and 5 and based on the average response (Z) curves in Figures 1 and 2, the best combinations for dry solder defect and shorting defect become

D2 F1 G1 H1 and A1 B2 C2 D1 E1 F2 G2 H2 I1,

respectively. So, it is observed that for the best levels dry solder and shorting are not the same. The purpose is to choose a combination which will be optimum with respect to dry solder as well as shorting. Thus, a trade-off was made by noting the criticality of the defects and giving preference to the minimization of critical defects.

It is known from the concerned engineers that the dry solder defect is more severe than the shorting defect, because when the operator rectifies the dry solder defect, it gives a thermal shock to the PCB that might affect it adversely. Hence, the best combination was determined by giving priority to the minimization of the dry solder defect. Thus, the

Table 2. Experimental Layout

SL NO./ COL. NO.	A (4)	B (11)	C (5)	D (1)	E (6)	F (8)	G (2)	H (9)	I (12)
1	0.80	0.2	210	80	230	11	1.75	E[a]	Low
2	0.80	0.15	210	80	230	11.5	1.75	R[a]	High
3	0.78	0.2	215	80	225	11	1.75	E	High
4	0.78	0.15	215	80	225	11.5	1.75	R	Low
5	0.80	0.15	210	80	225	11	1.65	E	Low
6	0.80	0.2	210	80	225	11.5	1.65	R	High
7	0.78	0.15	215	80	230	11	1.65	E	High
8	0.78	0.2	215	80	230	11.5	1.65	R	Low
9	0.80	0.15	215	75	230	11	1.75	R	Low
10	0.80	0.2	215	75	230	11.5	1.75	E	High
11	0.78	0.15	210	75	225	11	1.75	R	High
12	0.78	0.2	210	75	225	11.5	1.75	E	Low
13	0.80	0.2	215	75	225	11	1.65	R	Low
14	0.80	0.15	215	75	225	11.5	1.65	E	High
15	0.78	0.2	210	75	230	11	1.65	R	High
16	0.78	0.15	210	75	230	11.5	1.65	E	Low

[a]E denotes existing direction; R denotes reverse direction.

Table 3. Experimental Data

EXP. NO.	NO. OF DRY SOLDER UNDER LEVEL 1 OF UNCONTROLLABLE FACTOR	NO. OF DRY SOLDER UNDER LEVEL 2 OF UNCONTROLLABLE FACTOR	NO. OF SHORTING UNDER LEVEL 1 OF UNCONTROLLABLE FACTOR	NO. OF SHORTING UNDER LEVEL 2 OF UNCONTROLLABLE FACTOR
1	36	57	7	12
2	68	43	8	12
3	26	58	10	8
4	68	58	12	8
5	33	42	13	4
6	53	57	6	6
7	45	41	6	11
8	42	60	5	1
9	44	38	5	2
10	42	32	12	13
11	42	48	17	13
12	44	32	15	17
13	47	46	13	16
14	37	51	11	16
15	43	60	15	15
16	29	50	10	15

Table 4. Analysis of Variance (for Dry Solder)

SOURCE	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	*F*-RATIO
A	1	0.04730	0.04730	—
B	1	0.00047	0.00047	—
C	1	0.00090	0.00090	—
D	1	1.30235	1.30235	18.18[a]
E	1	0.00937	0.00937	—
F	1	0.34854	0.34854	4.86[b]
G	1	0.00437	0.00437	—
H	1	3.52107	3.52107	49.14[a]
I	1	0.07986	0.07986	—
A × B	1	0.10423	0.10423	—
D × E	1	0.03090	0.03090	—
D × G	1	0.92291	0.92291	12.88[a]
F × G	1	0.00709	0.00709	—
Pooled residue	(11)	(0.78811)	(0.07165)	
Total	15	6.88298		

[a] $F_{1,11;0.01} = 9.65$; significant at 1% level of significance.
[b] $F_{1,11;0.05} = 4.84$; significant at 5% level of significance.

Table 5. Analysis of Variance (for Shorting)

SOURCE	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	*F*-RATIO
A	1	0.97993	0.97993	—
B	1	0.00238	0.00238	—
C	1	6.82527	6.82527	13.23[a]
D	1	14.81826	14.81826	28.72[a]
E	1	6.70134	6.70134	12.99[a]
F	1	0.02632	0.02632	—
G	1	0.47042	0.47042	—
H	1	6.32731	6.32731	12.26[a]
I	1	4.52075	4.52075	8.76[b]
A × B	1	4.01179	4.01179	7.77[b]
D × E	1	1.44229	1.44229	—
D × G	1	11.58269	11.58269	22.45[a]
F × G	1	11.60538	11.60538	22.49[a]
Pooled residue	(7)	(3.61159)	(0.51594)	
Total	15	70.00437		

[a] $F_{1,7;0.01} = 12.25$; significant at 1% level of significance.
[b] $F_{1,7;0.05} = 5.59$; significant at 5% level of significance.

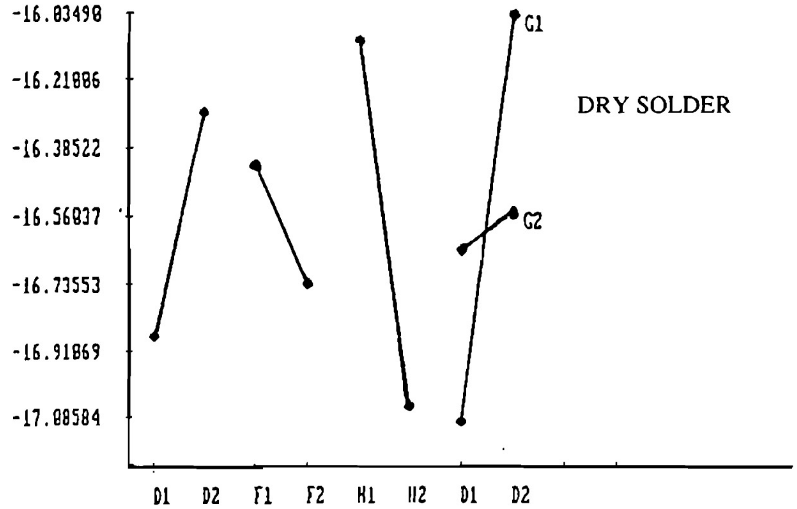

Figure 1. Average response curve for dry solder.

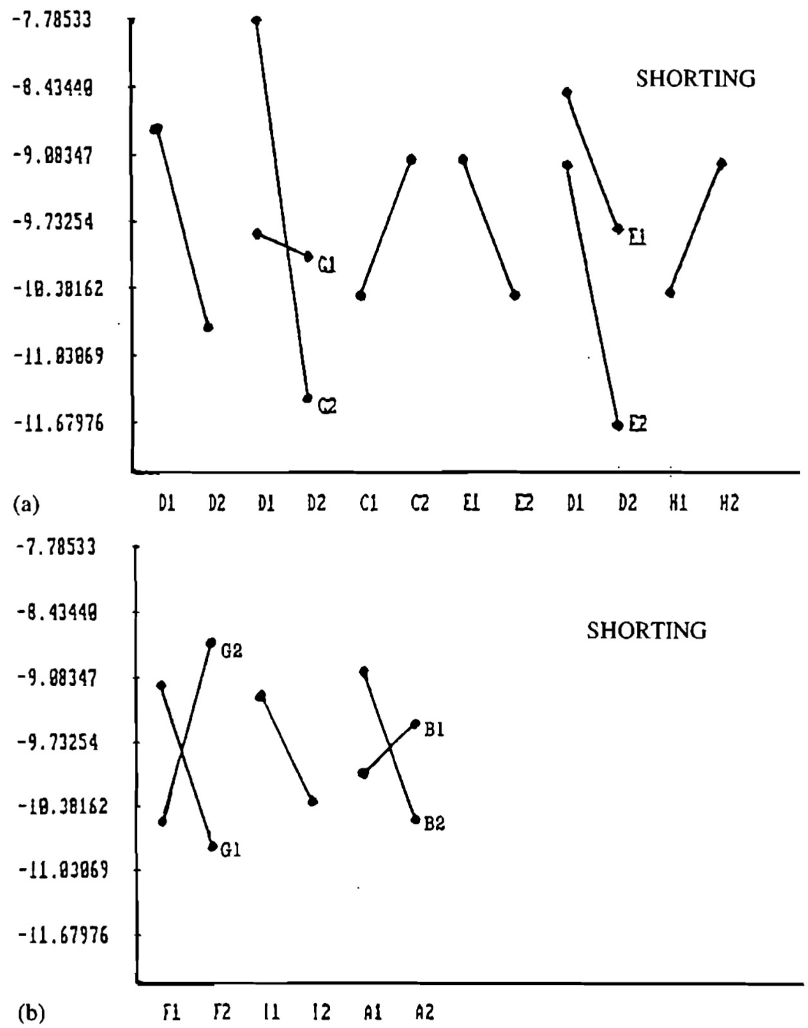

Figure 2. Average response curves for shorting.

best combination was A1 B2 C2 D2 E1 F1 G1 H1 I1. This combination does not belong to the set of experimental combinations that were tried. So, the expected performance of this best combination had been predicted in the following manner.

Expected Number of Defects Under Best Combination

The expected number of defects under best combination was determined as follows:

Dry Solder

The best combination for dry solder was determined to be D2 G1 F1 H1. So,

$$
\begin{aligned}
Z_{\text{best}} &= \bar{T} + (\overline{D2} - \bar{T}) + (\overline{D2\,G1} - \overline{D2} - \overline{G1} + \bar{T}) \\
&\quad + (\overline{F1} + \bar{T}) + (\overline{H1} - \bar{T}) \\
&= \overline{D2\,G1} - \overline{G1} + \overline{F1} + \overline{H1} - \bar{T} \\
&= (-16.03490) - (-16.56037) + (-16.42930) \\
&\quad + (-16.10778) - (-16.57689) \\
&= -15.43472.
\end{aligned}
$$

Thus, the expected number of dry solder defects in 10 cards is predicted as follows:

$$-10 \log_{10} \sum \frac{y_i^2}{n} = -15.43472$$

or

$$\log_{10} \sum \frac{y_i^2}{n} = 1.543472$$

or

$$\tfrac{1}{2}(y_1^2 + y_2^2) = 10^{1.543472} = 34.95$$

or

$$\tfrac{1}{2}(x_1 + x_2) = 34.95,$$

or

$$x = 34.95$$

which can be taken as 35.

Shorting

The final combination for the shorting defect was determined to be A1 B2 C2 D2 E1 F1 G1 H1 I1. So,

$$
\begin{aligned}
Z_{\text{best}} &= \bar{T} + (\overline{A1\,B2} - \overline{A1} - \overline{B2} + \bar{T}) + (\overline{C2} - \bar{T}) \\
&\quad + (\overline{D2} - \bar{T}) + (\overline{E1} - \bar{T}) + (\overline{H1} - \bar{T}) + (\overline{I1} - \bar{T}) \\
&\quad + (\overline{D2\,G1} - \overline{D2} - \overline{G1} + \bar{T}) + (\overline{F1\,G1} - \overline{F1} - \overline{G1} + \bar{T}) \\
&= (\overline{A1\,B2} + \overline{C2} + \overline{E1} + \overline{H1} + \overline{I1} + \overline{D2\,G1} + \overline{F1\,G1}) \\
&\quad - (\overline{A1} + \overline{B2} + 2\overline{G1} + \overline{F1} + \bar{T}) \\
&= (-9.52892) + (-9.11686) + (-9.12282) \\
&\quad + (-10.39884) + (-9.23844) + (-10.05298) \\
&\quad + (-9.13035) - (-9.52251) - (-9.75780) \\
&\quad - (-19.88292) - (-9.81055) - (-9.76999) \\
&= (-66.58921) - (-58.74377) \\
&= -7.84544
\end{aligned}
$$

Thus, the expected number of shorting defects in 10 cards is predicted as follows:

$$-10 \log_{10} \sum \frac{y_i^2}{n} = -7.84544$$

or

$$\log_{10} \sum \frac{y_i^2}{n} = 0.784544$$

or

$$\tfrac{1}{2}(y_1^2 + y_2^2) = 10^{0.784544} = 6.08897$$

or

$$\tfrac{1}{2}(x_1 + x_2) = 6.08897$$

or

$$x = 6.08897,$$

which can be taken as 6.

Confirmatory Trial

Under the best levels that have been determined, a confirmatory trial, based on 10 tuner cards, was made. Both oxidized as well as nonoxidized PCB boards were used. The result obtained with this combination is as follows:

	Actual	Predicted
No. of dry solder defects:	38	35
No. of shorting defects:	5	6

Thus, the confirmatory trial has shown that the actual results do favorably agree with the predictions made.

Conclusion

Thus, using a systematic approach, the best levels of the various factors for the wave soldering process had been ob-

Table 6. Best Combination of Process Parameters

CODE	FACTOR	BEST LEVEL
A	Flux specific gravity	0.8
B	Foam pressure	0.15 kg/cm^2
C	Blower heater temperature	210 °C
D	Preheater temperature	75 °C
E	Solder bath temperature	230 °C
F	Wave height	11.5 mm
G	Conveyor speed	1.75 m/min
H	Direction of PCB	Existing
I	Jig height	High

tained so as to reduce the soldering defects. The best combination of process parameters thus arrived at is given in Table 6.

Implementation

The above parametric combination in Table 6 had been implemented in the shop floor after incorporating the same as their process standard. Due to the introduction of this standard as a regular practice, the extent of rework had been reduced to the extent of 40%.

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