Jurnal Mekanikal, Jilid II, 1999

CHARACTERIZATION OF A WAVE SOLDERING PROCESS USING TAGUCHI METHOD

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ABSTRACT

This paper outlines the Taguchi methodology as an approach to identify the "optimal" wave soldering machine parameter setting that has significant effect on a key quality characteristic of interest, namely, soldering defects per unit(SDPU). The method is briefly discussed and its application is illustrated by an industrial case study as an example. Several machine controllable factors were investigated as to their effect on the SDPU. The result of the study shows an improvement of up to 70 percent of SDPU. Its potential in cost savings is thus apparent.

Keywords: *Wave Soldering Process, Design of Experiments (DOE), Taguchi Method, Analysis of Variance (ANOVA)*

1.0 INTRODUCTION

The process of manufacturing and assembly of electronic components in an electronic company have been very competitive. Everyone believes in quality. Today, equipped with better and higher technology, more complex designs are required and better quality is expected. In other words, quality plays a prominent role in any kind of manufacturing industry. Continuous quality improvement is the only path to increase customer satisfaction, market share and profit and also to ensure the survival of any business.

The objectives of the this study were:

1. To determine optimal combination of wave soldering machine parameter setting that gives the least SDPU.
2. To establish the significant machine parameter settings and their levels
3. To verify the optimal combination of machine parameter setting

The study is limited to the examination of control circuit board assembly that has to go through wave soldering process. The model 28 DU-OK1 is selected in this case study. The numerical index for calculating SDPU is based on part-per-milion(PPM) Pareto defect analysis. This industrial case study was conducted at an electronic manufacturing company in Senai, Johor.

2.0 PROBLEM IDENTIFICATION

For the case study, the product that had the highest amount of defects based on PPM will be selected. Figure 1 shows the value of PPM for various high demand models for a period of six months.

The graph above shows that model 28 DU-OKI has the highest PPM value after soldering process. Therefore the model 28 DU-OKI is selected based on Pareto analysis.

The rejected quantity from a process is measured in terms of PPM. The calculation of the PPM is illustrated below :

Example : Model 28 DU

No. of solder points per PCB = 92

Monthly production of PCB = 1128

$$\text{Total defect points} = 30$$

$$\therefore \text{PPM} = \frac{\text{defects per month}}{\text{total components}} \times 1{,}000{,}000 = \frac{30}{92 \times 1128} \text{ x } 10^6$$

$$= 289$$

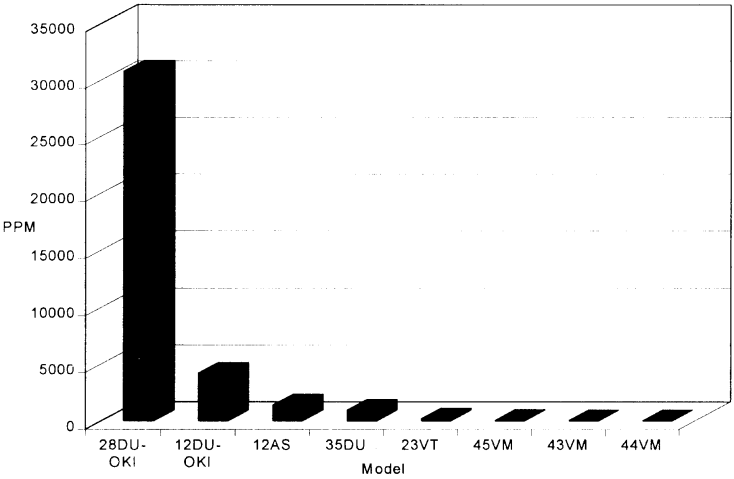

Figure 1 PPM values for various models of circuit board assembly

In order to identify the major defects, data from check sheets were analyzed using Pareto diagram as shown in Figure 2.

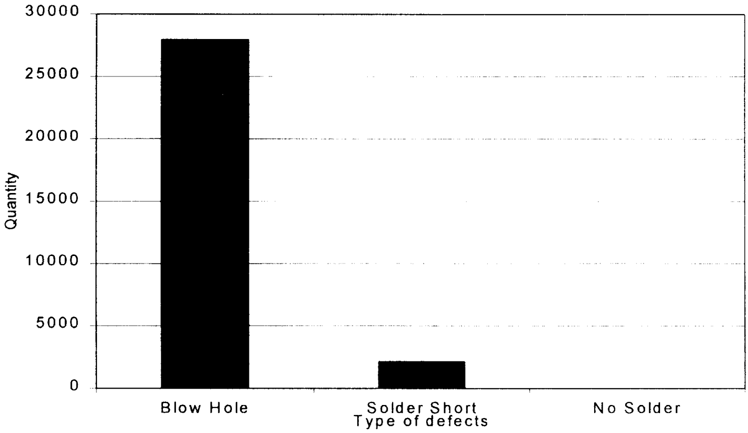

Figure 2 Quantity of defect for different types of defect

From the chart, it can be seen that the major causes that contributed to the high number of defects are blow holes, solder short and no solder.

The next step is to construct cause and effect diagram to determine the most likely cause. This activity is accomplished through several brainstorming sessions and literature study[1]. The results of the activity to determine the causes of solder short defect as an example is shown in Figure 3.

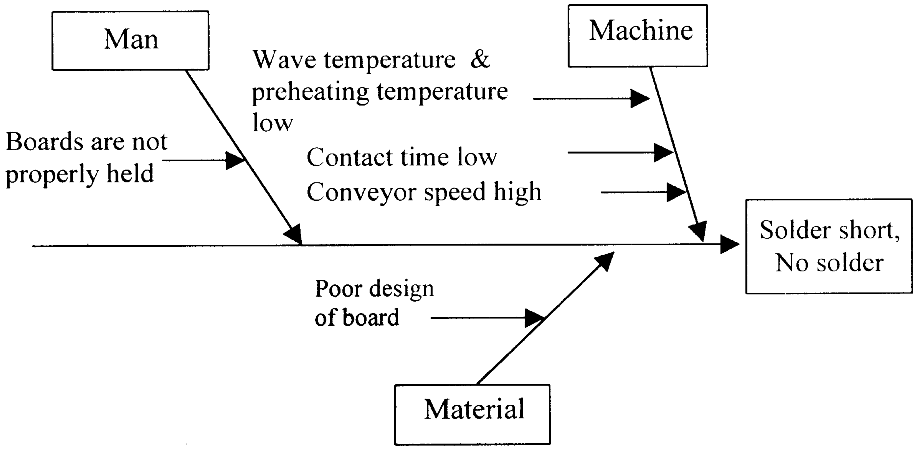

Figure 3 Cause and effect diagram for solder short and no solder defect

3.0 TAGUCHI METHODOLOGY

The main purpose of experimental design technique is identifying sources of variation and determining design and process characterization. To achieve a successful experiment and reproducible results, the following steps will be followed [2].

3.1 Objective / Goal of the Experiment

The objective of the experiment was to determine the most significant factors and its level affecting a critical quality characteristic and subsequently to reduce the soldering defects.

3.2 Selection of the Output Response

Having identified the objective of the experiment, the next step was to identify an appropriate response for the experiment. The response of interest here is the PPM value.

3.3 Selection of Controllable Factors and its Interactions

Selection of factors and their interactions was achieved by a thorough brainstorming session with people from production, quality control and shop floor.

Six control factors and one interaction were thought to have some impact on the PPM value. These six control factors and the interaction are :

i) Conveyor Speed (A)
ii) Contact Time (B)
iii) Wave Temperature (C)
iv) Preheater #1 and #2 (D)
v) Preheater #3 (E)
vi) Preheater #4 (F)
vii) Interaction AB

3.4 Selection of Number of Levels

It was then decided to consider two levels for each of these factors for conducting the experiment. The details of these factors and their levels are presented in Table 1.

Table 1. List of control factors and levels for the case study

Factors	**Labels**	**Units**	**Level 1**	**Level 2**
Conveyor speed	A	m/min	0.5	0.6
Contact time	B	sec	3	4
Conveyor speed * Contact time	A*B	-	dummy	dummy
Wave temperature	C	°C	245	255
Preheater #1 & #2	D	°C	365	370
Preheater #3	E	°C	370	375
Preheater #4	F	°C	380	385

3.5 Selection of OA

The choice of an OA depends on the number of degrees of freedom required for studying the main and interaction effects[3]. As six factors (each at two levels) and interaction AB are to be studied, the total number of degrees of freedom required for the experiment is seven.

Therefore, the closest number of experimental trails (from the standard OAs) is an L_8 OA.

3.6 Assignment of Factors and Interaction

Based on the linear graph in Figure 4, each main factor and the interaction AB is assigned to the appropriate column in the selected OA as shown in Table 2.

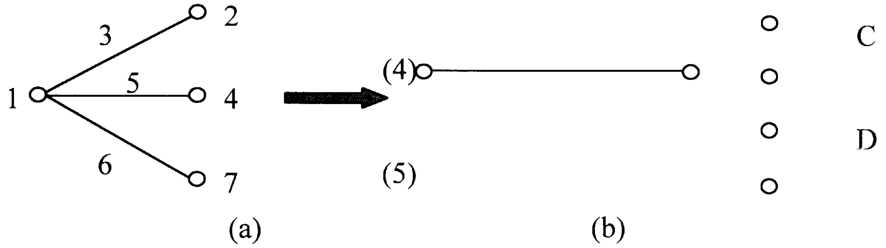

Figure 4 Selecting suitable linear graph; (a) standard linear graph; (b) modified linear graph

Table 2 Assigned OA for the case study

Treatment Conditions	Factors						
	A	B	A*B	C	D	E	F
1	1	1	1	1	1	1	1
2	1	1	1	2	2	2	2
3	1	2	2	1	1	2	2
4	1	2	2	2	2	1	1
5	2	1	2	1	2	1	2
6	2	1	2	2	1	2	1
7	2	2	1	1	2	2	1
8	2	2	1	2	1	1	2

3.7 Conducting Experiment

Having constructed the design matrices, the next step was to run the experiment according to the prepared matrix.

The experiment was conducted based on the design matrix and the response values were recorded on a data sheet for analysis. The resulting response table is shown in Table 3.

Table 3 Output response table

Treatment Conditions	Factors							Total	Average
	A	B	A*B	C	D	E	F		
1	1	1	1	1	1	1	1	25	1.25
2	1	1	1	2	2	2	2	38	1.9
3	1	2	2	1	1	2	2	54	2.7
4	1	2	2	2	2	1	1	52	2.6
5	2	1	2	1	2	1	2	36	1.8
6	2	1	2	2	1	2	1	18	0.9
7	2	2	1	1	2	2	1	25	1.25
8	2	2	1	2	1	1	2	37	1.85

4.0 RESULTS ANALYSIS AND DISCUSSION

4.1 Response Graph

Based on the output response table in Table 3, the effect of each factor and its level are calculated as follows :

$$\overline{A}_1 = (1.25 + 1.9 + 2.7 + 2.6)/4 = 2.12$$

$$\overline{A}_2 = (1.8 + 0.9 + 1.25 + 1.85)/4 = 1.45$$

Values from the preceding calculations are placed in an average response table, as shown in Table 4. The absolute difference, Δ, between level 1 and level 2 is calculated and placed in the table.

Table 4. Average response values and effect of factors

Factors	**Mean response at Level 1**	**Mean response at Level 2**	**Effect**
A	2.12	1.45	0.67
B	1.46	2.10	0.64
A*B	1.56	2.00	0.44
C	1.75	1.81	0.06
D	1.68	1.89	0.21
E	1.88	1.69	0.19
F	1.50	2.06	0.56

Having computed the estimates of the factor effects, it was decided to construct a main effects plot for the factors. A main effects plot will provide a visual presentation of the importance of the factor effects. Figure 5 illustrates the main effects plot for the factors.

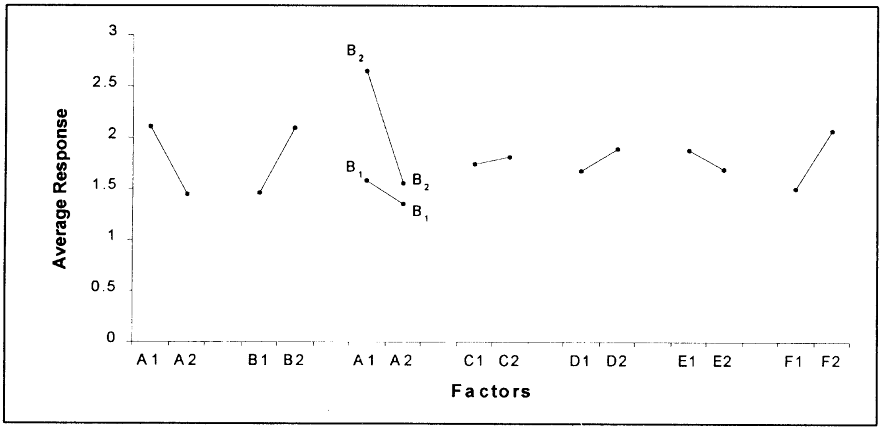

Figure 5 Response graph for the average for soldering

Another way of estimating the factor effects is by using a simple rule as a guideline to analyze which of the factors has a strong effect on the process and which is merely a natural variation. The largest difference, which in this case is 0.67 is taken, and then divided in half, to give 0.335. All differences equal to or above 0.335 are considered to be strong effects.

Therefore, using the one-half guideline and also from the main effects plot, it is found that the strong effects are A, B, F and interaction AB. This will be followed by factors D, E and C.

The interaction is plotted to determine the level for those factors involved in the interaction. Using the results in Table 3, the calculations are

$A_1B_1 = (1.25 + 1.9)/2 = 1.58$

$A_1B_2 = (2.7 + 2.6)/2 = 2.65$

$A_2B_1 = (1.8 + 0.9)/2 = 1.35$

$A_2B_2 = (1.25 + 1.85)/2 = 1.55$

These values are plotted in Figure 5. Analysis of the AB interaction shows that A_2 and B_1 give the best interaction results.

4.2 Analysis of Variance (ANOVA)

In order to obtain the statistical significance of the effects, ANOVA for the mean response was performed. The ANOVA table and the pooled ANOVA table are shown in Table 5 and Table 6 respectively. Pooling is a method of combining the effects with low sum of squares in magnitude in order to obtain a reasonable estimate of the error variance. The rule of thumb is to pool the effects with low sum of squares until the error degrees of freedom is nearly half the total degrees of freedom .

Table 5. ANOVA Table

Factors	**df**	**Sum of Squares (SS)**	**Variance (V)**	**F-Ratio (F)**	**Pure Sum of Squares (SS')**	**Percent Contribution P (%)**
A	1	0.877	0.877		0.877	30.534
B	1	0.812	0.812	-	0.812	28.273
A*B	1	0.382	0.382	-	0.382	13.316
C	1	0.007	0.007	-	0.007	0.271
D	1	0.090	0.090	-	0.090	3.141
E	1	0.070	0.070	-	0.070	2.445
F	1	0.632	0.632	-	0.632	22.012
Other / Error, *e*	0					13.653
Total	7	2.874				100.00

Table 6. Pooled ANOVA

Factors	df	Sum of Squares (SS)	Variance (V)	F-Ratio (F)	Pure Sum of Squares (SS')	Percent Contribution P(%)
A	1	0.877	0.877	15.634 **	0.821	28.589
B	1	0.812	0.812	14.476 **	0.756	26.328
A*B	1	0.382	0.382	6.818*	0.326	11.366
C	(1)	(0.007)	Pooled	-	-	-
D	(1)	(0.090)	Pooled	-	-	-
E	(1)	(0.070)	Pooled	-	-	-
F	1	0.632	0.632	11.27**	0.576	20.064
Other / Error, *e*	3	0.167	0.055			13.653
Total	7	2.874				100.00

Note : $F_{0.1,1,3} = 5.5383$ and $F_{0.05,1,3} = 10.128$.

** shows that a factor is significant at 90 per cent and 95 per cent confidence levels,

* shows that a factor is significant at 90 per cent confidence levels (α).

The ANOVA table shown that the most dominant factor effects are main effects A, B, F and interaction AB. Having identified the significant factor effects, the next step was to determine the optimal settings of these factors which will bring the mean response as close as possible to the target. The optimal condition based on the mean response (refer to Figure 5) is :

$A_2\ B_1\ C_1\ D_1\ E_2\ F_1$

4.3 Confirmation Experiment

A confirmation run was carried out to check the reproducibility and prediction of result. A confirmation experiment is essential before making a change to the manufacturing process based on the results of a robust design experiment. The experiment was run at settings $A_2\ B_1\ C_1\ D_1\ E_2\ F_1$.

The following result was achieved :

No. of solder points per PCB = 92

Monthly production of PCB = 8628

Total defect points = 71

$$\therefore \ \text{PPM} = \frac{\text{defects per month}}{\text{total components}} \times 1{,}000{,}000 = \frac{71}{92 \times 8628} \times 1{,}000{,}000$$

$$= 89.45$$

The value of PPM has been reduced, though it is still above 50 PPM. It should be noted that other factors such as noise factors have not been considered in this study.

5.0 CONCLUSION

A project aimed at improving the quality level of an electronic manufacturing company was carried out. The major problem selected was the high rejects from the solder plant. The Model 28 DU-OKI was selected for the project.

The problem was solved using the Taguchi Methodology in order to increase the quality level. Through this industrial case study, the SDPU for the selected model has been reduced from 289 PPM to 89 PPM.

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