CASE 92

Semiconductor Rectifier Manufacturing by On-Line Quality Engineering

Abstract: In quality engineering, the optimum controlling conditions are determined by balancing the cost of control and the cost of quality. This approach is effective and widely applicable in all manufacturing processes. This study reports a successful case that was applied to a manufacturing process for semiconductor rectifiers. In the process, the temperature-measuring interval was determined such that the cost was reduced while the quality was maintained, which contributed to customer satisfaction.

1. Introduction

Where lead and pellets are soldered in a semiconductor manufacturing process, we place a product in a heat-treating furnace. Figure 1 outlines a semiconductor manufacturing process. To control the furnace we take a periodic measurement with another temperature recording instrument (Figure 2). However, while the adjustable limits are set the same as in the manufacturing specifications, we have never done a thorough economical study of the checking interval because it had always been determined according to past experience and results. To verify its validity, we applied the concept of feedback control of process conditions from quality engineering.

2. Selection of Parameters for Mounting Process Conditions

By investigating actual situations in the mounting process in our semiconductor manufacturing line, we selected parameters for the case where there was feedback control.

1. *Measurement cost: B* yen. Fifteen minutes is needed to measure the heat-treating furnace. We have

$$\frac{2400 \text{ yen (hourly labor cost)}}{60 \text{ minutes}} \times 15 \text{ minutes} = 600 \text{ yen} \qquad (1)$$

2. *Measurement interval: n* units. The hourly number of heat-treating products is 170,000, and they are measured every eight hours. Thus,

$$(170{,}000)(8) = 1{,}360{,}000 \text{ units} \qquad (2)$$

3. *Adjustment cost: C* yen. Adjustment cost is based on hourly labor cost. Therefore, considering that one hour is required for adjustment, the hourly labor cost is 2,400 yen, and the adjustment needs another measurement, we obtain

$$2400 \text{ yen} + 600 \text{ yen} = 3000 \text{ yen} \qquad (3)$$

4. *Mean adjustment interval: u* units. Over the past year, out-of-tolerance situations occurred approximately once every 100 days after a long-term consecutive holiday (e.g., at the beginning of the year, in the "Golden Week" from April 29 through May 5, in the summertime Bon Festival holidays).Thus, the mean adjustment interval, u, is estimated as follows:

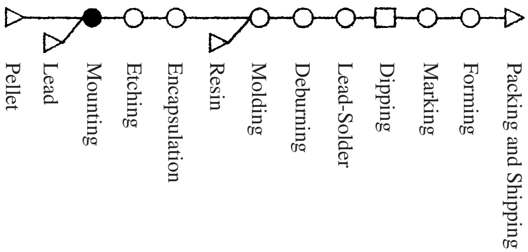

Figure 1
Quality control process chart for semiconductor manufacturing

$$170{,}000 \text{ units (hourly production volume)} \times 2400 \text{ hours} = 408{,}000{,}000 \text{ (units)} \quad (4)$$

5. *Rejected product handling cost:* A yen. We discard rejected products after screening them. Therefore, we need the sum of processing cost, material cost, and screening cost up to the mounting process. In this case, this costs 3 yen per rectifier.
6. *Tolerance of process condition's temperature:* Δ. The temperature range that satisfies the tolerance of the objective characteristic of a semiconductor rectifier $\pm\ \Delta_0$ is $m \pm 10$°C. Thus, the tolerance of process condition's temperature is 10°C.
7. *Adjustable limit:* D_0. The adjustable limit is 5°C).
8. *Measurement time lag:* l. Since the measurement time lag is represented by the number of products manufactured during measurement of the heat-treating furnace, it amounts to 5900 units.

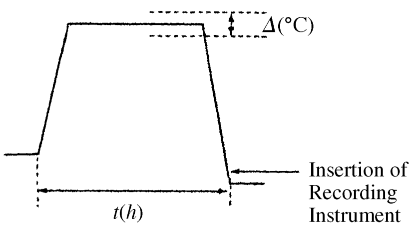

Figure 2
Temperature recording of heat-treating furnace in mounting process

9. *Measurement error variance:* σ_m^2. For the error variance of the temperature-recording instrument, using the formula in JIS Z 8403:1996, *Quality Characteristics of Products: General Rules for Determination of Specific Values*, we computed the value. As the parameters of the measurement error variance, we selected once a year as the checking interval, drift of the measuring instrument within the depreciation period of five years as the correctable limit, D, and 0.5°C as the error of the standard, σ_s:

$$\sigma_m^2 = \frac{D^2}{3} + \frac{n}{2}\frac{D^2}{u} + \sigma_s^2$$

$$= \frac{2^2}{3} + \frac{979{,}200{,}000}{2}\left(\frac{2^2}{4{,}896{,}000{,}000}\right) + 0.5^2$$

$$= 1.98°\text{C} \quad (5)$$

Necessary values for calculating an optimal control system are $A = 3$ yen, $B = 600$ yen, $C = 3000$ yen, $D = 5$°C, $n = 1{,}360{,}000$ units, $l = 5900$ units, $u = 408{,}000{,}000$ units, $\Delta = 10$°C, $\sigma_m^2 = 1.98$°C.

3. Optimization Calculation for Mounting Process

We computed process management parameters according to the definitions in on-line quality engineering.

Current overall loss:

$$L_0 = \frac{B}{n_0} + \frac{C}{u_0} + \frac{A}{\Delta^2}\left[\frac{D_0^2}{3} + \left(\frac{n_0+1}{2} + l\right)\frac{D_0^2}{u_0} + \sigma_m^2\right]$$

$$= \frac{600}{1{,}360{,}000} + \frac{3000}{408{,}000{,}000} + \frac{3}{10^2}\left\{\frac{5^2}{3} + \left[\frac{1{,}360{,}000+1}{2} + 5900\right]\left(\frac{5^2}{408{,}000{,}000}\right) + 1.96^2\right]\right\}$$

$$= 0.000441 + 0.000007 + 0.25 + 0.001261 + 0.117612$$

$$= 0.369 \text{ yen} \quad (6)$$

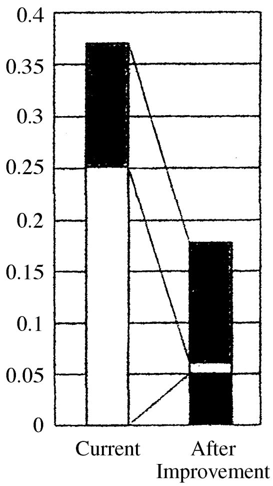

Figure 3
Overall loss for each product in mounting process

Optimal measurement interval:

$$n = \sqrt{\frac{(2)(408{,}000{,}000)(600)}{3}}\left(\frac{10}{5}\right) = 807{,}960 \rightarrow 805{,}000 \text{ units (once per 5 hours)} \qquad (7)$$

Optimal adjustable limit:

$$D = \left[\frac{(3)(3000)}{3}\left(\frac{5^2}{408{,}000{,}000}\right)(10^2)\right]^{1/4} = 0.37°\text{C} \qquad (8)$$

Mean adjustment interval:

$$u = 408{,}000{,}000\left(\frac{0.37^2}{5^2}\right) = 2{,}234{,}208 \text{ units} \qquad (9)$$

The result reveals that the optimal adjustable limit, D, is approximately $\frac{1}{10}$ of the current adjustable limit. Yet, due to unavailability of a comparable high-precision measuring instrument that can meet this level, we decided to set up D = 3°C as a provisional intermediate point between the optimal and current limits.

Using D = 3°C, we determined an improvement measurement and estimated the overall loss:

$$L = \frac{600}{800{,}000} + \frac{3000}{2{,}234{,}208} + \frac{3}{10^2}\left[\frac{3^2}{3}\left(\frac{800{,}000+1}{2} + 5900\right)\left(\frac{3^2}{2{,}234{,}208}\right) + 1.98^2\right]$$
$$= 0.00075 + 0.00134 + 0.009 + 0.0495 + 0.117612$$
$$= 0.178 \text{ yen} \qquad (10)$$

The difference between the current and overall losses is

$$L_0 - L = 0.369 - 0.178 = 0.19 \text{ yen} \qquad (11)$$

The improvement amounts to 0.19 yen per product (Figure 3 and Table 1). On a yearly basis, this turns out to be 18,605 million yen = (0.19)(170,000)(24)(240).

The result that the current loss is beyond the correctable limit and the standard errors are computed to be a considerable amount proves objectively how ambiguous our empirical management values are. In contrast, under the optimal configuration, using a high-precision measuring

Table 1
Current losses versus improvements

	Current	After Improvement
Measurement error variance	0.117612	0.117612
Loss beyond adjustable limit	0.00126	0.00075
Loss within adjustable limit	0.25	0.009
Adjustment loss	0.000006	0.00134
Measurement loss	0.000441	0.04905

instrument, we would be able to obtain an improvement of 0.25 yen per product, which is equal to approximately 88 million yen on a yearly basis. We need to improve or develop the measuring instrument in-house, since such an instrument is not currently available in the marketplace.

Reference

Nobuhiro Ishino and Mitsuo Ogawa, 1999. Study of online QE for manufacturing of the "rectifiers" semiconductor. *Quality Engineering*, Vol. 7, No. 6, pp. 51–55.

This case study is contributed by Nobuhiro Ishino.