CASE 91

Control of Mechanical Component Parts in a Manufacturing Process

Abstract: To evaluate actual dimensional control practices in a manufacturing line, we analyzed them using on-line quality engineering. With the cooperation of several companies, we sampled mechanical component parts that were actually produced in manufacturing lines in accordance with each line's checking interval, and remeasured their dimensions. At the same time, by obtaining actual operation data from companies we attempted to identify inherent problems using on-line quality engineering.

1. Introduction

The following are products that we used and their dimensions. The dimensions that we used for our study are boldfaced.

- *Metal plate* (*thickness*): **2.0** × 10.0 × 20.0 mm
- *Plastic tube A* (*height*): ϕ19.5 × **8.255** mm
- *Plastic tube B* (*height*): ϕ19.3 × **10** mm
- *Metal cap* (*inside diameter*): ϕ**29.55** × 3.9 mm

Using on-line quality engineering, we performed several studies regarding these products and dimensions. Control constants (parameters) related to the analysis were researched by the suppliers.

2. Actual and Loss Function–Based Tolerances

Table 1 compares actual tolerances in process and optimal tolerances, Δ, calculated by the following equation:

$$\Delta = \sqrt{\frac{A}{A_0}}\,\Delta_0 \qquad (1)$$

where A is the producer's loss, A_0 the average consumer's loss, and Δ_0 the consumer's functional limit.

For the metal cap, we can see a remarkable difference between the calculated optimal and current tolerances. Our investigation revealed that the reason was that the tolerance was arbitrarily set to ±50 μm for a functional limit of ±100 μm. In addition, the difficulty in the measurement of the metal cap's inner diameter was also related. In this type of case, where there is a considerable difference between the current and optimal situations, tolerance design was implemented improperly.

3. Actual Control of Measuring Instrument and Evaluation by the Loss Function

Investigating measurement control in actual processes and performing an analysis according to JIS Z 9090:1991 *Measurement: General Rules for Calibration System*, we determined problems with our current control system. As line 1 of Table 2 shows, we used a measuring instrument identical to those introduced by each supplier.

Optimal Checking and Correction Interval

Table 2 summarizes the management parameters. On the basis of the current controlling conditions shown in lines 2–8, using the following equations

Table 1
Comparison of tolerances of mechanical component parts (nominal-the-best characteristics)

	Metal Plate (Thickness)	Plastic Tube A (Height)	Plastic Tube B (Height)	Metal Cap (Inside Diameter)
1. Producer's loss, A (yen/unit)	15	5	5	5
2. Functional limit, Δ_0 (μm)	15	40	400	100
3. Average loss, A_0 (yen/unit)	500	25	1000	400
4. Calculated optimal tolerance, Δ(μm)	2.6	18	28	11
5. Current tolerance (μm)	3	25	35	50

derived in Appendix 1 of JIS Z 9090, we estimated losses related to the optimal controlling condition in line 13 and the losses in lines 9–12 and 16–19 of the same table.

Next, we set up the following equations where A is the producer's loss, B the checking cost, C the correction cost, D_0 the current correctable limit, n_0 the current checking interval, u_0 the current correction interval, Δ the current tolerance, and σ_0^2 the error variance of the standard used for calibration.

Loss:

$$L_0 = \frac{B}{n_0} + \frac{C}{u_0} + \frac{A}{\Delta_0}\left(\frac{D_0^2}{3} + \frac{n_0}{2}\frac{D_0^2}{u_0} + \sigma_s^2\right) \tag{2}$$

Optimal checking interval:

$$n = \sqrt{\frac{2u_0B}{A}\frac{\Delta}{D_0}} \tag{3}$$

Optimal correctable limit:

$$D = \left(\frac{3C}{A}\frac{D_0^2}{u_0}\Delta^2\right)^{1/4} \tag{4}$$

Since the optimal correction interval can be calculated after the optimal correction limit is clarified, we computed the estimation of the optimal correction interval by using the following equation:

$$u = u_0\frac{D^2}{D_0^2} \tag{5}$$

Our current control procedure was formed through empirical rules. However, as compared with the optimal conditions, it cannot balance the control cost (checking cost plus correction cost) and quality loss, thereby inflating the total loss. In short, this highlights how empirical rules are ambiguous.

Estimation of Measurement Error

1. *Error in using measuring instrument.* In reference to Appendix 2 of JIS Z 9090, considering the measurement environment in the actual processes, we experimentally estimated the magnitude of error in using a measuring instrument, σ^2 (Table 2, line 20).
2. *Equation for calibration and error of calibration.* Referring to Appendix 3 of JIS Z 9090, we selected a reference-point proportional equation as the calibration equation and calculated the estimated magnitude of error in calibration operation, σ_c^2(Table 2, line 21).
3. *Error of the standard for calibration.* Since a commercial metal gauge is used as the standard for calibration, we defined its nominal error in the specification as the estimated magnitude of the standard's error, σ_0^2 (Table 2, line 22).
4. *Overall error in measuring operation.* The estimated magnitude of error variance in measuring operation σ_T^2 is expressed by the sum of the error variances 1 to 3 (Table 2, line 23):

$$\hat{\sigma}_T^2 = \hat{\sigma}^2 + \hat{\sigma}_c^2 + \hat{\sigma}_0^2 \tag{6}$$

Now, as the estimated range of error, we defined the double value of σ_T (Table 2, line 24), which is regarded as an error corresponding to uncertainty. We can see that the error for the metal cap is re-

Table 2
Comparison in control of measuring instrument used for mechanical component parts

	Metal Plate (Thickness)	Plastic Tube A (Height)	Plastic Tube B (Height)	Metal Cap (Inside Diameter)
1. Measuring instrument Used	Snap micrometer	Low-measuring force micrometer	Low-measuring force micrometer	Caliper
2. Producer's loss (yen/unit)	15	5	5	5
3. Current tolerance (μm)	3	25	70	50
4. Current checking interval (unit)	600	23,000	17,280	4800
5. Current correctable limit (μm)	0.5	5	5	10
6. Current correction interval (unit)	3,500	23,000	17,280	4800
7. Checking cost (yen)	100	200	200	200
8. Correction cost (yen)	200	800	800	400
9. Current checking cost per unit (yen/unit)	0.1667	0.0087	0.116	0.0417
10. Current correction cost per unit (yen/unit)	0.0571	0.0348	0.0463	0.0833
11. Current quality loss per unit (yen/unit)	0.1746	0.1667	0.0417	0.0850
12. Current total loss per unit (yen/unit)	0.3984	0.2102	0.0995	0.2100
13. Optimal checking interval (unit)	1300	6780	11,760	4340
14. Optimal correctible limit (μm)	0.4	4	6	13
15. Estimated optimal correction interval (unit)	2250	16,610	28,800	7510
16. Optimal checking cost per unit (yen/unit)	0.0772	0.0295	0.017	0.0461
17. Optimal correction cost per unit (yen/unit)	0.0891	0.0482	0.0278	0.0532
18. Optimal quality loss per unit (yen/unit)	0.1662	0.0776	0.0448	0.0993
19. Optimal total loss per unit (yen/unit)	0.3325	0.1553	0.0896	0.1987
20. Estimated error variance in use (μm^2)	0.09	1.05	8.68	103.24
21. Estimated calibration error variance (μm^2)	0.01	1.61	5.71	104.68
22. Estimated error variance of standard (μm^2)	0.0004	0.0004	0.0441	1
23. Estimated error variance in measuring operation (μm^2)	0.10	2.66	14.44	208.92
24. Range of error (2σ) (μm)	0.6	3	8	29

markably large. Considering that it exceeds the estimated optimal tolerance, we should use a more accurate measuring instrument in place of a caliper, which has a large measurement error. However, a part can be judged as proper in a functional inspection process when it can be assembled or inserted, even if its error is larger in an actual process, indicating that dimensional inspection is not greatly emphasized. In other words, the manufacturer does not trust tolerance to a great extent.

As for a control practice, because the optimal checking (measurement) interval and other values are calculated numbers, we should adjust them into values that can be managed more easily. For instance, looking at the measuring instrument control of plastic tube A, we can see that one checkup is conducted every day because the current checkup and correction interval is 23,000 units, and at the same time, 23,000 units are produced daily using this process. Under optimal conditions, these numbers are estimated as 6780 for checking and 16,610 for correction. Thus, since these numbers are not convenient for checking operations, we changed them slightly to 6710-unit (7-hour) and 16,290-unit (17-hour) intervals. Furthermore, with careful consideration of the loss, we can also change them to 7670-unit (8-hour) and 15,330-unit (16-hour) intervals by taking into account that three 8-hour shifts are normally used in a day.

4. Actual Process Control and Evaluation by the Loss Function

As we had earlier, we investigated manufacturing process control of the products studied and compared the parameters with the optimal parameters based on the loss function. Using the following equations, we computed the optimal conditions and summarized them (Table 3). The magnitude of error variance, σ_m^2, was not added to the quality loss. Additionally, as in the measuring instrument control, the value estimated was used as an optimal adjustment interval.

Each value is defined as follows: A, producer's loss, B, measurement cost, C, adjustment cost, D_0, current adjustable limit, l, time lag, n_0, current checking interval, u_0, current adjustment interval, Δ, current tolerance, and σ_m^2, error variance of measurement.

Loss:

$$L_0 = \frac{B}{n_0} + \frac{C}{u_0} + \frac{A}{\Delta_0}\left[\frac{D_0^2}{3} + \left(\frac{n_0+1}{2} + l\right)\frac{D_0^2}{u_0} + \sigma_m^2\right] \tag{7}$$

Optimal checking interval:

$$n = \sqrt{\frac{2u_0 B}{A}\,\frac{\Delta}{D_0}} \tag{8}$$

Optimal adjustable limit:

$$D = \left(\frac{3C}{A}\,\frac{D_0^2}{u_0}\,\Delta^2\right)^{1/4} \tag{9}$$

Estimated optimal adjustment limit:

$$u = u_0\,\frac{D^2}{D_0^2} \tag{10}$$

As we can see by measuring instrument control, the control cost (measurement cost plus adjustment cost) and quality loss are better balanced and the total loss is reduced under optimal conditions. The fact that there is a particularly large difference between the current and optimal losses indicates a laxity in management.

5. Evaluation of Product's Error in the Loss Function

After sampling products from the actual processes for 30 checkup intervals, we computed the losses for them using the loss function and summarized the results in Table 4.

$$L = \frac{A}{\Delta^2}\sigma^2 = \frac{A}{\Delta_0}\,\frac{1}{n}\sum_i^n (y_i - m)^2 \tag{11}$$

In addition, we decomposed the error in equation (11) into a factor of deviation from a target value and dispersion factor. Using the resulting equation, we calculated the split-up losses:

$$L = \frac{A}{\Delta^2}\,\frac{1}{n}\left[n(\bar{y} - m)^2 + \sum_i^n (y_i - \bar{y})^2\right] \tag{12}$$

It is commonly known that the deviation in process can easily be corrected. With the computed loss by deviation, we can estimate the benefit due to correction.

Table 3
Comparison in process control of mechanical component parts

	Metal Plate (Thickness)	Plastic Tube A (Height)	Plastic Tube B (Height)	Metal Cap (Inside Diameter)
1. Producer's loss (yen/unit)	15	5	5	5
2. Current tolerance (μm)	3	25	70	50
3. Current checking interval (units)	600	23,000	5760	4800
4. Current adjustable limit (μm)	1	5	25	50
5. Current adjustment interval (units)	2400	23,000	17,280	177,600
6. Time lag	300	240	120	80
7. Measurement cost (yen)	200	700	800	200
8. Adjustment cost (yen)	1200	1500	1600	20,000
9. Current measurement cost per unit (yen/unit)	0.3333	0.0304	0.1389	0.0417
10. Current adjustment cost per unit (yen/unit)	0.5000	0.0652	0.0926	0.1126
11. Current quality loss per unit (yen/unit)	0.9706	0.1688	0.3233	1.7365
12. Current total loss per unit (yen/unit)	1.8059	0.2644	0.5548	1.8908
13. Optimal checking interval (units)	760	12,690	6580	3770
14. Optimal adjustable limit (μm)	1	5	20	25
15. Estimated optimal correction interval (units)	2280	22,750	11,400	46,170
16. Optimal measurement cost per unit (yen/unit)	0.2635	0.0552	0.1215	0.0531
17. Optimal adjustment cost per unit (yen/unit)	0.5271	0.0659	0.1403	0.4332
18. Optimal quality loss per unit (yen/unit)	0.9993	0.1232	0.2662	0.4886
19. Optimal total loss per unit (yen/unit)	1.7898	0.2443	0.5281	0.9748

Table 4
Summary of quality losses in process control of mechanical component parts

	Metal Plate (Thickness)	Plastic Tube A (Height)	Plastic Tube B (Height)	Metal Cap (Inside Diameter)
1. Quality loss	0.227	1.6074	0.1469	0.5713
2. σ^2 (μm)	0.14	200.9	144.0	285.7
3. σ (μm)	0.37	14.2	12.0	16.9
4. Loss due to deviation	0.219	0.4128	0.0416	0.2385
5. Loss due to dispersion	0.008	1.1946	0.1053	0.3328

The magnitude of error discussed here should be the sum of the error in the measuring operation in Table 2 and the sum of the error in process control in Table 3, yet Table 4 reveals that it is not equivalent to the sum. Scrutinizing this phenomenon in depth, we found that the operator sometimes remeasures a part or takes another action after discarding a part when the measured result falls in an abnormal range.

Since parameters handled in on-line quality engineering have not often been considered to date, it has been quite difficult to help companies to understand the process. Therefore, we have spent a great deal of time investigating actual parameters. However, considering that many problems of current control practices have been identified through a series of analyses, we believe that these parameters should be managed as a matter of course. This example symbolizes vagueness in many current conventional management methods.

6. Conclusions

Through a comparative investigation of actual processes and optimal results based on the ideas of online quality engineering, we have shown how to utilize this management tool.

Reference

Yoshitaka Sugiyama, Kazuhito Takahashi, and Hiroshi Yano, 1996. A study on the on-line quality engineering for mechanical component parts manufacturing processes. *Quality Engineering*, Vol. 4, No. 2, pp. 28–38.

This case study is contributed by Yoshitaka Sugiyama.