Part V

Robust Engineering

Taguchi's Quality Engineering Handbook. Genichi Taguchi, Subir Chowdhury and Yuin Wu

14 System Design

14.1. Design and System Selection

The core of quality engineering is to improve productivity by improving functionality and by reducing cost. For any given objective function, there are several technical means to achieve it. For example, the paper feeder for a copy machine can use belts, air, or rollers. Selection of the mean for this objective function is called *system design*. The department that is responsible for determining an objective function is the product planning department. Selection of the function directly relates to future sales of the company. Traditionally, only the objective function has been studied. To distinguish it from an objective function, the function of the mean is called a *generic function*. In the case of the paper feeder for a copy machine, for example, the objective function is no misfeed or no multifeed. If a roller were used as the technical mean, the generic function would be the relationship between the roller-rotating angle and the paper travel distance.

To be successful in system selection, it is better to select a complex system rather than a simple one. The more complex the system being studied, the more chance of the system being improved. For example, in a development of a transistor transmitter by Yokogawa Hewlett-Packard, 38 control factors were studied by simulation [1]. In the development of LIMDOW direct-overwrite disks, it involved over 90 control factors [2]. In the early stage of this development, a traditional approach was used for six years without their being able to obtain a satisfactory prototype. After Taguchi methods were applied, the formation of multilayers was stabilized in just three years.

A large system may be divided into several subsystems. The objective function of each subsystem and its generic function must be defined. An example of determining an objective function is the selection of product types to satisfy customers. Engineers have to select the generic function based on the objective function selected, and the generic function selected must be optimized.

Selecting the system of a generic function means to combine elements or component parts so that the objective function can be performed. If the system selected does not exist, a patent can be applied for. Once a system is selected, the parameter levels of individual elements or component parts are determined. Depending on which levels are selected, the functionality changes.

To improve functionality, studies must be conducted by varying parameter levels to see how much the functionality can be improved. This is called *parameter design*. In product or process design, there are three steps:

1. *System design:* selection of a system for a given objective function
2. *Parameter design:* selection of the optimum levels of parameters
3. *Tolerance design:* determination of tolerance around each parameter level

Of the three steps, system design is the most important, but it is difficult to judge whether the system selected is the best without conducting parameter design. Since parameter design takes time and is costly, it is important to be efficient. As we can see, parameter design is the core of quality engineering. It is used to improve a system and to find the ultimate functionality of a system.

One example of the use of quality engineering is that by the Asahi Industrial Company in Japan, which developed the products used as the standards for Rockwell hardness testers. Prior to these studies, there had been only one source in the world for such hardness standards. To develop the standards, a joint research effort was undertaken by several large steel companies in Japan. But they did not succeed, despite several years of research efforts.

Assisted by the Japanese Bearing Inspection Institute and the National Research Laboratory of Metrology, using the robust technology development approach, Asahi successfully developed standards of quality superior to those existing. The development was completed in a year and a half.

14.2. System Functionality and Evaluation

The *quality* discussed in quality engineering is the variation related to (1) the loss caused by deviation from the ideal function of an objective function, and (2) the loss caused by harmful items, including the cost when the product is used. We are not going to study an objective function itself here, but will study how the function is close to the ideal function. Quality engineering is the evaluation of functionality. In quality engineering, a measure called the *signal-to-noise ratio* (SN ratio) is used for this purpose. Conceptually, it is the ratio of the magnitude of energy consumed for the objective function divided by the magnitude of energy consumed for variability. The total output is decomposed into the following two parts:

$$\text{total output} = (\text{output of useful part}) + (\text{output of harmful part}) \qquad (14.1)$$

The SN ratio is the first term on the right side of the equation divided by the second term. Actual calculation is different from one generic function to another. That is the main focus of quality engineering.

Many systems exist that perform a specific objective function. If the wrong system were selected, its functionality could not be improved. As a result, expensive tolerance design would have to be performed; thus, the company would lose its competitiveness in the market.

How much improvement can be accomplished depends not only on the new and old of the system but on the system's complexity. If a system is not complicated enough, it is difficult to improve its functionality by parameter design. It seems that selecting and improving a complicated system would be costly. But if the gain (improvement in SN ratio) were 10 dB, the trouble caused in the market or during the production stage could be reduced to one-tenth through the process. If the gain were 20 dB, half of it (10 dB) could be consumed for quality improvement, and the other half could be used to loosen up tolerance or increase production speed.

If a simple system were selected, there would be little possibility for improvement of functionality, and the improvement would need to be done by conducting tolerance design, controlling the causes of variation that increases cost.

❐ Example [3,4]

The resistance of a resistor can be measured by connecting the two ends, applying a certain voltage, and reading the current. Letting the resistance, voltage, and current be *R, V,* and *I*, respectively, *R* is given by

$$R = \frac{V}{I} \tag{14.2}$$

This system is shown in Figure 14.1, the parameters are unknown resistance, *R*, power source, *V*, and ammeter, *X*. Since it is so simple, it seems to be a good system from the cost viewpoint. However, parameter design cannot be conducted to improve the function for such a simple system. In this case it cannot be performed to improve the precision of measurement. Because there is no complexity in the system, there are no control factors to be studied for parameter design. In Figure 14.1 there is only one control factor: power voltage. When there are variations either in voltage or ammeter, there is no way to reduce their effects and to reduce the measuring error of current. The relative error of resistance is given approximately by

$$\frac{\Delta R}{R} \approx \frac{\Delta V}{V} - \frac{\Delta I}{I} \tag{14.3}$$

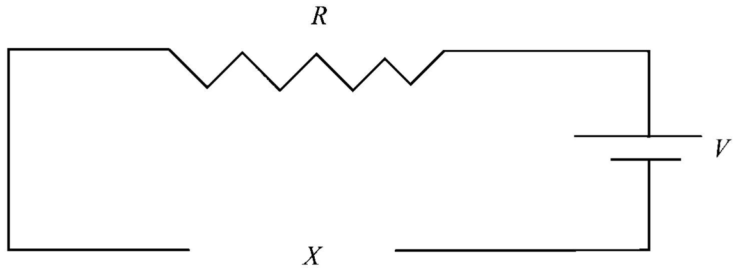

Figure 14.1
Simplest system to measure a resistance

In a simple system such as Figure 14.1, the only way to reduce measurement error is to reduce the causes of variation: in this case, either to reduce the variation of input voltage or to use a more precise ammeter.

To provide a constant voltage, we need to use a long-life power source with a small voltage variation. Or we need to develop a constant-voltage power-supplying circuit. For the former attempt, there is no such ideal power source. For the latter attempt, a complicated circuit is necessary. A precise ammeter must be a large unit and expensive. To improve quality, use of a simple circuit would end up being too expensive. It is why a more complicated circuit such as the Wheatstone bridge (Figure 14.2) is used. In the figure, X is an ammeter, B is a rheostat (continuously variable resistor), C and D are resistors, E is power voltage, A is the resistance of the ammeter, and F is the resistance of the power source.

A resistor of unknown resistance, y, is measured as follows: y is connected between a and b. Adjust the rheostat, B, until the reading of the ammeter, X, becomes zero.

$$y = \frac{BD}{C} \tag{14.4}$$

Even when the ammeter indicates zero, there is actually a small amount of current flowing. There are also some variations of resistance in resistors C, D, and F. There might be variation in the rheostat. In such cases,

$$y = \frac{BD}{C} - \frac{X}{C^2E}[A(D + C) + D(B + C)][B(C + D) + F(B + C)] \tag{14.5}$$

Compared with Figure 14.1, Figure 14.2 looks complicated, but by varying the values of control factors C or D, the impacts of the variability caused by the variations of input power voltage or ammeter can be reduced substantially.

Parameter design is to reduce the variation of an objective function by varying the levels of control factors without trying to reduce the source of variation, which

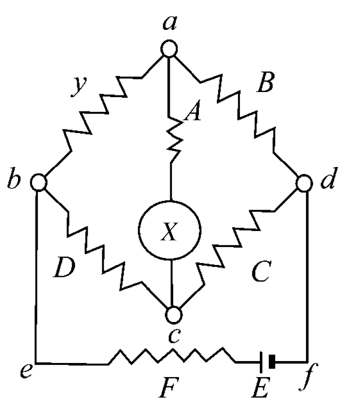

Figure 14.2
Wheatstone bridge

is costly and difficult to do. The more control factors in the system, the more possibility for improvement. The more complications between the input signal (the unknown resistance to be measured) and the output (the reading of rheostat), the higher the possibility for improvement.

Using a Wheatstone bridge, the power supply voltage variation has scarce effect-to-measurement error. Variation caused by the ammeter can often be reduced to a fraction of 100. The effect of variation caused by an inexpensive battery that is difficult to improve can also be minimized to nearly zero.

But the variation caused by resistors *C, D,* and *B* cannot be improved through parameter design, so higher-grade resistors have to be used. How high the grade should be is determined by the last step of product design: tolerance design.

References

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