Part X

Design of Experiments

27 Introduction to Design of Experiments

27.1. What Is Design of Experiments?

Traditional design of experiments was developed by Ronald A. Fisher of England in the 1920s for the rationalization of agricultural experimentation. The approach was later applied in medical and biological studies.

In biology, there is substantial variation in the output characteristics, which is caused by individuals. Therefore, the content of the traditional design of experiments consists primarily of ways to express individual variation and ways to separate such variation. These include blocking to separate conditional difference, randomization of experimental order, repetition of experiments, distribution, and test of significance, among others.

Design of experiments means to find the relationship between various factors (variables) and responses to them. It is therefore important to express their relationship precisely and efficiently by an equation. If the interactions between variables (factors) are significant, it is important to include the terms of interactions in the equation.

Traditional design of experiments is the study of response. To find an equation with a small error, many variables that might affect the output characteristic are listed and an experiment is planned. The equation is written as

$$y = f(M, x_1, x_2, \dots, x_n) \tag{27.1}$$

where y is the output characteristic, M the input signal, and $x_1, x_2, \dots, x_n$ the noise factors.

This approach is appropriate for scientific studies. But for engineering studies, where the objective is to develop a good product efficiently at low cost, the

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approaches are entirely different. In engineering, monetary issues are most important. But in science, there is no economical consideration.

There are basically two areas in quality engineering: off-line and on-line. The first relates to technology development, and the second is applied in daily production activities for process control or management.

There are three steps in off-line quality engineering: *system selection, parameter design,* and *tolerance design.* Selection of a system is a task for engineers working in a specialized engineering field. Parameter design is to improve the function of a product by varying the parameter levels in a system. The function of a system is expressed and evaluated by the SN ratio. Many design variables are listed up and assigned to an orthogonal array.

Tolerance design is to assign noise factors that affect variability to an orthogonal array and study the effects of every noise factor. Removal of noise factors by upgrading of components or raw materials is determined by the use of the loss function.

27.2. Evaluation of Functionality

For the evaluation of functionality, equation (27.1) is decomposed into two parts:

$$\begin{aligned} y &= f(M, x_1, x_2, \ldots, x_n) \\ &= \beta M + [f(M, x_1, x_2, \ldots, x_n) - \beta M] \end{aligned} \tag{27.2}$$

where βM is the useful part and $[f(M, x_1, x_2, \ldots, x_n) - \beta M]$ is the harmful part. The SN ratio is the ratio of the first term to the second. The larger the ratio, the better the functionality.

The basic difference between the traditional design of experiments and the design of experiments for quality engineering is that the SN ratio is used as an index for functionality instead of using a response. In the traditional design of experiments, there is no distinction between control factors and noise factors. Error is considered to vary at random, and its distribution is discussed. But in quality engineering, neither random error nor distribution are considered.

27.3. Reproducibility of Conclusions

In technology development or product design study, the reproducibility of conclusions is most important, since it is conducted at an early stage in the laboratory and the conclusions must be reproduced downstream.

Reproducibility of conclusions does not mean reproducibility under the same conditions but:

- ❑ Reproducibility of the results from a study conducted using test pieces or using a computer to simulate the actual product
- ❑ Reproducibility of the results from a small-scale experiment to a large-scale manufacturing process
- ❑ Reproducibility of the conclusions from limited conditions to various other conditions

How can one assure that the conclusions from a test piece study in a laboratory can be reproduced downstream, where the conditions are totally different? Since the conditions are different, the characteristic (output) to be measured will be different. Therefore, we have to give up reproducibility of the output characteristic. The characteristic will be adjusted or tuned at the second stage of parameter design. At the development stage, only improvement of functionality is sought. That is why the SN ratio is used in parameter design.

By use of the SN ratio, it is expected that the difference in the stability of a function can be reproduced. However, there is no guarantee of reproducibility. Therefore, a method to check reproducibility is needed. Orthogonal arrays are used for this purpose. This is discussed in a later chapter.

27.4. Decomposition of Variation [1]

In the design of experiments for quality engineering, the steps include (1) selection of characteristics, (2) layout of experiment, and (3) data analysis. Selection of the characteristics used for analysis is the most important and also the most difficult step.

Once the characteristics to be used are determined, the next step is the layout of the experiment. From many factors with different numbers of levels, we select the combinations of factor levels so that reliable conclusions may be obtained efficiently. Orthogonal arrays are used for the layout.

After the experiment is conducted and the data collected, data will be analyzed and conclusions drawn. The analysis includes decomposition of variation, calculation of factorial effects, estimation of the optimum condition, and many other factors, discussed in the following chapters.

Reference

1. Genichi Taguchi et al., 1973. *Design of Experiments*. Tokyo: Japanese Standards Association.