Achieving Robust Designs through Quality Engineering: Taguchi Method

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Development processes must be constantly reviewed to quickly provide superior products that meet the complex demands of the marketplace. Quality engineering (also known as the Taguchi Method) is a systematized methodology for technology development that is attracting much attention. Quality engineering focuses on the functionality (generic functions) of products and separates the components of systems into three function categories: signal factors, control factors, and error factors. Although quality engineering may be difficult to understand for engineers used to conventional methods, it should be actively promoted to change their mindset as well as that of the divisions to which they belong. This will help ensure innovation in manufacturing. This paper outlines efforts made to promote quality engineering and analytical tools such as WebSTAT and ParaNAVI that are used to support it. It also gives examples of its application in simulation, the development of process materials, and software evaluation.

1. Introduction

Robust designs are those that make products resistant to variations in production processes and enable them to withstand influences in the environments in which they are used. However, this does not just mean making designs that are resilient, it also means attaining maximum stability under limited design conditions, and an important means of achieving this is quality engineering (also called the Taguchi Method[1)]).

Quality engineering is a technology development methodology created and systematized by Dr. Genichi Taguchi and was widely adopted in the US as the Taguchi Method in the 1980s, principally in the automobile industry. It was first introduced in Japanese companies in the 1990s. The Quality Engineering Forum was established in 1993 and was later renamed the Quality Engineering Society[2)] when the Taguchi Method became known as quality engineering. Initially, quality engineering was used for optimizing design (parameter design) and has since been expanded to include the Mahalanobis-Taguchi System (MTS) and function evaluation procedures.

In a method-ranking survey recently conducted by NIKKEI BizTec magazine,[3)] quality engineering was ranked top for recognition as a development and production support tool and for adoption rate, showing that its introduction is proceeding in various types of companies.

Quality engineering focuses on the functionality of a system (generic functions) and then makes an evaluation of the system's components according to three function categories — signal factors, control factors, and error factors — with a view to system optimization. Quality engineering aims, as far as possible, to streamline development by evaluating the good and bad points of various technologies in the upstream stages of the product commercialization process.

Although quality engineering is not a panacea for all problems, the practice of early and accurate evaluation is an effective means of avoiding product recalls and customer complaints, and as a methodology for innovation, it occupies an important position in product creation.

In this paper, we consider efforts at the organizational level to expand the use of quality engineering, the tools used to support this expansion, and some examples of quality engineering application.

2. Fujitsu's response to quality engineering

Fujitsu is among the Japanese companies that have been introducing quality engineering. Initially, it was only included in Fujitsu as part of training, but the extent of its adoption has steadily increased.

2.1 Efforts in the 1990s

In the 1990s, Fujitsu began company-wide training on quality engineering as part of its training program for engineers, and so far, more than 4000 people have undergone this training. The training was stepped up in 1997 with the start of case-study meetings. Although the training shortened development times for process design and control, feature upgrades for mechanical devices, and elemental technology development, the following problems arose:

1) Most engineers went no further than just receiving the training.
2) When engineers applied quality engineering, there were problems in the way it was done and benefits were not always realized. As a result, the engineers tended to stop using quality engineering.
3) There were not enough engineers in Fujitsu divisions who could become key persons in quality engineering.

2.2 Renewed efforts towards quality engineering (fiscal 2004 onwards)

In view of this situation, in fiscal 2004, Fujitsu embarked on projects aimed at providing an environment in which engineers could properly apply quality engineering and enhance their skills in order to reinforce their development capability (**Figure 1**). The basic goals of these projects were to:

1) Focus more on problem-solving than on

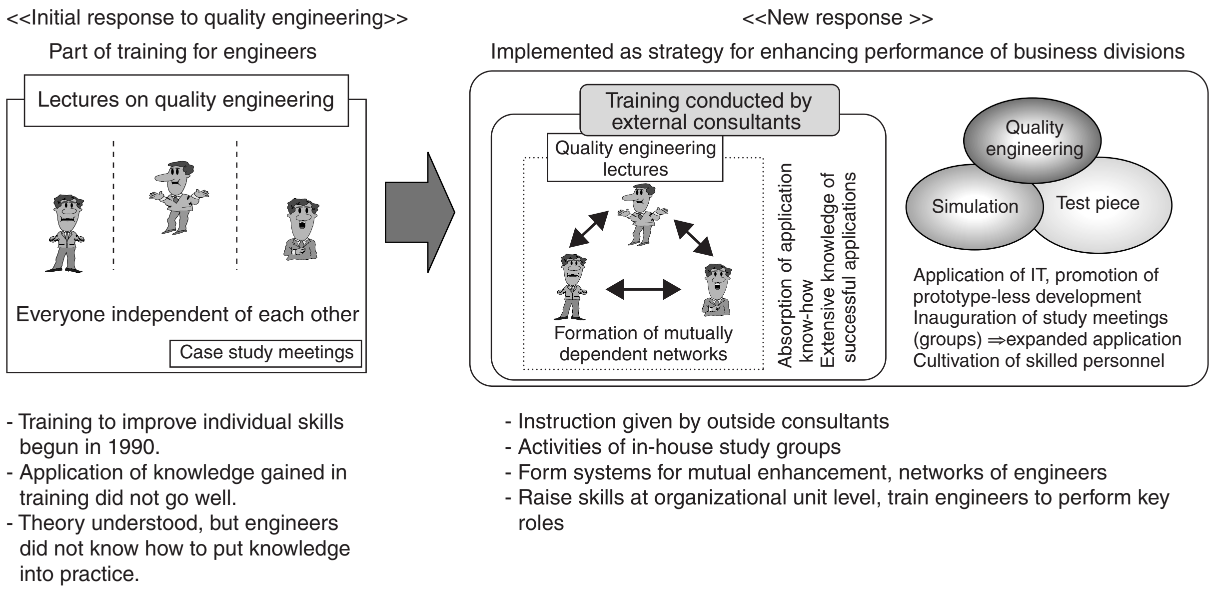

Figure 1
Activity scheme.

training, and

2) obtain better results by listening to lecturers from outside the company who have abundant experience of quality engineering (to accumulate knowledge of successful applications)

Therefore, in fiscal 2004, we strengthened our secretariat for promoting quality engineering, formed a group of in-house experts, and began addressing the major issues concerning quality engineering in Fujitsu's business divisions. Then, in fiscal 2005, we began holding in-house study meetings to share information and study ways of solving common problems, with the most experienced persons from each division acting as the key participants. Furthermore, we expanded the base of activities by restructuring the training system to include e-learning and introduced a skills-recognition system.

3. Support tools

In the application of quality engineering, statistical calculations are needed to obtain the SN ratio, which is an indicator of the effect of variation, and sensitivity, which is a measure of the influence of parameters. Although there are various types of software for this purpose on the market, it is not instantly available to engineers when they need it. For this reason, Fujitsu has developed the following three software applications and made them available on our in-house Website (**Figure 2**).

This Website also provides case studies and information about upcoming events.

1) WebSTAT

WebSTAT is provided as an entry-level software tool. It can be used from any computer in the company that has a Web browser.

In addition to quality engineering functions, WebSTAT provides a function for testing significance and other much-used statistical functions. Overall, WebSTAT is used more than 10 000 times a year.

2) ParaNAVI

ParaNAVI is provided mainly for intermediate-level users and can be run in Excel. This tool can handle large volumes of data that would be difficult to achieve under WebSTAT.

3) CAOS[4]

This is a simulator linkage tool having functions for automatic parameter insertion and results collection.

4. Application to design of magnetic recording heads

In this section, we will look at the application of quality engineering to magnetic recording head design as an example of optimization using simulation.[5]

1) Problem

Figure 3 shows the structure of a magnetic recording head, and **Figure 4** shows the distribution of the head's write magnetic field. For optimum function, the magnetic field must be concentrated where it is required and suppressed in other areas. It must also have characteristics that are not easily affected by manufacturing variations.

2) Solution

Conventionally, several representative points are selected and the best design is sought through trial and error by monitoring changes in their values. However, for this head, we quickly opti-

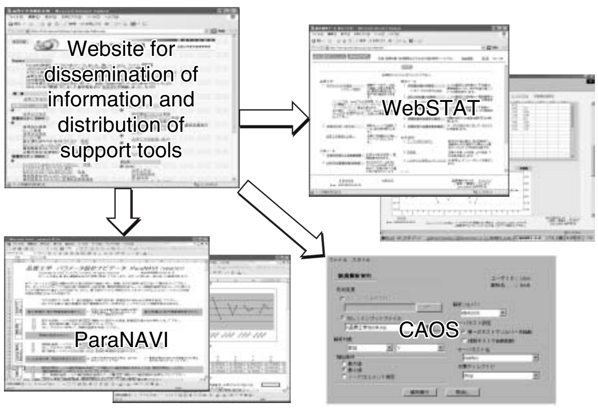

Figure 2
Support tools.

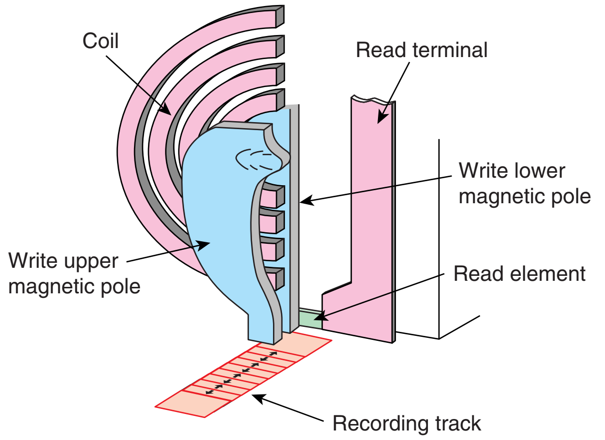

Figure 3
Magnetic recording head.

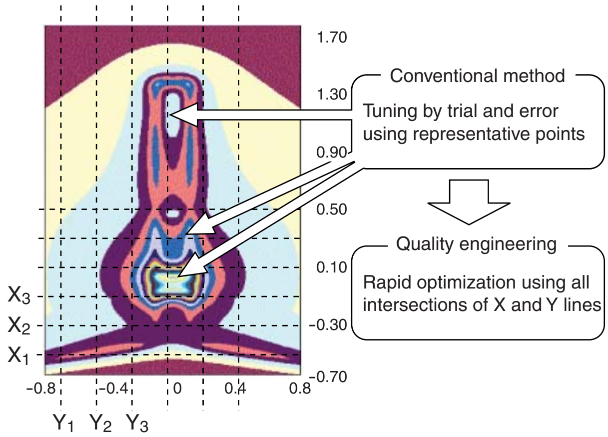

Figure 4
Optimization of write magnetic field.

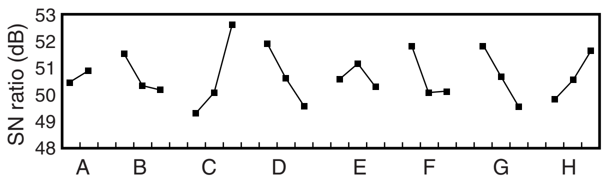

Figure 5
Response graph.

mized several design parameters (control factors) by evaluating the stability (standard SN ratio) of output values at each intersection of the X and Y lines in Figure 4 using quality engineering.

Some of the results of the analysis are shown in **Figure 5**. Using quality engineering, we compare the response for each factor using a graph such as the one shown in Figure 5. On the horizontal axis, A to H correspond to various dimensions and physical properties of the materials of each part. The points in the upper part of the graph (high SN ratio) indicate superior conditions.

The optimum conditions determined by this procedure achieved an improvement of 8.5 dB over the original design conditions (variation reduction of 62%).

Figure 6 shows 2-dimensional distributions of the magnetic field before and after optimization and shows how much the optimization reduced the variation.

5. Application to improvement of adhesive characteristics

The following describes an example of applying quality engineering in the process and materials fields to develop an adhesive for optical components.[6)]

1) Problem

The optical path of optical drives consists of lenses, prisms, and other optical components, most of which are mounted using a UV-hardened adhesive. The locations indicated with circles in **Figure 7** indicate the places where the adhesive is used. Changes in the dimensions of the adhesive as it hardens and ages cause deviations in the position of the optical components. This leads to deterioration in the performance of the optical drive, so such changes must be minimized.

2) Solution

The optical components must be precisely positioned; therefore, the adhesives used to mount them must have excellent adhesion and shape retention. If these are achieved, there will be negligible displacement of the optical components, even in the presence of temperature changes or external forces.

After considering the above situation based on quality engineering principles, two generic functions were identified:

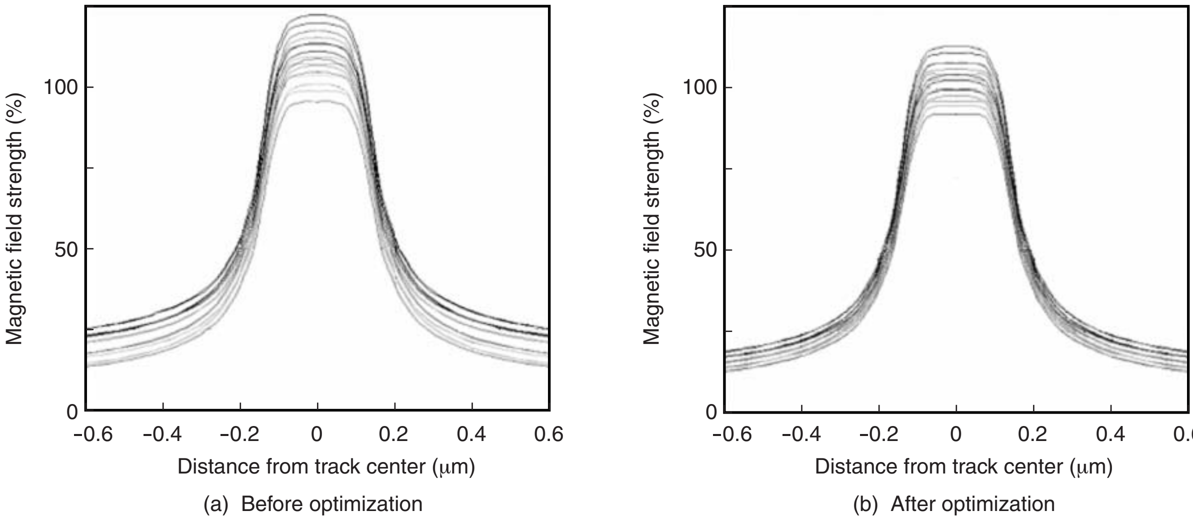

Figure 6
Magnetic field before and after optimization.

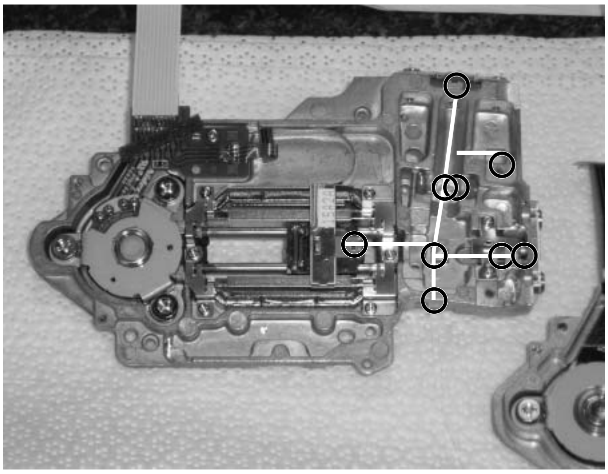

Figure 7
Optical sensor head assembly.

- The hardening rate with respect to UV irradiation
- The shape retention after hardening

We collaborated with an adhesives maker to find the best adhesive in terms of the two generic functions and then tested the adhesive. As advocated by quality engineering, the sample used for the test was not an actual component but a test piece. The dimensions of this test piece, which was made by casting, are shown in **Figure 8**.

Figure 9 shows the improvements that were achieved for the hardness and length retention of the test piece.

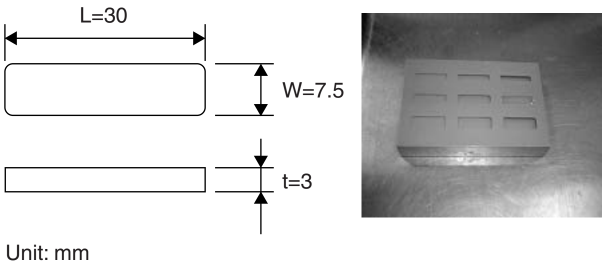

Figure 8
Test piece and mold.

In this example, product characteristics were improved by upgrading generic functions, which is the essence of quality engineering.

After the adhesive was selected, we performed parameter design to fine-tune the hardness and viscosity. We eventually achieved a stability improvement of 5 dB (44%) in the product. This example clearly shows the importance of generic function evaluation in successful technology development.

6. Application to software evaluation

In this section, we report on efforts to apply quality engineering in the software field.

The orthogonal array is a traditional black-box test procedure for debugging software and

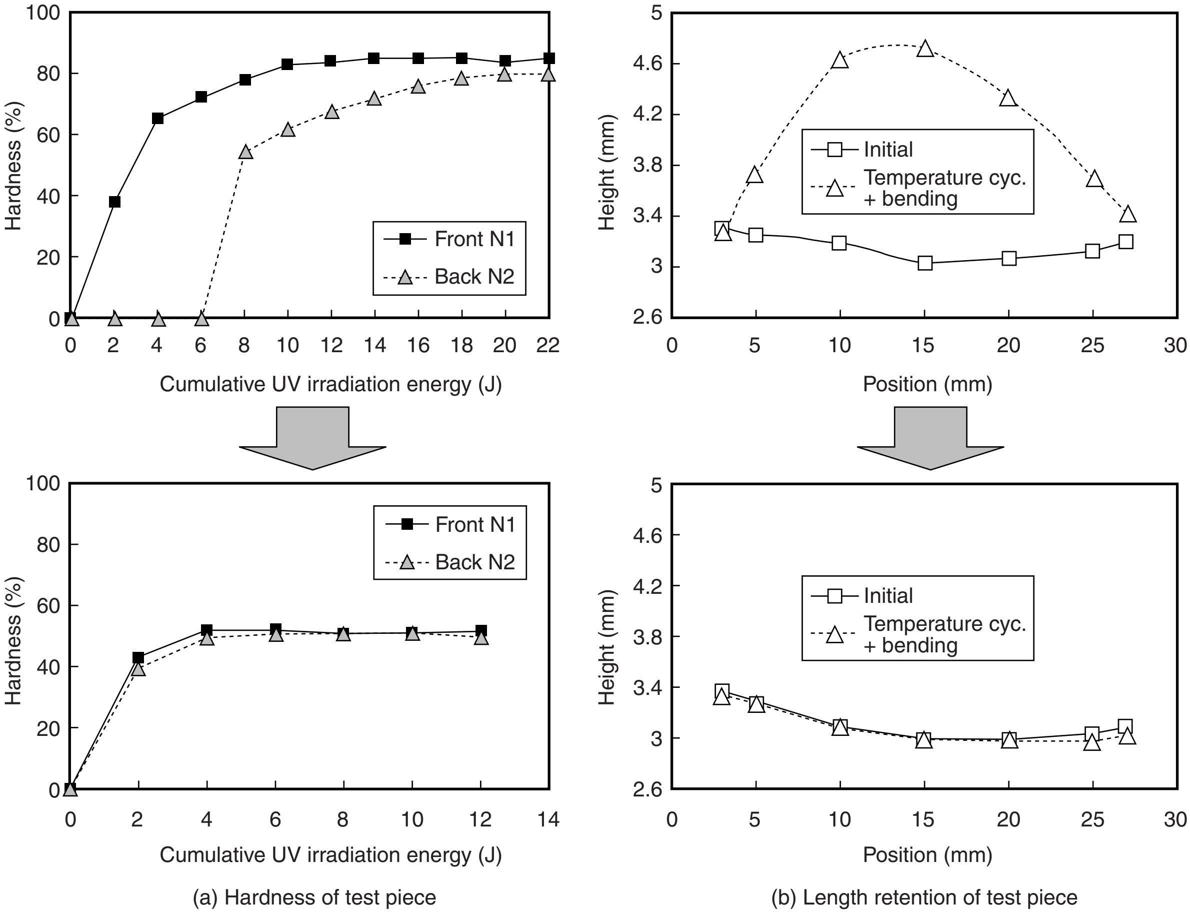

Figure 9
Improvement of generic functions.

systems.[7] It is efficient to use an orthogonal array in a test plan because it enables all combinations between two factors to be easily shown.

Table 1 shows an example of some test conditions. Factors 1 to 6 have four levels, and factors 7 to 38 have 2 levels. Using normal procedures, in order to investigate all combinations of the factors and levels, a test would have to be performed a tremendous number of times ($4^6 \times 2^{32} \fallingdotseq 1.7 \times 10^{13}$). The orthogonal array, however, enables each combination between two factors to be tested very efficiently. We assigned an L64 orthogonal array to the example in Table 1, and the test only had to be performed 64 times to investigate a huge number of combinations.

Although testing efficiency can be greatly increased through the use of the orthogonal array, the following problems occur when it is used:

1) Specialist knowledge is required to assign orthogonal arrays having only particular types of combinations of program functions and options (levels).
2) One hundred percent coverage can be guaranteed for two-factor testing, but the coverage is indeterminate for combinations of three or more factors.
3) Elimination of non-existent combinations (excluded combination processing)

To solve these problems, a program that automatically generates test plans for any combinations of factors and options and evaluates coverage is currently being developed. This program was used to make the coverage graph in **Figure 10** for the test plan of the L64 orthogonal array in Table 1. We found that as the test progresses, the coverage for two factors increases

Table 1
Test conditions table.

No.	Test Mode	Level 1	Level 2	Level 3	Level 4
1	Memory test	N	R	I	F
2	File test	Noise	Random	SHIFT	Fixed
3	Graphic-A	Triangle	Wave	Circle	Rect.
4	Graphic-B	Triangle	Wave	Circle	Rect.
5	Graphic-C	Triangle	Wave	Circle	Rect.
6	Serial	None	Odd	Even	Mark
7	MemTest-A	Random	Seq.		
8	MemTest-X	Positive	Negative		
≀	≀	≀	≀	≀	≀
35	Fan_A-spd	H	1		
36	Fan_B-spd	1	2		
37	I/O-A_UP	0	-2		
38	I/O-B_DN	Yes	No		

4 levels × 6 factors, 2 levels × 32 factors

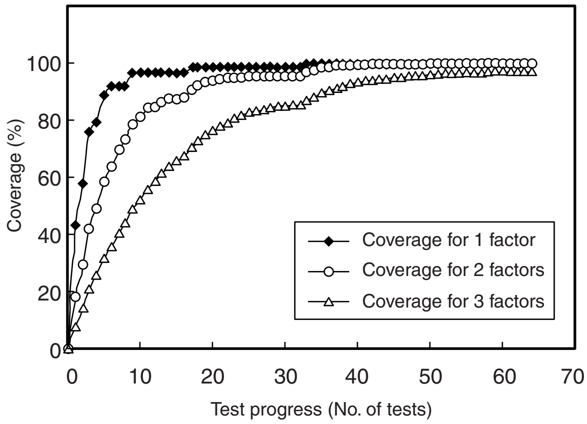

Figure 10
Coverage of L64 test plan.

sharply, approaching 100% in the 35th test, while the coverage for three factors reached only 97% in the 64th test. Therefore, being able to quantitatively evaluate coverage in this way is very important for increasing testing efficiency.

7. Conclusion

In this paper, we presented examples of the application of quality engineering. Quality engineering may be applied in a wide variety of fields, and recently its use in simulation has been rapidly increasing. A major difference between quality engineering and the response surface and Monte Carlo methods — two well-known simulation methods for optimization — is that quality engineering strongly focuses on production variations and the effects of actual usage conditions (error factors). Quality engineering achieves robust designs through the accurate evaluation of such error factors.

In the process of applying quality engineering, engineers need to have a clear understanding of systems and be able to accurately analyze them. The key to success in quality engineering is the ability to make a precise response to the questions raised by it; for example: what are the error factors in the end user's usage conditions and what are the control factors that the designer can determine? Quality engineering is therefore a systematic approach that causes engineers to think deeply.

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