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APPLICATION OF THE TAGUCHI DESIGN IDEAS IN  
MISSILE CONTROL SYSTEM DESIGN

by

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ABSTRACT

This paper introduces the applications, effects and experiences of the Taguchi method in missile control system design.

1. Purpose of the application

Design is a project which involves a number of scientific fields and different technologies. It requires the guidance of methodology, and also relies on the practical experiences of various specialty theories and specialty technology. The quality of the product is first of all designed. If one wants to occupy the domestic market with a high quality product, he must spend a lot of time in design. This requires constant updating of the basic design data and design methods in order to increase the speed of development and increase the quality of the product.

For linear constant systems, there is a set of classical design methods and stability design criterion. However, for design of such things as missile control systems which are complex, non linear, time-variant systems, there is constant search for the optimum design methods and design criterion for strong resistance to jamming. In the process of developing the control system for a certain unnamed missile, we used such optimized design methods as the orthogonal testing method, the gradient method, the 0.618 method and the Monte Carlo method as well as mathematical statistical methods. At the present time, computer aided design, the tertiary method, the modular design method and intelligent

engineering are all widely used in engineering projects.

In the seventies, the famous Japanese quality expert Doctor Taguchi applied mathematical statistics and economics into quality management, creating a tertiary design method centered around parameter design. In Japan, Europe and the United States this was widely used with marked success. The United States named this method the "Taguchi method".

There are two primary points to the Taguchi design idea. The first is the introduction of quality loss factors, any deviation from the target value and there is loss, and the greater the deviation the greater the loss. The second is the introduction of the signal to noise ratio, making this a criterion of stability, searching for a design scheme where the signal to noise ratio is greatest, that is, searching for a scheme with strong jamming resistance capabilities and which is stable and reliable.

## 2. Applications

In the process of overall system design in the application of the Taguchi method to missile control systems, we have encountered the following problems:

(1). Nature of dynamic characteristics and definition of signal to noise ratio

In the process of our research into applying the Taguchi methods to the overall design of missile control systems, we have discovered that the Taguchi dynamic characteristics calculation formula  $\eta = \beta^2 / \sigma^2$  is only applicable to open loop domains, and cannot be used in close loop control system domains. To use the Taguchi method in closed loop control systems, it is necessary to redefine

the signal to noise ratio and its computational formula. In order to do this we solved for three key technologies.

a. Proposed the new concept of Wangxiao (phonetic) dynamic characteristics

Based on the dynamic properties of the control system for the missile were developing: Whether angular velocity of sighting line movement (signal factor)  $M$  was small or large, it was necessary that the error of missile deviation from the sighting line (output characteristic)  $Y$  be the smaller the better, we defined this type of dynamic characteristics the Wangxiao (phonetic) dynamic characteristics.

b. Defining the signal to noise ratio of the Wangxiao (phonetic) dynamic characteristics

$$Y = \alpha + \beta M + \epsilon$$

In this equation,  $M$  is the signal factor,  $Y$  is the output characteristics, and  $\epsilon$  is the experimental error  $N(0, \sigma^2)$ .

We defined the Wangxiao (phonetic) dynamic characteristics signal to noise ratio as

$$\eta_B = \frac{1}{\beta^2}$$

and

$$\eta_V = \frac{1}{\sigma^2}$$

c. Proposed the calculation formula for the signal to noise ratio of the Wangxiao (phonetic) dynamic characteristics

We proposed the following calculation formula for the signal to noise ratio of the Wangxiao (phonetic) dynamic characteristics:

$$\eta_B = 10Lg \frac{1}{\frac{1}{\gamma}(S_B - V_e)}$$

$$\eta_v = 10Lg \frac{1}{V_e}$$

In these equations,  $\gamma$  is the effective divisor,  $S_B$  is the mean square sum of fluctuation, and  $V_e$  is the estimate of the random error  $\sigma^2$ .

after solving these three key technologies, the signal to noise ratio was introduced to the closed loop control system, and we proceeded with missile control system design, and called this method of using the signal to noise ratio in closed loop control systems the "signal to noise ratio method".

#### (2). Downstream reproducibility of optimum design

The basic nature of the Taguchi method is to use an orthogonal array, with arrangements for only the primary effects. Therefore, we selected incomplete orthogonal arrays, and then determined their results through demonstration tests. If the demonstration tests were consistent with test results, this indicated that there was little interaction, and the conclusion was accurate. If the demonstration tests were not consistent with the experimental results, this indicated that there were major interaction effects, and after parameter design further demonstration testing was conducted.

#### (3). Method of determining optimum scheme

In the designing of missile control systems, consideration must be given to dynamic characteristics as well as static characteristics. Therefore, when conducting parameter design for

the signal to noise method, we first determined the properties of the missile control system dynamic characteristics, the definition of the signal to noise ratio and the calculation formula, the level of controllable factors, the level of the signal factors and the level of the error factors. For dynamic characteristics parameter design, the focus of the research should be placed on improving the basic functions of the missile control systems. Then we determined the qualitative characteristic values of the static characteristics of the missile control system, the controllable factors and the error factors, and proceeded with static characteristic parameter design. Then we combined the results of dynamic characteristic parameter design and static characteristics parameter design, coming up with a scheme for optimum parameter design.

### 3. Application results and experiences

We named the method of using the signal to noise ratio in closed loop control system domains the signal to noise ratio method. We also used this signal to noise ratio in the missile control system design of a model under development. The basic design idea of the signal to noise ratio is to use orthogonal testing methods to arrange a testing program and to study the interaction between the factors. We checked whether or not the interaction was less than the primary effect, used error factor modelling for each type of interference, used the signal to noise ratio for a test index for statistical analysis. We combined the results of dynamic characteristic parameter design and static characteristic parameter design to find the optimum combination of parameter levels.

In the design of missile automatic pilot subsystems, the optimum scheme designed had a signal to noise ratio 2.849 decibels

greater than that of the original plan. We also used this in the automatic pilot flight testing of a project underway, and the flight test results indicate that with the optimum scheme designed, the missile rolling angle over its entire flight was within seven degrees, extremely satisfactory results.

Using the signal to noise ratio method in the overall system design of missile control systems, the optimum scheme designed had a dynamic capability for  $n_b$  is 7.344 dB greater than the original plan,  $n_v$  is 1.375 dB greater than the original plan and static characteristic  $n$  is 11.588 dB greater. This indicates that optimum schemes can greatly increase the stability, controllability and resistance to jamming of the missile control system.

Using the optimum parameters designed using the signal to noise ratio in the development of a key model project, we were first successful in a test of missile total trajectory control on October 22, 1994. After this we had a number of successful controlled flight tests.

The success of the signal to noise ratio method in missile control system design provides a criterion for non-linear time-variant control system design. That is, using the signal to noise ratio as the optimum design estimates to find the design scheme with the maximum signal to noise ratio, is a design plan for finding the strongest resistance to jamming and optimum capabilities.

In summary, the signal to noise ratio method has located a new optimum design method for non-linear, time-variant control system design. Missile control systems designed using the signal to noise ratio method have control capabilities which are not sensitive to noise, thus having improved product quality. The signal to noise

method can also be used in the design of other types of missile control systems and other closed loop control domains.

The experiences of the application process have been as follows:

(2). The Taguchi method is an extremely effective method of improving product quality. The Taguchi method using fluctuation analysis method for design research is a major contribution to quality engineering. Arranging error factors for testing and using the signal to noise ratio as a test index for data analysis can improve research efficiency greatly over the analytical method.

(2). We conducted tolerance design in the design of a missile automatic pilot subsystem, and the design results indicate that the tolerance requirements of some components can be relaxed, that is, it is possible to use third class product components to design a first class device. However, the application of these design results in missile control systems requires a process of practical testing.

(3). The Taguchi method is a modern design method developed on the basis of the Feixie'er (phonetic) testing design method. Also, Doctor Taguchi presents some new views every year. For example, in 1993 he expanded it to technology development and in 1994 he expanded the signal to noise ratio to the domain of chemical reactions.

Therefore, the Taguchi method should be applied in accordance with the actual situation existing in a specialty. It conforms to the patterns of development to propose new concepts and definitions during the application process, depending on the situation in that specialty.

(4). Experience is the only criterion for empirical truth. Any design method which has been demonstrated as proper through practice is reasonable. The Taguchi method itself stresses that when demonstration tests results are consistent with design results, the conclusion is that it is proper.

(5). Design methods are not unique, so a number of different methods can exist side by side if this improves product quality. Naturally the Taguchi method can serve as a primary method. For example, in the process of improving the Japanese Toyota automobile, the Taguchi method constituted more than 60 percent.