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Simultaneous Optimization for Robust Parameter Design Using Signal-to-Noise Ratio

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Abstract

Taguchi's robust parameter design is an approach to reduce the performance variation of quality characteristics in products and processes. In robust design, the signal-to-noise ratio (SN ratio) was used to find the optimum condition to minimize the variation of quality characteristics as much as possible and bring the average of quality characteristics closer to the target value. In this paper, we propose a simultaneous optimization method based on a linear model of the SN ratio as a method to find the optimal condition of the control factor in case of multi-characteristics. In addition, the proposed method and the existing method were compared and studied by taking actual cases.

Keywords : Robust parameter design, Simultaneous optimization method, Signal-to-noise ratio

1. Introduction

Taguchi's robust parameter design (Taguchi[1,2], Taguchi and Wu[3], and Kackar[4]) aims to reduce as much as possible the variation (variance or standard deviation) as well as the mean of quality characteristics. It is different from the traditional experimental design method, which tends to find the optimal conditions, mainly focusing on improving the average of the quality characteristics. In the Taguchi parameter design, the product array using an orthogonal array table is the control factor (or design factor) in the inner array and the noise factor (or uncontrollable factor) in the outer array. The product array using the orthogonal array table was subjected to data analysis using the SN ratio by performing experimental setup considering all the interaction effects of the control factor and the noise factor. In the product array, the noise factor plays a role in reducing quality variation of quality characteristics, which makes it possible to design a parameter which can find the optimum condition of control factor approaching the target value while the average of quality characteristics is insensitive to variation. In parameter design, the SN ratio, which is a performance measure that combines the mean and variation, is used to analyze the quality characteristic value (or response variable). There are three types of quality characteristics: the larger-is-better characteristics, the smaller-is-better characteristics, and the nominal-is-best characteristics. The larger the SN ratio in all characteristic values, the better the performance measure.

In the experimental design method, in most cases, the optimal condition of control factors with one response variable is sought, but in practice, in most cases, there are several quality characteristic values to be considered simultaneously. Derringer and Suich[5], and Khuri and Conlon[6] study to find the optimal condition of the control factor in multi-characteristics, but the methods studied by them are simultaneous multi-characteristic optimization methods that do not consider quality variations.

In this paper, a method of simultaneous optimization in case of multi-characteristics in robust parameter design using performance measures using a linear model of SN ratio is presented, and the analysis results of the existing multi-characteristic experiment (Sung-Hyun Park[7], p. 255-272) and I want to compare. In Chapter 2, a multi-characteristic simultaneous optimization method is presented, in Chapter 3, the simultaneous optimization method proposed in this paper is compared with the existing optimization method using

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actual cases, and in Chapter 4, the features and advantages of the proposed simultaneous optimization method are listed.

2. A Simultaneous Optimization Procedure for Robust Parameter Design

2.1 Proposed Optimization Method Using SN Ratio

If there are p types of quality characteristics $y_1, y_2,..., y_p$ in a system or product, p types of SN ratios $SN_1, SN_2,..., SN_p$ are calculated for each quality characteristic corresponding to them. If the number of experimental numbers in the given experimental arrangement is n, there will be $p \times n$ total calculated SN ratios. Considering the mean and standard deviation for each of p quality characteristics, let p standardized SN ratios be $SN_1^*, SN_2^*,..., SN_p^*$. For example, when n SN ratios in the SN ratio SN_p of the p-th quality characteristic are referred to as $SN_{p1}, SN_{p2},..., SN_{pn}$, and these n averages and standard deviations are respectively $\overline{SN_p}$ and $sd(SN_p)$, the standardized SN_p becomes

$$SN_p^* = \frac{SN_p - \overline{SN_p}}{sd(SN_p)}$$

Considering that the larger the SN ratio is for all characteristic characteristics, the better the performance measure is, and we propose a performance measure using the standardized linear model of the SN ratio in order to find the simultaneous optimal condition of the control factor in the case of multiple characteristics.

$$SM = \sum_{i=1}^{p} \omega_i SN_i^* \quad (1)$$

Here, ω_i is the weight of the b-th quality characteristic value. The sum of all weights becomes 1, that is, $\sum_{i=1}^{p} \omega_i = 1$. ω_i take advantage of the characteristics of the experiment, so the greater the weight, the greater the weight of the quality characteristic. In multi-characteristics where there are several quality characteristics to be considered, the optimal condition of the control factor may change as much as the weight of each quality characteristic changes, unlike the case of one quality characteristic. Therefore, various observation processes through exploratory data analysis are necessary. In particular, it would be a good study to observe the change in the optimal condition of the control factor according to the change in the weight of each quality characteristic through a graph. The experimental data of the performance measure SM is calculated by the number of experimental numbers. From the calculated n experimental data, we find the optimal condition for the multi-characteristic simultaneous control factor in the following order.

(1) Calculate the sum of SM for each level of control factor.

(2) Prepare an analysis of variance table.

Lastly, with the sum of SM for each level and the analysis of variance table, finally finding the optimal condition for multiple characteristics of control factors. Let’s look at the detailed optimization process in Chapter 3.

2.2 Conventional optimization procedure

In the case of multiple characteristics in the existing robust parameter design, the simultaneous optimization method is in the following order.

Calculate the SN ratio of all quality characteristics.

(2) Prepare the sum of SN ratios by level and analysis of variance table for each quality characteristic.

(3) Comprehensive result table for factor effect is prepared by leveling design factors that are significant for all quality characteristics.

Finally, the optimal level is judged by looking at the comprehensive result table for factor effects. Note that when a certain control factor is significant in two or more certain quality characteristics at the same time, when the optimal level is different for each quality characteristic, the criteria for selecting the optimal level are as follows.

(a) Select the optimum level among quality characteristics with a greater weight.

(b) Among the quality characteristics, if the difference between factor levels is greater than the difference in weight, that is, select the optimal level of the control factor that is statistically more significant.

The decision-making process above must reflect the opinions of experts such as product-related technicians and designers.

3. Numerical Example

In the multi-characteristic simultaneous optimization method for robust parameter design, the conventional

Table 1. Control factor placement

Column	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Factor	A	H	I				B	D	F	J					C

Table 2. Experimental data and *SN* ratio

	experimental data															SN ratio				
	Workability			Appearance						X-ray			Tensile	Elongation					
				Front			Back												
	g	p	b	g	p	b	g	p	b	g	p	b	kg/cm^2	%	SN_1	SN_2	SN_3	SN_4	SN_5
1	0	1	0	1	0	0	1	0	0	3	1	0	43.70	33.60	-6.02	0.00	-2.43	43.70	33.60
2	0	1	0	0	1	0	0	0	1	3	1	0	40.20	40.20	-6.02	-8.13	-2.43	40.20	40.20
3	0	1	0	0	1	0	0	1	0	4	0	0	42.40	30.50	-6.02	-6.02	0.00	42.40	30.50
4	1	0	0	1	0	0	0	1	0	2	2	0	44.70	23.70	0.00	-3.98	-3.98	44.70	23.70
5	1	0	0	0	1	0	0	0	1	2	2	0	42.40	34.70	0.00	-8.13	-3.98	42.40	34.70
6	0	0	1	0	0	1	0	0	1	4	0	0	45.90	21.80	-9.54	-9.54	0.00	45.90	21.80
7	1	0	0	1	0	0	0	1	0	2	2	0	42.20	24.80	0.00	-3.98	-3.98	42.20	24.80
8	0	0	1	0	1	0	0	0	1	3	1	0	40.60	29.80	-9.54	-8.13	-2.43	40.60	29.80
9	0	1	0	0	1	0	1	0	0	2	1	1	42.40	33.70	-6.02	-3.98	-5.74	42.40	33.70
10	0	1	0	0	1	0	0	1	0	3	1	0	45.50	25.50	-6.02	-6.02	-2.43	45.50	25.50
11	0	1	0	1	0	0	0	1	0	3	1	0	43.60	36.90	-6.02	-3.98	-2.43	43.60	36.90
12	0	1	0	0	1	0	1	0	0	4	0	0	40.60	29.00	-6.02	-3.98	0.00	40.60	29.00
13	1	0	0	1	0	0	0	0	1	0	3	1	44.00	30.30	0.00	-6.99	-7.20	44.00	30.30
14	0	0	1	0	0	1	0	0	1	3	0	1	40.20	39.00	-9.54	-9.54	-4.77	40.20	39.00
15	0	1	0	1	0	0	0	1	0	1	3	0	42.50	27.90	-6.02	-3.98	-5.12	42.50	27.90
16	0	1	0	1	0	0	1	0	0	4	0	0	46.50	40.80	-6.02	0.00	0.00	46.50	40.80

here, g=good, p=plain, b=bad

optimization method and the method using the performance measure SM using the SN ratio proposed in Chapter 2 are compared through an example.

An example experiment was a case in 1959 at the Songim Plant of the Japanese National Railways (Taguchi[2], p. 189-191). When electric welding two steel plates, we try to find the optimal conditions for the control factors for five quality characteristics, such as workability, appearance, X-ray inspection, mechanical tensile strength of the welded area, and elongation. Using an orthogonal arrangement table for the inner arrangement, 9 control factors of all 2 levels were arranged as shown in Table 1. In this study, only the main effect will be considered. Table 2 is the experimental data and SN ratio of five quality characteristic values. Workability, appearance, and X-ray inspection are coefficient classification values. Let each SN ratio (Sung-Hyun Park[7], p. 258, 261, 263) be SN_1, SN_2, SN_3. As for the tensile strength and elongation, the SN ratio cannot be calculated because repeated experiments for the noise factor are not performed.

However, since both characteristics are the larger-the better characteristics, for convenience, the original experimental data is treated as SN ratio and analyzed as SN_4 an SN_5.

3.1 Optimization Method by Performance Measure SM

Using the SN ratio (SN_1, SN_2, SN_3, SN_4, SN_5) of the five quality characteristics obtained in Table 2, let's find the optimal conditions for the control factors by the performance measure. Let SN_1, SN_2, SN_3, SN_4 and SN_5 be normalized to be SN_1^*, SN_2^*, SN_3^*, SN_4^* and SN_5^*. In this experiment, if the proportions of the five quality characteristics are the same, it becomes $\omega_1=\omega_2=\omega_3=\omega_4=\omega_5=0.2$. From Equation (1), the performance measure value

Table 3. Performance measure SM value

i	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
SM	2.55	-0.84	0.43	1.11	0.41	-1.53	0.05	-3.44	-0.93	0.03	1.70	-0.02	-0.58	-3.62	-1.58	6.25

Table 4. Sum of SM values by factor level

Factor level	A_0	A_1	B_0	B_1	C_0	C_1	D_0	D_1	F_0	F_1
Sum of SM	-1.26	1.26	-4.19	4.19	9.58	-9.58	2.06	-2.06	6.09	-6.09
Factor level	G_0	G_1	H_0	H_1	I_0	I_1	J_0	J_1	0	1
Sum of SM	1.42	-1.42	4.04	-4.04	-4.51	4.51	-4.13	4.13	9.10	-0.10

Table 5. ANOVA table

Source	Sum of square	Degree of freedom	Mean square	F	Significance probability
A	0.397	1	-	-	-
B	4.395	1	-	-	-
C	22.951	1	22.951	5.464	0.035
D	1.060	1	-	-	-
F	9.259	1	-	-	-
G	0.502	1	-	-	-
H	4.071	1	-	-	-
I	5.090	1	-	-	-
J	4.267	1	-	-	-
Error	29.765	6	-	-	
(Error)	58.805	14	4.200	-	
Sum	81.756	15			

according to the experiment number (i, No. 1-16) in the orthogonal arrangement table $L_{16}(2^{15})$ is calculated as Table 3. Table 4 is obtained by calculating the sum of SM values for each factor level of the control factor from Tables 1 and 3, and Table 5 is obtained by preparing an analysis of variance table. Table 5 the analysis of variance table considered only the C factor that was significant at the significance level of 10%, and the other factors were pooled in the error term, and an analysis of variance table was prepared. From Table 5, factor C is a very significant control factor at the significance level of 5% as a result of analysis of variance. The average sum of the performance measures SM by factor level From Table 4, the optimal level of the control factor is $A_1B_1C_0D_0F_0G_0H_0I_1J_1$.

3.2 Result of Conventional Optimization Procedure

For the experimental design as an example, Sung-Hyun Park[7] (p. 255-272) calculated the optimum level of control factors in the case of multi-characteristics using the conventional optimization method mentioned in Section 2.2. In the composite result table (Sung-Hyun Park[7], p. 270-271) for the factor effects, which summarized the significant control factors for all quality characteristics, the optimal level of the control factor was $A_1B_1C_0D_0F_0G_1H_0I_1J_1$.

3.3 Comparative Study

The proposed performance measure can be compared with the simultaneous multi-characteristic optimization method using SM and the conventional optimization method. From Sections 3.1 and 3.2, the simultaneous optimization condition in the conventional method was $A_1B_1C_0D_0F_0G_1H_0I_1J_1$ and the simultaneous optimization condition using the proposed performance measure is $A_1B_1C_0D_0F_0G_0H_0I_1J_1$. It can be seen that the difference between the optimal condition of the proposed method and the conventional method is in the G factor. This is because G factor in the existing method is significant at the same time in four quality characteristics such as workability, appearance, tensile strength, and elongation. This is because G factor in the conventional method is significant at the same time in four quality characteristics such as workability, appearance, tensile strength, and elongation. In this case, it is because, as mentioned in Section 2.2 above, when a certain control factor is significant in two or more certain quality characteristics at the same time and the optimal level is different for each quality characteristic, the optimal level is selected according to two criteria. In addition, it can be seen from Tables 4 and 5 that the *G* factor is not significantly different in the sum of SMs for each level in the performance measure also in the analysis of variance using *SM*. Therefore, the optimal condition of the control factor in the proposed method and the conventional method was able to obtain almost similar results.

4. Conclusions

When there are many quality characteristics to be considered in robust parameter design, a performance measure *SM* using a linear model of *SN* ratio is proposed. As a result of applying the proposed optimization method to the actual case, it was possible to find an optimal condition that almost coincided with the conventional method. Finding the optimal conditions for control factors in multiple characteristics is in most cases very complex depending on various cases, unlike the case of single quality characteristics. Therefore, in the case of multi-characteristics, the optimization performance measure for finding simultaneous optimal conditions should be simple and clear to be useful in practice. In multi-characteristics, the optimum condition of the control factor can be changed as much as the change in the weight of each quality characteristic. In this respect, the proposed performance measure can be said to be a performance measure that is convenient, easy to use, and easy to calculate because it can easily reflect the change in the weight of each quality characteristic compared to the conventional methods.

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