CASE 47

Stability Design of Shutter Mechanisms of Single-Use Cameras by Simulation

Abstract: In general, for a shutter mechanism of a single-use camera, a single-plate reciprocal opening mechanism of the guillotine type is adopted that controls the amount of light onto a photosensitive film by opening and closing the cover plate. Predetermination of the shutter speed is regarded as one of the most difficult performances to predict. In terms of the initial design of each dimension and specification, for efficient and objective design of a stable mechanism in a limited period, we conducted parameter design using simulation in the early design stage.

1. Introduction

Since we open and close the cover plate (which we subsequently call a *sector*) by pressing a shutter button that releases a compressed coil spring's force, there is no transitional control process for the series of actions (Figure 1). Therefore, it is difficult to predict a shutter speed in the early design phase, and if it causes estimated design constants or part dimensions to exceed their upper and lower limits, we need to go back to the prototype confirmation stage and modify the initial design.

In our conventional design procedure, based on data created by three-dimensional computer-aided design systems, we performed kinematic simulation. In this case, after allocating the initial value of each design parameter using our technical feeling and experience, we repeated simulation runs and fine tunings of parameters. According to the design values determined through this process, we prototyped an actual model and matched actual values with target values by the final adjustment. However, this was considered inefficient because we needed to modify the initial design if the amount of modification exceeded the limit predicted.

2. Input and Output of Shutter Mechanism

If we rely on simulation systems, we cannot handle environmental effects such as conditions regarding actual uses or time-lapsed deterioration. In this study, it was assumed that environmental effects appear as design factor errors, including part dimensions and physical properties. Therefore, errors were associated with control factors for simulation. It was considered ideal that there be no variation from the output under standard conditions. That is, a design whose output is insensitive to noise fluctuations can be regarded as robust to environmental deterioration. The three-dimensional model used for simulation is shown in Figure 2.

Method 1: Dynamic SN Ratio

This is a method of evaluating a sector's stability for motion time of a shutter mechanism by the SN ratio, which is based on the idea proposed in quality engineering. Although we can regard time as a signal and sector's position as an output value, we cannot deal with sector's motion as a dynamic characteristic because a sector has reciprocal motion (Figure 3*a*). To solve this problem, we

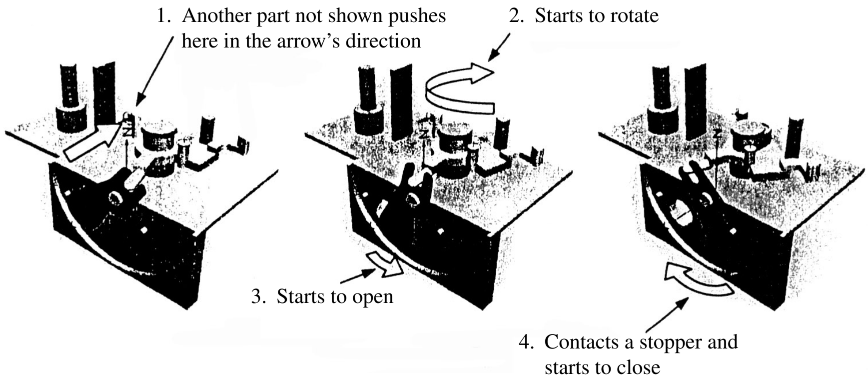

Figure 1
Shutter mechanism

substituted a cumulative value of motion angle that increases monotonously (Figure 3*b*).

Method 2: Standard SN Ratio

In method 1, because we obtained input/output relationships, as illustrated in Figures 4 and 5, we cannot see any direct relationship to the system. Thus, by setting an output value of the sector's position under the standard condition as signal, we considered a dynamic characteristic based on simulation results of the sector's position under noise conditions as outputs.

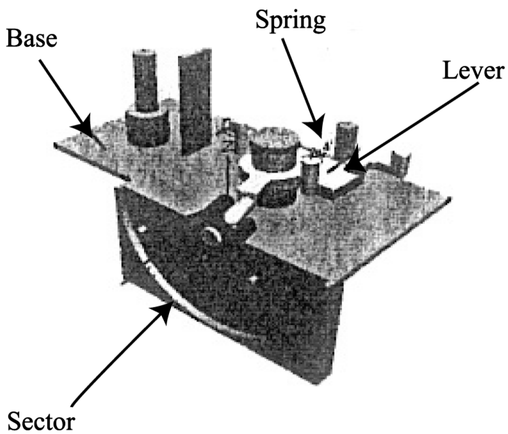

Figure 2
Three-dimensional model and part names

3. Parameter Design Using Method 1

After altering each control factor level by 5 to 10% around a standard condition, we compounded noise into two levels, positive side and negative side. By adding a standard condition to these two levels, we prepared three levels. We assigned eight factors, such as part dimensions, located positions, and spring constant to an L_{18} orthogonal array (Table 1).

Setup

We defined a motion time of a shutter mechanism as a signal factor, T, and a cumulative value of the sector's motion angle as an output value, y (Table 2).

Dynamic SN Ratio

We calculated the SN ratio by following the steps below. Because the system is nonlinear, V_e, which includes a nonlinear effect, is excluded from calculation of the SN ratio and sensitivity. Only the effect of $N \times \beta$ is used as error.

$$S_T = y_1^2 + y_2^2 + \cdots + y_{25}^2 \qquad (f = 15) \qquad (1)$$

$$r = M_1^2 + M_2^2 + \cdots + M_5^2 \qquad (2)$$

$$L_1 = y_{11}M_1 + y_{12}M_2 + \cdots + y_{15}M_5$$

$$L_2 = y_{21}M_1 + y_{22}M_2 + \cdots + y_{25}M_5 \qquad (3)$$

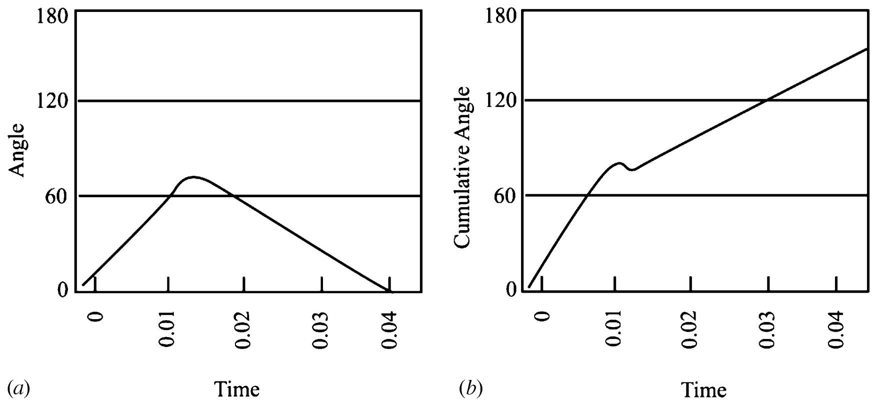

Figure 3
Data conversion of shutter angle

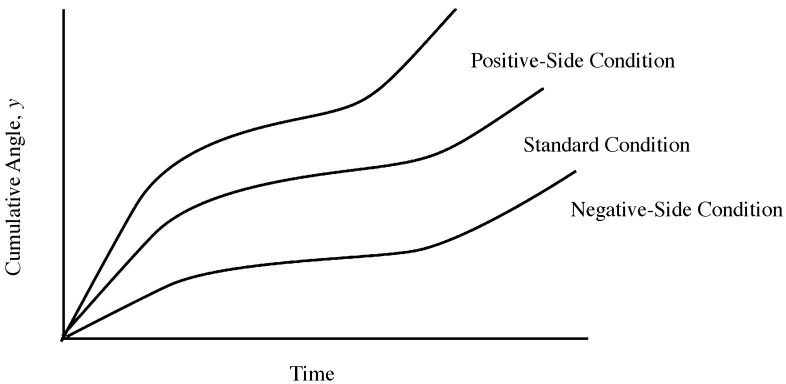

Figure 4
Input/output relationship in method 1

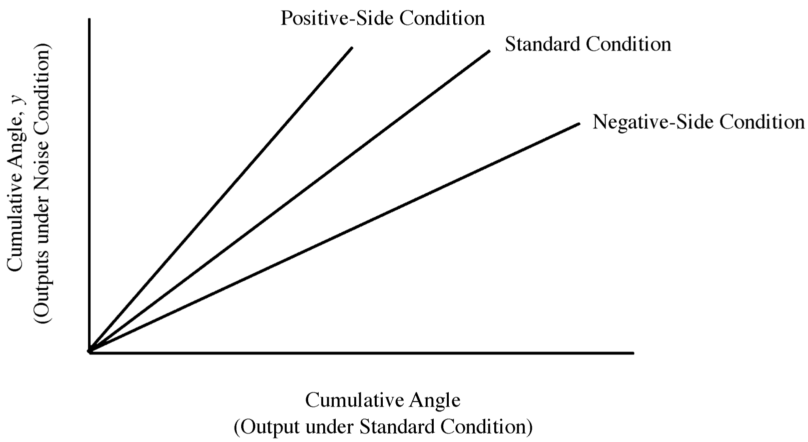

Figure 5
Input/output relationship in method 2

Table 1
Factors and levels

Control Factor		Level		
		1	2	3
A:	part A's weight	×0.5	Current	—
B:	part B's weight	×0.5	Current	×2.0
C:	part B's gravity center position	Current	Outside	More outside
D:	spring constant	Current	×1.3	×1.5
E:	spring attachment angle	A	B	C
F:	distance between parts C and D	Inside gravity center path	On gravity center path	Current
G:	part A's stroke	Short	Current	Long
H:	motion input	Weak	Current	Strong

Table 2
Data format

No.	Control Factor *A*	*B*	*C*	*D*	*E*	*F*	*G*	*H*	Error	Signal Factor T_1	T_2	T_3	T_4	T_5
1	1	1	1	1	1	1	1	1	N_1: standard condition	y_{11}	y_{12}	y_{13}	y_{14}	y_1
									N_2: positive-side condition	y_{21}	y_{22}	y_{23}	y_{24}	y_{25}
									N_3: negative-side condition	y_{31}	y_{32}	y_{33}	y_{34}	y_{35}
.	.	.	.	.	.	.	.	.	—	—	—	—	—	
.	.	.	.	.	.	.	.	.						
.	.	.	.	.	.	.	.	.						
18	2	3	3	2	1	2	3	1	N_1: standard condition					
									N_2: positive-side condition					
									N_3: negative-side condition					

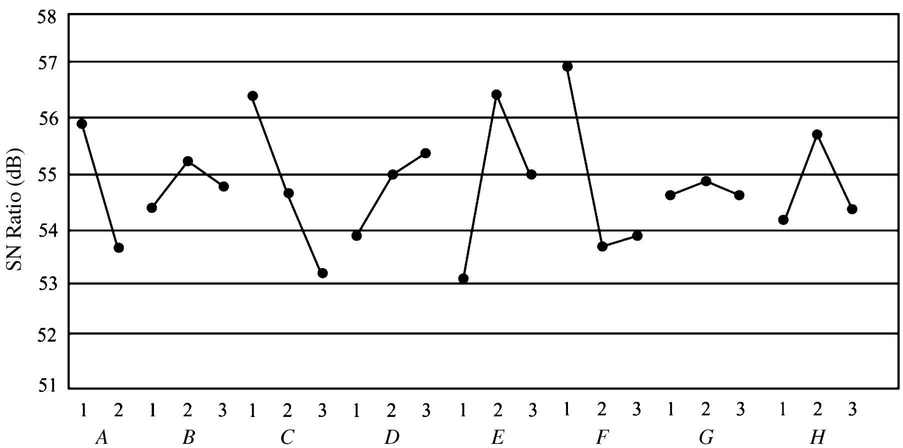

Figure 6
Response graphs of method 1

Table 3
SN ratio in confirmatory experiment dB

	Condition		
	Current	Optimal	Gain
Estimation	53.26	63.08	9.82
Confirmation	51.72	56.07	4.35

$$S_\beta = \frac{(L_1 + L_2 + L_3)^2}{3r} \qquad (f = 1) \tag{4}$$

$$S_{N\beta} = \frac{L_1^2 + L_2^2 + L_3^2}{r} - S_\beta \qquad (f = 2) \tag{5}$$

$$S_e = S_T - S_\beta - S_{N\beta} \qquad (f = 12) \tag{6}$$

$$V_e = \frac{S_e}{12} \tag{7}$$

$$V_N = \frac{S_{N\beta}}{2} \tag{8}$$

$$\eta = 10 \log \frac{(1/3r)(S_\beta - V_e)}{V_N} \tag{9}$$

Optimal Condition and Confirmatory Experiment

See Figure 6 and Table 3 for results of the confirmatory experiment.

4. Estimation of Gains and Results of Confirmatory Experiment

Figure 6 shows the response graphs. The current and optimal conditions are as follows:

Current Condition: $A_2B_2C_1D_1E_1F_3G_2H_2$

Optimal Condition: $A_1B_2C_1D_3E_2F_1G_2H_2$

The reproducibility is shown in Table 3; see also Figures 7 and 8.

Although we expected almost 10 dB of gain under the optimal condition as compared to that under standard conditions, our confirmatory experiment revealed that we can obtain only 4.3-dB improvement with poor reproducibility.

5. Parameter Design Using Method 2

We used the standard SN ratio in method 2 to compare with method 1.

Setup

We defined a simulation output (cumulative value of the sector's motion angle) under standard conditions and a simulation output (cumulative value of the sector's motion angle) under noise conditions as an output value, y (Table 4).

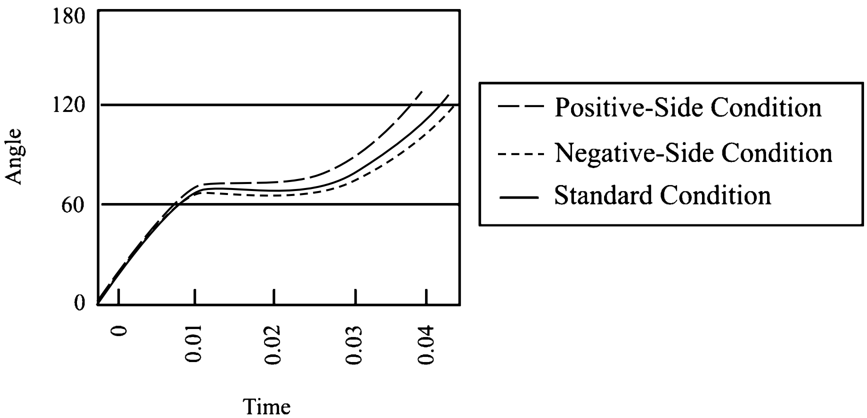

Figure 7
Angle change using method 1

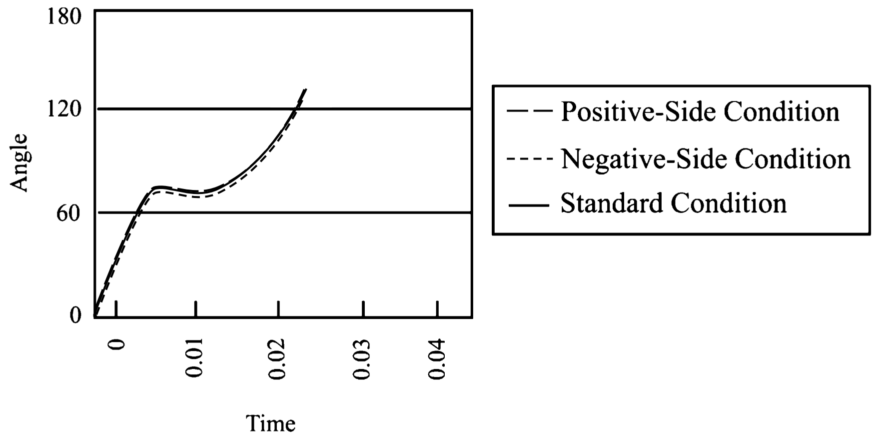

Figure 8
Angle under optimal condition in method 1

Standard SN Ratio

The calculations are as follows:

$$S_T = y_{11}^2 + y_{12}^2 + \cdots + y_{25}^2 \qquad (f = 10) \qquad (10)$$

$$r = M_1^2 + M_2^2 + \cdots + M_5^2 \qquad (11)$$

$$L_1 = y_{11}M_1 + y_{12}M_2 + \cdots + y_{15}M_5$$

$$L_2 = y_{21}M_1 + y_{22}M_2 + \cdots + y_{25}M_5 \qquad (12)$$

$$S_\beta = \frac{(L_1 + L_2)^2}{2r} \qquad (f = 1) \qquad (13)$$

$$S_{N\beta} = \frac{L_1^2 + L_2^2}{r} - S_\beta \qquad (f = 1) \qquad (14)$$

$$S_e = S_T - S_\beta - S_{N\beta} \qquad (f = 8) \qquad (15)$$

$$V_e = \frac{S_e}{8} \qquad (16)$$

$$V_N = \frac{S_{N\beta} + S_e}{9} \qquad (17)$$

$$\eta = 10 \log \frac{(1/2r)(S_\beta - V_e)}{V_N} \qquad (18)$$

Table 4
Data format

	Control Factor															
No.	***A***	***B***	***C***	***D***	***E***	***F***	***G***	***H***								
1	1	1	1	1	1	1	1	1	Signal	N:	standard condition	M_1	M_2	M_3	M_4	M_5
									Output	N_1:	positive-side condition	y_{11}	y_{12}	y_{13}	y_{14}	y_{15}
										N_2:	negative-side condition	y_{21}	y_{22}	y_{23}	y_{24}	y_{25}
⋮																
18	2	3	3	2	1	2	3	1	Signal	N:	standard condition					
									Output	N_1:	positive-side condition					
										N_2:	negative-side condition					

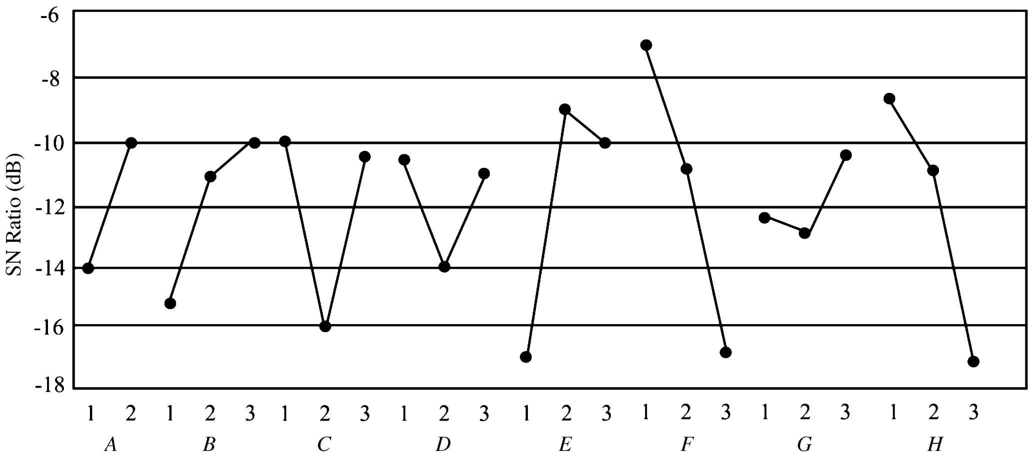

Figure 9
Response graphs of method 2

Optimal Condition and Confirmatory Experiment

The response graph of method 2 (Figure 9) was different from that in method 1 and we notice that there are fewer continuous-value factors that have a steep peak or V-shape in method 2 than in method 1. The current and optimal conditions are:

Current condition: $A_2B_2C_1D_1E_1F_3G_2H_2$

Optimal condition: $A_2B_3C_1D_1E_2F_1G_3H_1$

The reproducibility is shown in Table 5.

Comparing the gains of the two methods, both have poor reproducibility. In method 2, the gain is almost 20 dB from the estimate but only 13 dB from the confirmation. However, we concluded that a larger amount of improvement can be expected.

Table 5
SN ratio in confirmatory experiment (dB)

	Condition		
	Current	Optimal	Gain
Estimation	−13.49	6.49	19.98
Confirmation	−20.36	−7.65	12.71

The optimal condition under method 2 is shown in Figure 10.

6. Simulation Using Standard SN Ratio

This study predicates applying quality engineering to the simulation process in the uppermost stream of development, aiming for quality improvement. In simulation, environmental effects cannot be calculated. Under such circumstances, method 2 can bring more universal and satisfactory results than can method 1. This procedure can be regarded to have high generality and practicality because we can define input and output regardless of simulation contents or types. For mechanism designers, this is considered the most powerful tool to use to reduce technical risks in later phases because they can objectively evaluate unknown designs before actual products take shape.

In this example, since the sector's motion angle (Figure 3*a*) does not have a target curve, we have not made any adjustment tuning to a target value. When such tuning is needed, after securing functional stability as discussed in this example, we should make an adjustment by using simulation. This will enable us to develop products in a more efficient manner.

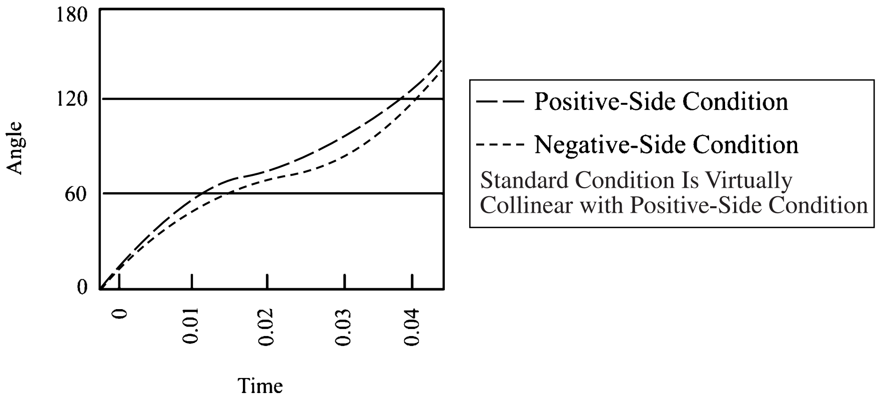

Figure 10
Angle change under optimal condition using method 2

Reference

Shuri Mizoguchi, 2001. Optimization of parameters in shutter mechanism designing. *Proceedings of the 9th Quality Engineering Symposium,* pp. 230–233.

This case study is contributed by Shuri Mizoguchi.