CASE 53

Improving Minivan Rear Window Latching

Abstract: In this project the authors built up an ADAMS computer model to simulate the closing/opening motions of the rear window glass latch of a minivan. This project was initially formulated to solve a high-closing/opening-effort problem with an initial latch design. However, in this study, closing/opening efforts are considered to be downstream quality characteristics and an upstream quality characteristic, input/output energy efficiency, was chosen as the surrogate. The objective and ideal functions of the latch system were also developed to evaluate the input/output relationship of the latch system. A design constraint of self-locking energy was also taken into consideration. Five control factors and one noise factor were selected to optimize the associated dynamic SN ratio and to meet the design constraint of self-locking energy through an L_{18} design of experiment (DOE) matrix. The improvements in the latch closing/opening efforts were validated and confirmed through prototypes.

1. Introduction

This project was initiated in October 1997. At that time, the project was at its early development stage; as a result, there was still much design freedom allowed for optimization of the latch system. The basic design of the latch is a four-bar linkage with a detent inside the handle to lock or unlock the latch (Figure 1).

2. Objective and Basic Functions

Initial clinic study showed that the opening/closing effort of the initial design was too high (around 110 N versus the target of 50 N) and quite sensitive to tolerance variations in the latch system. However, after thorough consideration, opening/closing effects were considered to be downstream quality characteristics; thus, they were not treated as the objective measurement in the study. Instead of the opening/closing efforts, the authors focused on the objective function of the latch system, to keep the window fully latched against the window seal strips. In other words, the basic function of a latch system is to convert latching (closing) energy into the sealing energy of weather strips so as to keep wind, audible noises, water, and so on, from coming into the vehicle. Simply put, the purpose of this case study was to enhance and smooth out the energy transformation of the latch system.

As mentioned above, the basic function of a latch system is to convert the closing energy of a latch into the sealing energy of window weather strips. Thus, the input is the energy required to close the latch, and the output would be the energy stored in the compressed weather strips. From this description, we defined the basic function of the latch (Figure 2).

In an ideal condition, all input energy would be converted in the sealing energy of weather strips and no energy would be wasted. However, under real working conditions, there would be numerous

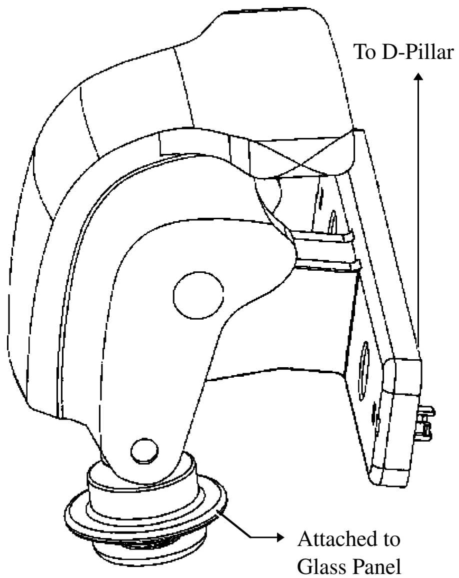

Figure 1
Rear window latch of a minivan

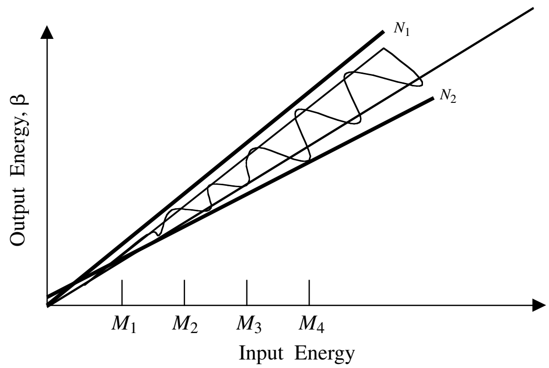

Figure 3
Real function

3. Design Constraints

In addition to its basic function, this latch has a design constraint, that is, it needs a certain amount of self-locking energy to prevent itself from unlocking. There is no strict requirement for this self-locking energy. However, the maximum opening effort will be strongly correlated to this self-locking energy (Figure 4).

noise factors that take away some input energy and convert it into wear, deterioration, vibration, rattle, and so on, in the latch system. The purpose of the robust engineering study was to maximize the energy efficiency and to reduce the variation of the basic function (Figure 3). To achieve this purpose, the authors maximized the dynamic SN ratio of zero-point proportional type.

4. Control and Noise Factors

The goal of a robust engineering study is to find out a good combination of control factors to make the

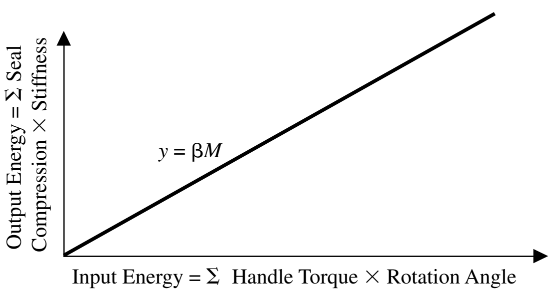

Figure 2
Ideal basic function

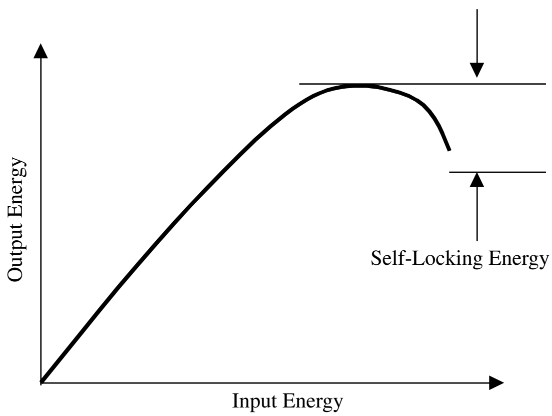

Figure 4
Design constraint of self-locking energy

target system insensitive to the noise factors selected and also to make the mean (i.e., average) output response meet its predetermined target value. In the study, the dimensions of the four-bar linkage of the latch were considered control factors and applied to achieve the robust engineering objective above. For convenience in computer simulations, the authors chose the handle length and the nominal values of the *x*- and *y*-coordinates of two key points, *A* and *B*, as control factors. In addition, the internal friction coefficient of the latch was considered to be a noise factor, *N*. Details of control and noise factors are shown in Table 1.

5. Dynamic SN Ratio

The following equations were applied to calculate the dynamic SN ratio for the real function of Figure 3. In the calculation, k is 4 and r_0 is 2.

$$y_{ij} = \beta M_i \ (i = 1, \ldots, k, \quad j = 1, \ldots, r_0) \tag{1}$$

$$S_\beta = \frac{\left(\sum Y_i M_i\right)^2}{r_0 \sum M_i^2} \qquad Y_i = \sum y_{ij} \tag{2}$$

$$S_T = \sum\sum y_{ij}^2 \tag{3}$$

$$\beta = \frac{\sum Y_i M_i}{r_0 \sum M_i^2} \tag{4}$$

$$\sigma^2 = V_e = \frac{S_T - S_\beta}{kr_0 - 1} \tag{5}$$

$$\mathrm{SN} = 10 \log\left(\frac{\beta^2}{\sigma^2}\right) \tag{6}$$

6. Simulation Data and Analysis

Next, the input/output energy data in the L_{18} DOE matrix of Table 2 were generated through the ADAMS/AVIEW model. The data were analyzed through General Motors' DEXPERT system. The main effects charts of the five control factors are shown in Figures 5 and 6.

In addition to the main effects charts, the ANOVA tables for SN, β, and the self-locking energy are given in Tables 3, 4, and 5.

Using the main effects charts and ANOVA tables above, the authors chose a good combination of the five control factors to maximize the SN ratio and to keep the self-locking energy at a reasonable level. Based on trade-off among SN ratios, β, and

Table 1
Control and noise factors

Factor	Abbreviation	Level 1	Level 2	Level 3
Control factors				
Handle length	C	Low	High	—
x-coordinates of *A*	A_x	Low	Mid	High
y-coordinates of *A*	A_y	Low	Mid	High
x-coordinates of *B*	B_x	Low	Mid	High
y-coordinates of *B*	B_y	Low	Mid	High
Noise factor				
Friction coefficient of the latch	N	Low	High	—

Table 2
L_{18} DOE matrix[a]

Run	Factor					M_1								β	SN Ratio	Average Self-Locking Energy	Seal Energy at Locking Postion
						10,000 Energy Units		20,000 Energy Units		30,000 Energy Units		40,000 Energy Units					
	C	A_x	A_y	B_x	B_y	N_1	N_2	N_1	N_2	N_1	N_2	N_1	N_2				
1	1	3	2	3	1	5,679	5,925	12,469	12,407	20,617	20,493	−10,000	0	0.241143	−95.9907	37,839	48,519
2	1	1	3	3	2	3,750	3,846	7,211	7,115	10,250	10,769	13,519	13,461	0.345375	−59.6395	10,115	41,676
3	1	1	2	2	3	3,600	3,900	7,360	7,400	11,300	11,060	15,000	15,020	0.373633	−50.2029	7,730	48,515
4	1	2	1	3	3	3,452	3,571	7,095	7,142	11,056	11,000	15,000	15,119	0.370235	−56.1026	809	59,286
5	1	1	1	1	1	4,167	4,214	8,367	8,761	13,381	13,310	18,095	18,476	0.448323	−58.1531	6,125	55,000
6	2	1	2	2	3	4,660	4,620	8,760	8,780	11,700	11,820	15,100	15,020	0.392333	−65.1758	7,620	48,293
7	2	3	1	2	2	5,625	5,630	11,188	11,313	18,750	19,312	0	9	0.284072	−90.7171	35,812	34,255
8	1	2	2	1	2	5,125	5,313	11,250	11,312	18,563	18,125	38,000	36,750	0.774377	−76.3228	37,906	12,096
9	2	2	1	3	3	3,928	3,952	7,809	7,857	12,071	12,119	16,404	16,476	0.405503	−54.0386	1,761	23,886
10	2	1	1	1	1	4,190	4,690	8,405	8,571	13,286	13,452	18,404	18,571	0.451577	−59.2203	6,023	55,353
⋮																	

[a] Per unit of input or output energy = 1.74533×10^{-5} J.

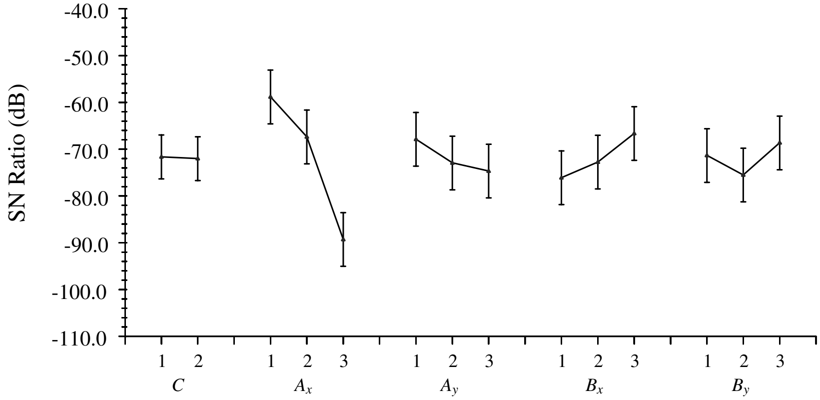

Figure 5
Main effects on the SN ratio

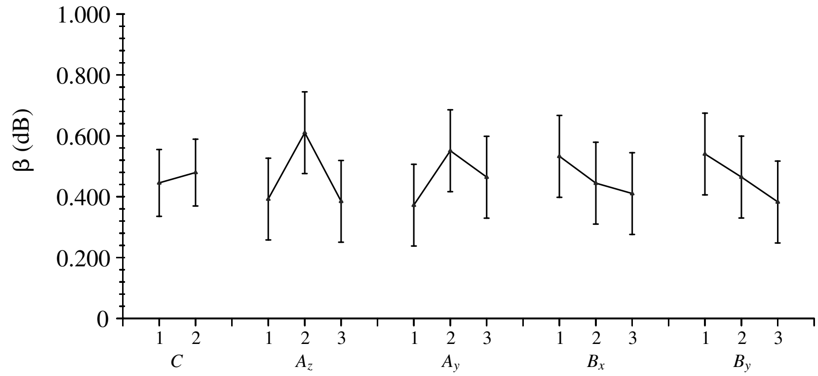

Figure 6
Main effects on beta (energy efficiency)

Table 3
ANOVA for the SN ratio

Source	d.f.	Percent Contribution
C (handle length)	1	0.00
A_x	2	78.50
A_y	2	2.07
B_x	2	5.26
B_y	2	0.57
Error	8	13.60
Total	17	100.00

Table 4
ANOVA for beta

Source	d.f.	Percent Contribution
C (handle length)	1	0.00
A_x	2	31.40
A_y	2	11.10
B_x	2	1.45
B_y	2	6.80
Error	8	49.25
Total	17	100.00

Table 5
ANOVA for the self-locking energy

Source	d.f.	Percent Contribution
C (handle length)	1	0.02
A_x	2	59.40
A_y	2	13.30
B_x	2	9.71
B_y	2	17.00
Error	8	0.57
Total	17	100.00

self-locking energy, the authors determined that the optimal design is C = level 1, A_x = 1, A_y = 2, B_x = 1, B_y = 1. Table 6 is a comparison of an initial (2,3,3,3,3) and an optimal (1,1,2,1,1) design.

7. Confirmations and Validations

Five prototypes of new latch design were made to validate the results of the computer simulation. Since it is extremely difficult to measure the input and output energy of the latch system, the authors applied downstream quality characteristics such as maximum opening/closing efforts and a water-leak test to conduct the validation tests. The maximum closing/opening efforts and water-leak test results are shown in Table 7. From this table the latch effort and the associated variation in the optimal design are seen to be better than the initial design. In other words, the new latch design meets customer requirements and also exhibits less variation.

8. Conclusions

In this project, the authors developed an objective and ideal function for the rear window latch of minivans. Next, the authors optimized five control fac-

Table 6
Comparison between initial and optimal designs

	Design		
	Initial	Optimal	Improvement
SN radio (dB)	−86.44	−63.56	−22.88
β (energy efficiency)	0.2715	0.6116	0.3410
Total closing energy (J)	1.30	1.28	0.02
Sealing energy at locking position (J)	0.68	0.84	0.16
Self-locking energy (opening energy) (J)	0.47	0.33	0.14

Table 7
Validation test results

	Design	
	Initial	Optimal
Water leak	Questionable	Pass
Maximum opening/closing effort (N)	95.70 ± 31.05	44.73 ± 10.52

tors to maximize the SN ratio while maintaining a reasonable amount of self-locking energy for the latch. An optimal design was achieved and the energy efficiency improved. Consequently, the mean value and variation of the maximum opening/closing effort have been improved by 53 and 66%, individually. As a result, the latch effort met the customer requirements and is more robust against the variation caused by assembly and usage conditions.

Acknowledgments The authors would like to thank Ron Nieman of Exterior Design, MLCG, and Jeffrey Flaugher of LOF for their input and efforts in this project, and Mike Wright of VSAS, MLCG, General Motors, for his guidance in using the DOE features of ADAMS/AVIEW. Thanks are also due to Tony Sajdak of MDI for his technical support of ADAMS/AVIEW. Finally, the authors wish to thank Dan Drahushak for his support in making this project a reality.

References

Genichi Taguchi, 1993. *Taguchi Methods: Design Of Experiment*. Quality Engineering Series, Vol. 4. Livonia, Michigan: ASI Press, pp. 34–38.

Kenzo Ueno and Shih-Chung Tsai (translator), 1997. *Company-Wide Implementations of Robust-Technology Development*. New York: ASME Press.

This case study is contributed by Shih-Chung Tsai and Manohar B. Motwani.