Study the effect of the weather strip on side door closing effort for passenger vehicle

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Abstract

The weatherstrip is one of the main factors affecting side door closing efforts. Primary and the secondary seals are the major contributor of door closing efforts. This paper study the effect of the manufacture variation for the compresses load deflection (CLD) for the weather strips on side door closing efforts and the manufacture variation of the seal gap too. The seal gap will be divided to segments to analysis the effect of each segment individually. The goal of this study is to optimize the closing effort by optimizing the seal gap variation for the secondary seal and optimize the manufacture tolerance for the primary and the secondary seals CLDs. Also, identify which seal segment is the main contributor for side door closing effort. These results are particularly helpful in developing and optimizing weather strip designs by computing efforts toward door-seal designs.

Keywords seal gap, door closing efforts, dynamic seal and seal CLD

INTRODUCTION

The door is the first system to interact with a vehicle's driver. It allows entry into the vehicle; therefore, priority has been given to its performance. The number of studies by automotive door engineers has increased during the past years, while the customer and the market have changed their quality standards.

The door closing effort is a quality issue concerning automobile designers and customers. However, the precise prediction of the door closing energy hasn't been fully developed.

The functions of the automotive door seals are to prevent dust and water from entering the vehicle and to isolate noise. To achieve these design targets, a door seal should have a reaction force higher than a specific criterion, while the effort to close the door requires a minimum reaction force. A door-seal design can be defined as a process of compromise between these two reciprocal design targets.

Automotive weatherstrip seals are used in between the doors and vehicle body along the perimeter of the doors. Door sealing is one of the most important automotive quality issues. The design and manufacturing process are important aspects for functionality and performance of the sealing system. However, door sealing involves many design and manufacturing factors.

Problem Statement

One of the main factors that has an effect on the closing effort is the weatherstrip in terms of the CLD and the seal gap. However, designers consider the nominal seal gap and the seal gap variation, thereby, predicting the value by using the DVA study. In many assembly plants, the measured points of the seal gap is different than the designed seal gap value (door inboard or outboard). This effects the side door closing effort and the wind noise. This study will collect the real data from the assembly plant and analyze the effect of the seal gap variation on the side door closing effort. Analysis will be made by using response surface methodology (RSM) to optimize the closing effort and the seal gap variation. RSM is a mathematical and statistical technique used in the development of an adequate functional relationship between a response of interest, y, and a number of associated control variables denoted by $x_1;\ x_2 \ldots .x_n$

To conduct these trials in the mathematical model, it would require a significant amount of time and effort. It would require 2187 experiments. However, with the response surface methodology and the DOE as a Box-Behnken design technique (which are experimental designs for RSM), the number of trials has been reduced to 62, thus, reducing time, effort, cost, and the possibility of errors due to the large number of experiments.

Seal Compression

The seal compression sink energy shown in Figure 1. Figure 1 should be the same for the following seals: primary, secondary, header, margin, and the rocker seal. Lowering the seal CLD improve door closing effort but it effect door closing sound quality [1]. To have a better understanding of the CLD curve, one needs to take a look at the ideal CLD curve and how the seal gap affects seal behavior such as the compression in Figure 2. Compression load deflection (CLD) behavior of a non-linear type of joint, automotive weatherstrip seal made of Ethylene Propylene Diene Monomer (EPDM) sponge rubber is examined using finite element modeling technique [2].

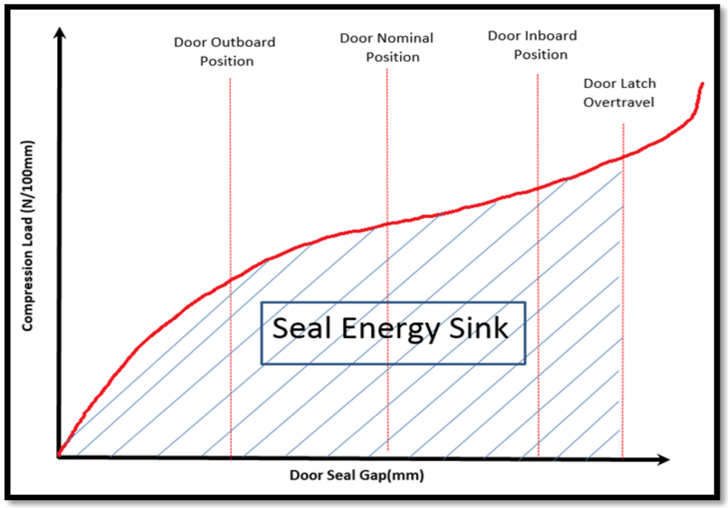


Figure 1. Figure 1. Showing the Sink Seal Energy

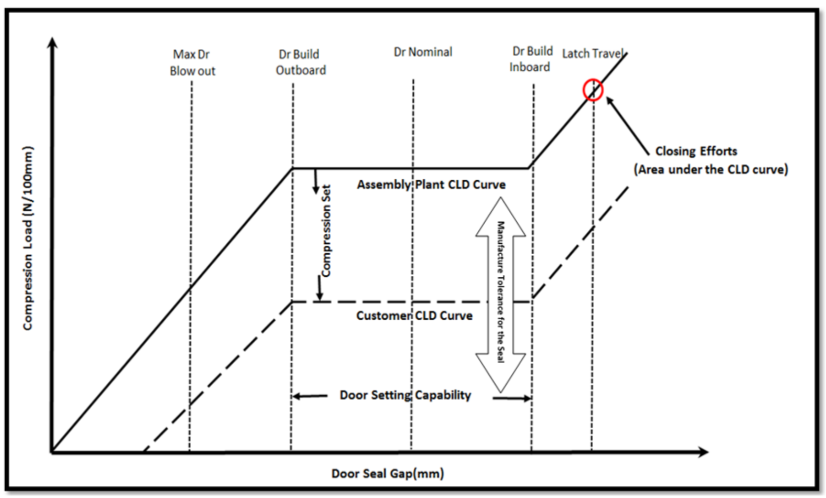


Figure 2. Ideal CLD Curve vs. Assembly Plant CLD Curve

Experimental Approach

Response Surface Methodology (RSM) includes the application of regression analysis and a powerful set of optimization techniques. RSM used to design a set of experiments that will result in reliable predictions of the response function allowing the development of a mathematical model by performing tests of the hypothesis. After that, the optimal settings of the influencing factors or input variables may be determined to achieve the desired optimized dependent variable [3]. Box-Behnken designs are experimental designs for RSM to achieve the following goals:

- The design must be sufficient to fit a second order polynomial.

- The ratio of the number of experimental points to the number of coefficients in the quadratic model should be reasonable, which means more than one as value.
- The predicted variance should depend only on the distance from the center of the design and should not vary significantly inside the smallest hypercube containing the experimental points.

Each design may be considered as a combination of a 2k factorial design with an incomplete block design. In each block, a certain number of factors are put through all combinations of the factorial design, while the other factors remain at the central values. The resulting design is either rotatable or nearly rotatable and is typically very efficient concerning the number of runs. In such a design, the contours associated with the variance of the estimation values are concentric circles, and its primary advantage is avoiding treatment combinations that are extreme (corner points).

A 3-level, 7-factor factorial design requires 2187 runs, whereas a Box-Behnken design requires 62 runs. This Box-Behnken design for seven factors and three levels includes two blocks contains each block 31 experiments. It is necessary to include center points where all factors are at their central values. Therefore, Box-Behnken designs are considered economic and useful, especially when significant expenses are required to conduct the needed experimental runs. An additional benefit of the Box- Behnken design is the redundancy factor defined as R=N/L

Where N is the number of runs and L is the number of constants, L can be estimated as (k + d)! / k!* d! Where k is the number of quantitative experimental variables and d is the degree of the polynomial; therefore, L = (7 + 2)! / 7! 2! = 36 resulting in a redundancy factor of R = 62 / 36 = 1.93, a measure of the number of experimental runs required to determine each coefficient of the second degree polynomial. In comparison, the 3-level, 7-factor factorial design would have a redundancy factor of 2187/62 = 35.3.

Model Postulation

Upon identifying the significant factors using screening factorial experiments, a functional relationship between side door closing efforts and the selected independent variables can be represented by Equation (1).

$$E = CX_1^k X_2^m X_3^n X_4^p X_5^q X_6^r X_7^t \qquad \text{……………………………(1)}$$

Where: E is a velocity of the rear edge of the door measured by m/sec and

X_1: First secondary seal segment at the B-Pillar above the belt

X_2: Second secondary seal segment at the header

X_3: Third secondary seal segment at the rocker

X_4: Fourth secondary seal segment at the B-Pillar below the belt

X_5: Fifth secondary seal segment at the A-pillar for the front door and at the C pillar for the rear door

X_6: Secondary seal CLD

X_7: Primary seal CLD as shown in Figure 4

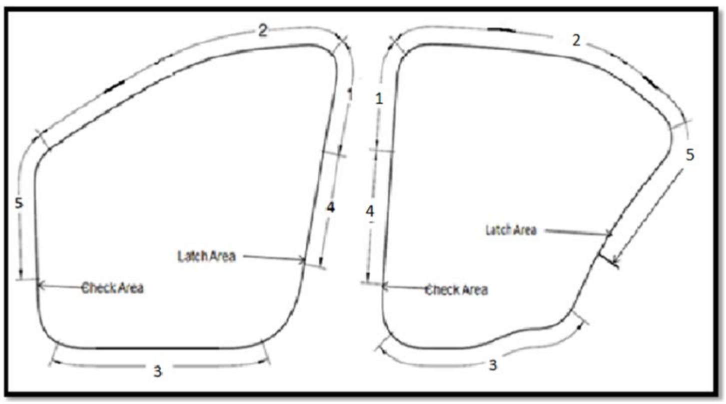


Figure 3. Numbers 1 to 5 Represent the Secondary Seal Segments X_1 to X_5

Equation (1) could write as:

$$\eta = \beta_o + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \beta_6 X_6 + \beta_7 X_7 + \varepsilon \qquad \text{…………(2)}$$

The above equation represents a logarithmic scale. The parameters β_1, β_2, …,β_7 are called regression coefficients or parameters and X_1, X_2, …, X_7 are logarithmic transformations of the input variables in the regression function. The experimental error is denoted as ε and may be defined as a combination of the random measurement error caused by sources such as test equipment and operators, as well as nonrandom errors caused by excluding factors from the designed experiment. Every experiment includes some degree of error that effect the value of the response corresponding to a specific combination of factor levels.

If the unknown parameters β_o, β_1,β_2,…, β_7 are replaced by estimates b0, b1,…, b7, the first-order prediction equation becomes:

$$\hat{y} = b_\circ + b_1 X_1 + b_2 X_2 + b_3 X_3 + b_4 X_4 + b_5 X_5 + b_6 X_6 + b_7 X_7 \qquad \text{…………….(3)}$$

The above "$\hat{y}$" is the estimated response on a logarithmic scale. The second order model can be represented by

$$\hat{y} = b_\circ + b_1 X_1 + b_2 X_2 + b_3 X_3 + b_4 X_4 + b_5 X_5 + b_6 X_6 + b_7 X_7 +$$
$$b_{11} X_1^2 + b_{22} X_2^2 + b_{33} X_3^2 + b_{44} X_4^2 + b_{55} X_5^2 + b_{66} X_6^2 + b_{77} X_7^2 +$$
$$b_{12} X_1 X_2 + b_{13} X_1 X_3 + b_{14} X_1 X_4 + b_{15} X_1 X_5 + b_{16} X_1 X_6 + b_{17} X_1 X_7 +$$

$$b_{23}X_2X_3 + b_{24}X_2X_4 + b_{25}X_2X_5 + b_{26}X_2X_6 + b_{27}X_2X_7 +$$
$$b_{34}X_3X_4 + b_{35}X_3X_5 + b_{36}X_3X_6 + b_{37}X_3X_7 +$$
$$b_{45}X_4X_5 + b_{46}X_4X_6 + b_{36}X_4X_7 +$$
$$b_{56}X_5X_6 + b_{66}X_5X_7 +$$
$$b_{67}X_6X_7 \quad \ldots\ldots\ldots\ldots\ldots\ldots(4)$$

If this polynomial exactly represents the response function ŷ, then b0 is the response at $X_1 = X_2 = X_3 = X_4 = \cdots = X_7 = 0$. The coefficients $b_1, b_2, b_3, \ldots. b7$ are the values of the 1st order partial derivatives$\frac{\partial \hat{y}}{\partial X_1}, \frac{\partial \hat{y}}{\partial X_2}, \frac{\partial \hat{y}}{\partial X_3}, \frac{\partial \hat{y}}{\partial X_4}, \frac{\partial \hat{y}}{\partial X_5}, \frac{\partial \hat{y}}{\partial X_6}, \frac{\partial \hat{y}}{\partial X_7}$, of $\hat{y}$ with respect to $X_1, X_2, X_3, X_4, \ldots X_7$ evaluated at $X_1 = X_2 = X_3 = X_4 = \cdots = X_7 = 0$ and are referred to as 1st order effects. The remaining coefficients $b_{11}, b_{22}, b_{33}, b_{44} \ldots b_{67}$ are defined as the values of the 2nd order partial derivatives, $\frac{\frac{1}{2}\partial^2 \hat{y}}{\partial x_1^2}, \frac{\frac{1}{2}\partial^2 \hat{y}}{\partial x_2^2}, \frac{\frac{1}{2}\partial^2 \hat{y}}{\partial x_3^2}, \frac{\frac{1}{2}\partial^2 \hat{y}}{\partial x_4^2}, \ldots. \frac{\frac{1}{2}\partial^2 \hat{y}}{\partial x_{7.}^2}$ respectively, at $X_1 = X_2 = X_3 = X_4 = \cdots = X_7 = 0$, and are called the 2nd order effects.

Coding of Variables

The range of settings for these quantitative factors will be determined. While experimenting, their measurement and control techniques must be defined.

The secondary seal gap segments', which are defined by X_1 to X_5, measured by the LMI device for several vehicle platform. The factors are designed with the same seal gap variation and have the same sealing system. Therefore, the zero will define the nominal seal gap, and the other factors will define the nominal seal CLD. (-1) will define the minimum seal gap (maximum door going inboard). The CLD factor will define the minimum CLD for the seals. (+1) represents the maximum seal gap (maximum seal going outboard in the plan) and the CLD factor will define the maximum seal CLD value. Table 1will illustrate the levels and the coding of the independent variables for front and rear doors.

Table 1. Levels and Coding of the Independent Variables for Front Doors

Independent Variable	1st B- pillar Segment above the Belt (mm)	2nd Header Segment (mm)	3rd Rocker Segment (mm)	4th B-Pillar Segment below the belt (mm)	5th A-Pillar & C Pillar Segment for the FR & RR DR Perspectival (mm)	6th Secondary Seal CLD (N/100mm)	7th Primary Seal CLD (N/100mm)
Code	X_1	X_2	X_3	X_4	X_5	X_6	X_7
-1	8.5	8.5	10.79	9.17	9.49	1.59	1.99
0	12.0	12.03	13.8	12.8	13	2.59	3.99
+1	16.79	17.82	18.33	16.08	18.5	4.59	5.99

Design of Experiments

A Box-Behnken design was aimed at estimating the maximum number of main effects in an unbiased (orthogonal) fashion by performing a minimum number of experimental runs. This research uses the Box-Behnken technique to reduce the number of experiments which are used with the mathematical model to calculate the side door closing effort. The data matrix represented in Table 2 required for studying seven factors in 62 trials. The plus signs indicate the high levels of the independent variables, while the minus signs represent the low levels, and the central levels are represented by zeroes as coded in The 36 coefficients for the second order model shown in Equation (4). One can determine the variables by conducting and analyzing the 62 runs outlined in Table 4. Full factorial design requires 152 runs compared to a Box-Behnken design, which consists of two blocks, each block including 31 trials, ending up with 62 experiments as shown in Table 2.

Experimentation

A mathematical model will be used to predict the side door closing effort with seven factors and three variables. This experimentation will consist of 62 runs as shown inTable 2. This Box-Behnken design for 7 factors involves 7 blocks, wherein each block contain 3 factors and it can vary through the 8 possible combinations of high and low. It is necessary to include center points where all factors are at their central values. The fundamental design matrix is written in the form as shown below:

$$DCE=\begin{bmatrix} 0 & 0 & 0 & \pm1 & \pm1 & \pm1 & 0 \\ \pm1 & 0 & 0 & 0 & 0 & \pm1 & \pm1 \\ 0 & \pm1 & 0 & 0 & \pm1 & 0 & \pm1 \\ \pm1 & \pm1 & 0 & \pm1 & 0 & 0 & 0 \\ 0 & 0 & \pm1 & \pm1 & 0 & 0 & \pm1 \\ \pm1 & 0 & \pm1 & 0 & \pm1 & 0 & 0 \\ 0 & \pm1 & \pm1 & 0 & 0 & \pm1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5)$$

Table 2. Coding and Actual Levels for the Front Doors

Run	X1	X2	X3	X4	X5	X6	X7	1st B- pillar Segment above the Belt (mm)	2nd Header Segment (mm)	3rd Rocker Segment (mm)	4th B-Pillar Segment below the belt (mm)	5th A-Pillar & C Pillar Segment for the FR & RR DR Perspectival (mm)	6th Secondary Seal CLD (N/100mm)	7th Primary Seal CLD (N/100mm)
1	0	0	0	-	-	-	0	12	12.03	13.8	9.3	9.5	1.59	3.99
2	0	0	0	+	-	-	0	12	12.03	13.8	16.08	9.5	1.59	3.99
3	0	0	0	-	+	-	0	12	12.03	13.8	9.3	18.5	1.59	3.99
4	0	0	0	+	+	-	0	12	12.03	13.8	16.08	18.5	1.59	3.99
5	0	0	0	-	-	+	0	12	12.03	13.8	10.0	9.5	4.59	3.99
6	0	0	0	+	-	+	0	12	12.03	13.8	16.08	9.5	4.59	3.99
7	0	0	0	-	+	+	0	12	12.03	13.8	9.3	18.5	4.59	3.99
8	0	0	0	+	+	+	0	12	12.03	13.8	16.08	18.5	4.59	3.99
9	-	0	0	0	0	-	-	8.5	12.03	13.8	12.8	13.0	1.59	1.99
10	+	0	0	0	0	-	-	16.79	12.03	13.8	12.8	13.0	1.59	1.99
11	-	0	0	0	0	+	-	8.5	12.03	13.8	12.8	13.0	4.59	1.99
12	+	0	0	0	0	+	-	16.79	12.03	13.8	12.8	13.0	4.59	1.99
13	-	0	0	0	0	-	+	8.5	12.03	13.8	12.8	13.0	1.59	5.99
14	+	0	0	0	0	-	+	16.79	12.03	13.8	12.8	13.0	1.59	5.99
15	-	0	0	0	0	+	+	8.5	12.03	13.8	12.8	13.0	4.59	5.99
16	+	0	0	0	0	+	+	16.79	12.03	13.8	12.8	13.0	4.59	5.99
17	0	-	0	0	-	0	-	12	8.53	13.8	12.8	9.5	2.59	1.99
18	0	+	0	0	-	0	-	12	17.82	13.8	12.8	9.5	2.59	1.99
19	0	-	0	0	+	0	-	12	8.53	13.8	12.8	18.5	2.59	1.99
20	0	+	0	0	+	0	-	12	17.82	13.8	12.8	18.5	2.59	1.99
21	0	-	0	0	-	0	+	12	8.53	13.8	12.8	9.5	2.59	5.99
22	0	+	0	0	-	0	+	12	17.82	13.8	12.8	9.5	2.59	5.99
23	0	-	0	0	+	0	+	12	8.53	13.8	12.8	18.5	2.59	5.99
24	0	+	0	0	+	0	+	12	17.82	13.8	12.8	18.5	2.59	5.99
25	-	-	0	-	0	0	0	8.5	8.53	13.8	9.3	13.0	2.59	3.99
26	+	-	0	-	0	0	0	16.79	8.53	13.8	9.3	13.0	2.59	3.99
27	-	+	0	-	0	0	0	8.5	17.82	13.8	9.3	13.0	2.59	3.99
28	+	+	0	-	0	0	0	16.79	17.82	13.8	9.3	13.0	2.59	3.99
29	-	-	0	+	0	0	0	8.5	8.53	13.8	16.08	13.0	2.59	3.99
30	+	-	0	+	0	0	0	16.79	8.53	13.8	16.08	13.0	2.59	3.99
31	-	+	0	+	0	0	0	8.5	17.82	13.8	16.08	13.0	2.59	3.99
32	+	+	0	+	0	0	0	16.79	17.82	13.8	16.08	13.0	2.59	3.99
33	0	0	-	-	0	0	-	12	12.03	10.79	9.3	13.0	2.59	1.99
34	0	0	+	-	0	0	-	12	12.03	18.33	9.3	13.0	2.59	1.99
35	0	0	-	+	0	0	-	12	12.03	10.79	16.08	13.0	2.59	1.99
36	0	0	+	+	0	0	-	12	12.03	18.33	16.08	13.0	2.59	1.99
37	0	0	-	-	0	0	+	12	12.03	10.79	9.3	13.0	2.59	5.99
38	0	0	+	-	0	0	+	12	12.03	18.33	9.3	13.0	2.59	5.99
39	0	0	-	+	0	0	+	12	12.03	10.79	16.08	13.0	2.59	5.99
40	0	0	+	+	0	0	+	12	12.03	18.33	16.08	13.0	2.59	5.99
41	-	0	-	0	-	0	0	8.5	12.03	10.79	12.8	9.5	2.59	3.99
42	+	0	-	0	-	0	0	16.79	12.03	10.79	12.8	9.5	2.59	3.99
43	-	0	+	0	-	0	0	8.5	12.03	18.33	12.8	9.5	2.59	3.99
44	+	0	+	0	-	0	0	16.79	12.03	18.33	12.8	9.5	2.59	3.99
45	-	0	-	0	+	0	0	8.5	12.03	10.79	12.8	18.5	2.59	3.99
46	+	0	-	0	+	0	0	16.79	12.03	10.79	12.8	18.5	2.59	3.99
47	-	0	+	0	+	0	0	8.5	12.03	18.33	12.8	18.5	2.59	3.99
48	+	0	+	0	+	0	0	16.79	12.03	18.33	12.8	18.5	2.59	3.99
49	0	-	-	0	0	-	0	12	8.53	10.79	12.8	13.0	1.59	3.99
50	0	+	-	0	0	-	0	12	17.82	10.79	12.8	13.0	1.59	3.99
51	0	-	+	0	0	-	0	12	8.53	18.33	12.8	13.0	1.59	3.99
52	0	+	+	0	0	-	0	12	17.82	18.33	12.8	13.0	1.59	3.99
53	0	-	-	0	0	+	0	12	8.53	10.79	12.8	13.0	4.59	3.99
54	0	+	-	0	0	+	0	12	17.82	10.79	12.8	13.0	4.59	3.99
55	0	-	+	0	0	+	0	12	8.53	18.33	12.8	13.0	4.59	3.99
56	0	+	+	0	0	+	0	12	17.82	18.33	12.8	13.0	4.59	3.99
57	0	0	0	0	0	0	0	12	12.03	13.8	12.8	13.0	2.59	3.99
58	0	0	0	0	0	0	0	12	12.03	13.8	12.8	13.0	2.59	3.99
59	0	0	0	0	0	0	0	12	12.03	13.8	12.8	13.0	2.59	3.99
60	0	0	0	0	0	0	0	12	12.03	13.8	12.8	13.0	2.59	3.99
61	0	0	0	0	0	0	0	12	12.03	13.8	12.8	13.0	2.59	3.99
62	0	0	0	0	0	0	0	12	12.03	13.8	12.8	13.0	2.59	3.99

Data Analysis

The T statistic describes how the mean of a sample with a certain number of observations is expected to behave. In this section, one will look for the regression coefficient, which is the coefficient divided by its corresponding standard error. The standard error is an estimate of the standard deviation of the coefficient. This may explain a measure of the precision with which the regression coefficient is measured.

The p-value for each term tests the null hypothesis that the coefficient is equal to zero (no effect). A low p-value (< 0.05) indicates strong evidence that the null hypothesis should be rejected. The coefficient of determination R-Squared R^2 for the regression predict model at 80.71% is adequate for fitting door closing effort. The adjusted R^2 value attempts to provide a more honest value to estimate R^2and an adjusted R^2 of 93.64% suggests the second order model is very adequate to represent the variability of the door closing effort as a function of all the noted factors. The regression equation or resulting model for front door closing effort is shown below in equation 6.

$$\begin{aligned} Front\ Door\ Closing\ Effort\ (J) &= 2.258 - 0.1157X_1 - 0.1468X_2 - 0.1026X_3 - 0.2005X_4 - 0.0515X_5 \\ &+ 0.6892X_6 + 0.6159X_7 + 0.0225X_1X_1 - 0.0211X_2X_2 - 0.0007X_3X_3 \\ &+ 0.1078X_4X_4 + 0.0655X_5X_5 + 0.3722X_6X_6 - 0.0188X_{67}X_7 + 0.0001X_1X_2 \\ &- 0.0000X_1X_3 - 0.0001X_1X_4 + 0.0003X_1X_5 - 0.0251X_1X_6 + 0.0001X_1X_7 \\ &- 0.0001X_2X_3 - 0.0001X_2X_4 - 0.0001X_2X_5 - 0.0951X_2X_6 + 0.0001X_2X_7 \\ &+ 0.0000X_3X_4 - 0.0000X_3X_5 - 0.0766X_3X_6 + 0.0000X_3X_7 - 0.0005X_4X_5 \\ &- 0.3372X_4X_6 + 0.0062X_4X_7 - 0.0458X_5X_6 - 0.0001X_5X_7 + 0.0001X_6X_7 \end{aligned} \quad \ldots\ldots(6)$$

The second iteration gives an improvement for the R-sq prediction from 80.71% to 93.52% and is excellent for fitting the door closing effort. The R-sq adjust from 93.64% to 95.53% and the Meta Model equation for the front door closing effort defined in the equation 7.

$$\begin{aligned} Front\ Door\ Closing\ Effort\ (J) &= 2.2799 - 0.1157X_1 - 0.1468X_2 - 0.1026X_3 - 0.2005X_4 + 0.6892X_6 \\ &+ 0.6159X_7 + 0.1032X_4X_4 + 0.3722X_6X_6 - 0.3372X_4X_6 \end{aligned} \quad \ldots\ldots(7)$$

Analysis the variable for Door Closing Effort in Meta Model equation

The contour plots of the fitted models are used for the characterization of the response surfaces. Figure 5 illustrates contour plots for the front door closing effort. The secondary seal CLD with higher CLD value X_6will have a major effect on the closing effort on the B pillar seal gap area $X_4$with tight seal gap value as shown in violet color. In addition, when seal CLD for both seals is high, then the closing effort will be high too. The secondary impact on the closing effort caused by the secondary seal CLD X_6 bundled with X_1, X_2 *and* X_3 as shown in light blue and it shows the closing effort reduced when the seal gap is wider.

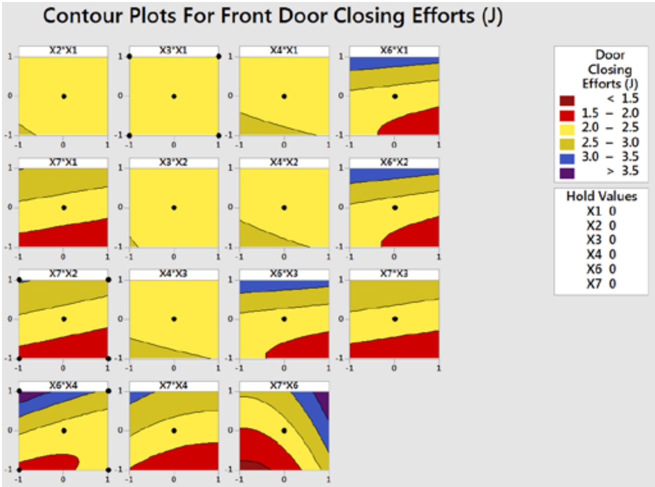


Figure 4. Contour Plots of the Surfaces Generated by the Prediction Equations for Front Door Closing Effort

Figure 5 for front door closing effort, the secondary seal CLD X_6 is the main variable that has effect on closing effort. The primary seal CLD X_7 is the secondary factor that is causes high closing effort for the front door. The third major variable that will effect the closing effort is the secondary seal gap variation at the B pillar X_4. The other variables are X_1, X_2, X_3 *and* X_5 have less effect on the closing effort. In other word, one needs to pay more attention in designing the main variables X_6, X_7*and* X_4 and working to control these variables.

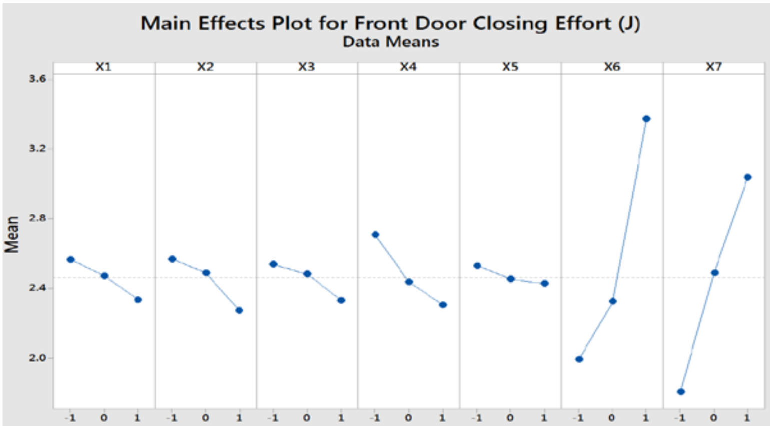
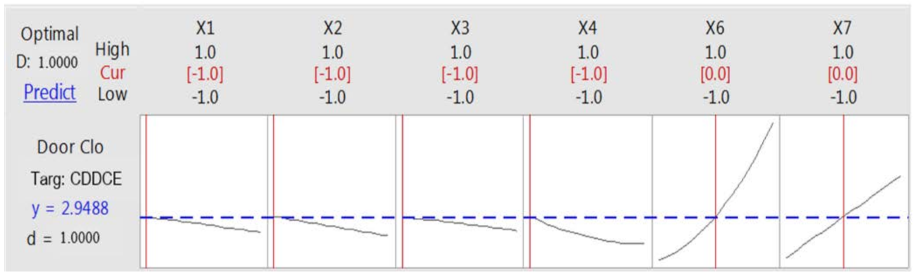


Figure 5. Main Effects Plot for Front Door Closing Effort (J)

Sensitivity Analysis

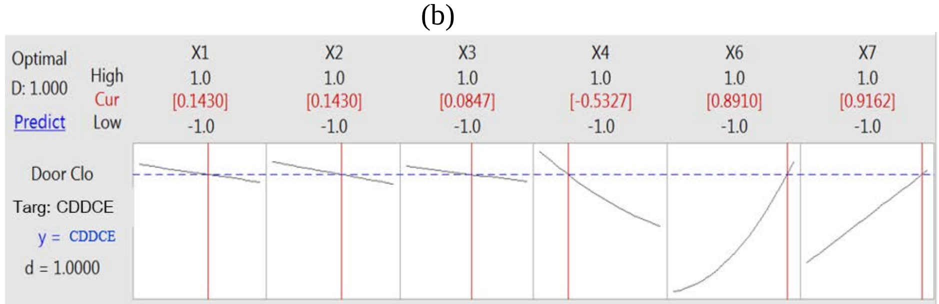
Sensitivity analysis is an essential tool in the process of building models, since most of the independent variables are part of the structures of these models. This model helps to define the optimum seal gap variation with optimum seal CLDs variation so that it can meet the Customer Desired Door Closing Energy (CDDCE). For this reason, many iterations be summarized for front and rear doors as follows:

- Nominal seal CLDs for the primary and secondary seals with tight seal gap variations as shown in the Figure 6a for the front This option can deliver 2.94J for the front However, this in feasible because it doesn't account for the seal's CLD variation .
- Propose a seal gap variation ±2.5 and the seals CLD's ±2.0. For the high end seal's CLD's, it shows that one can meet the CDDCE, but with infeasible conditions which is some seal segment's it can't accept any door build inboard condition. This is shown in Figure 6b.
- Propose a seal gap variation ±2.0 and the seals CLD's ±1.5. For the high end seal's CLD's, it shows one can meet the CDDCE. However, infeasible conditions some seal segments can't accept any door build inboard condition. This is shown in Figure6 c .
- Propose a seal gap variation ±2.5 and the seals CLD's ±1.0. For the high end seal's CLD's, it shows one can meet the CDDCE. However, infeasible conditions some seal segments can't accept any door build inboard conditions. This is shown in Figure 6d
- Propose a seal gap variation ±1.5 and the seals CLD's ±1.0. For the high end seal's CLD's, it shows one can meet the CDDCE.However, it is feasible with worst-case door build inboard conditions. This is shown in Figure 6e This technique helps to understand the behavior of all the variables on the door closing effort mode and optimize the variables to meet the CDDCE.

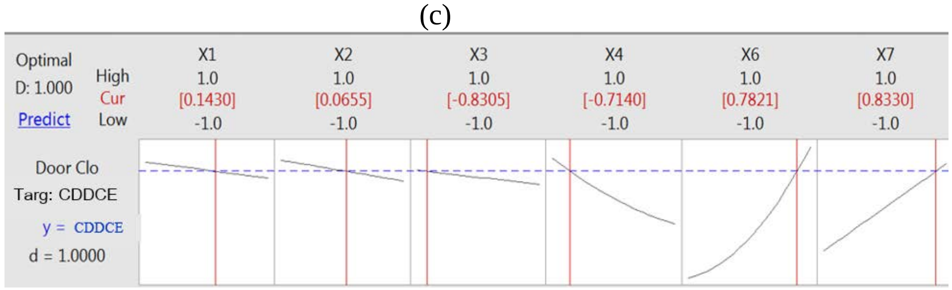


(a)

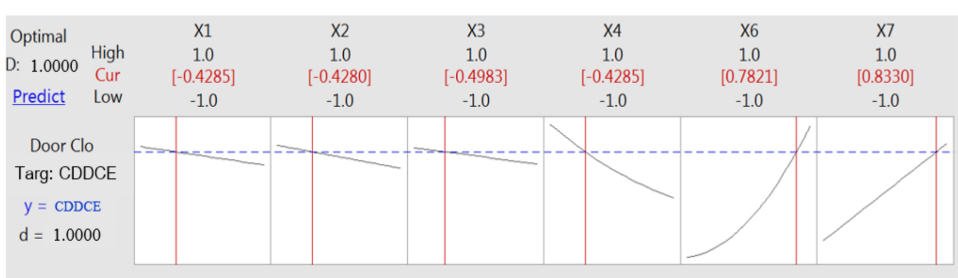
(b)



(c)



(d)



(e)

Figure 6. Optimize Front Door Closing Effort with Respect to the Effective Variables in Mathematical Model

Conclusions

One of the customer's initial impressions regarding the quality of the vehicle will be the behavior of the opening and closing of the door and energy that are required to obtain full latching. In order to optimize the closing efforts, the seal gap variations, which are delivered by the assembly plant, must be analyzed. This step will enable one to understand how to best meet the closing efforts with customer satisfaction. Response surface methodology enabled the second order models for the side door closing effort. A Meta Model or surrogate model for the front and rear door closing effort is a model of a model with insignificant terms. These created models accurately describe the side door closing effort values. To calculate the second order regression model coefficients, each design variable was studied at three distinct levels and a Box-Behnken design with 3-level. A 7-factor factorial design provided a redundancy factor 35.3%. Sensitivity analyses were performed where in the evaluated input parameters were part of the structures of the door closing effort models. The sensitivity analyses define the major factors that had an effect on the door closing efforts. The secondary seal CLD, with the manufacture tolerance, was the major variable effect on the door closing efforts. The primary seal CLD with the manufacture tolerance was the second variable. In addition, the seal gap manufacture variation, defined the seal gap at the upper and lower hinges. This was negligible for both front door, which it defined by the variable X_5 for front door. The seal gap variation at the hinge area is defined by X_1. This was the major variable that affected the closing effort then the header area X_2, B pillar margin seal above the belt X_2 and the least affect was the rocker area seal variation X_3.

This applied research focused on the development of an optimization process for the door closing efforts with multipul iterations. The output for this dissertation is meeting the customer satisfaction for side door closing efforts. This was combined by reducing the seal gap variation for all the primary and the secondary seal to ±1N without reduce the nominal seal CLD. In addition, needs to reduce the seal gap variation for the secondary seal to ±1.5mm for both front and rear doors.

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