Automotive Door Sealing System Analysis

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ABSTRACT

Door sealing system is one of the most important automotive quality issues. Problems with door seal system could cause water leakage, wind noise and hard to open or close, which impair customer's satisfaction of the vehicle. That is why the door seal problem is always among the Hardy Perennial Top 10 list in JD Power Tracking Study.

The design rationality and manufacturing process are important aspects for the functionality and performance of a sealing system. However, the door sealing system involves many design variables and manufacturing variables. It is almost impossible to precisely confirm individual quantitative effects on functionalities of these variables. Therefore, computer based simulation of door sealing system is more practical since it can isolate the critical factors and it is cost effective and time efficient.

LS-DYNA was used to simulate door seal system. The key structural component, the rubber seal, was modeled and simulated. Different types of elements, material models and contact algorithms from LS-DYNA element, material and contact libraries were tried and compared. Consequently, the best modeling and simulation technology was developed for the door sealing system analysis.

The newly developed method showed the great potential of comprehensive studies of door sealing system. The analysis results provided some major parameters, such as seal deformation, contact pressure and energy transformation, which would influence the functionality and performance of the door sealing system. The analysis results have been compared with some available test data, and very good correlations were obtained. The analysis also evaluated the influence of manufacturing deviations. With the results obtained from this analysis, the relationship between the major parameters could be established and used as a tool to derive a better sealing system design at early stage. This analysis method could also be used to evaluate the influence of certain type of process error. Eventually, this analysis method will be developed into a tool that is capable of predicting water leakage, wind noise and hard to open/close problems caused by either product design or manufacturing process.

INTRODUCTION

To develop high quality vehicles in a timely fashion necessitates a design process, which should not only conform design specifications but also could be evaluated mathematically prior to hardware build. It is too slow for the fiercely competitive market to iterate the process of design, physical prototype, test and redesign. Furthermore, it is not feasible to conduct a sufficient number of hardware tests to accurately determine expected conformance rates. GM and some seal suppliers have been using analysis method to support door seal design for quiet long time. The existing method could make some reliable prediction, like seal Compression-Load Deflection (CLD) curve and deformations at different seal cross sections. Some important parameters could be evolved by the existing analysis method. However, the analysis result from existing method would not provide adequate information if a sealing system is to be evaluated, such as the overall seal transient deformation, contact pressure and seal strain energy contributed to door closing effort based on door closing motion.

The scope of this paper has introduced that LS-DYNA was used as an analysis tool to the door sealing system analysis. The analysis results provided some information, which are either unavailable from any other sources or requires much more work to get. This new developed method showed the capability of providing more accurate and detailed information depending on the complexity of the math structure model.

APPROACH

LS – DYNA explicit code was used as the solver for this door sealing system analysis. By choosing proper element type, material model and contact algorithm, the analysis method has successfully captured the door closing dynamic effect and seal material non-linear nature.

The analysis has overcome several technical difficulties, such as large stiffness difference between sheet metal and rubber material, extremely small element size and fairly long run time. Since LS–DYNA was more often used for crash analysis, the difficulties caused by rubber material nonlinear nature and small element sizes are not often experienced by majority users. This new approach by LS–DYNA has resolved these difficulties by refining model mesh and adjusting solving parameters.

The analysis model has included critical parts to represent the door system. The major influencing factors have been extracted from results. However, this method holds the promise of simulating with more detailed structure model and providing further required information.

DISCUSSION OF RESULTS

CLD Curve

Fig. 1 has shown the analysis result of CLD curve. By applying Displacement Vs. Time load curve, the resultant force Vs time curve from seal at door nominal position was generated. The test CLD curve was shown in Fig. 2 by courtesy of SaarGummi Americas. Comparing the analysis result to the test result, they shown a reasonably good agreement within 10% error range. This correlation verified the material model used in LS–DYNA.

Energy Transformation

The energy transformation curve from analysis was shown in Fig. 3. The seal strain energy was about 1.75 joules when the door was fully closed at nominal position. To validate the analysis result, a test was performed on the vehicle with different conditions that were listed in Table 1. By subtracting the minimum energy required to close the door with the seal and without the seal, the seal strain energy could be got and was about the same as the analysis result. The conformance of the energy transformation between the analysis and the test results validated the analysis model further.

Figure 1: CLD Curve from Analysis

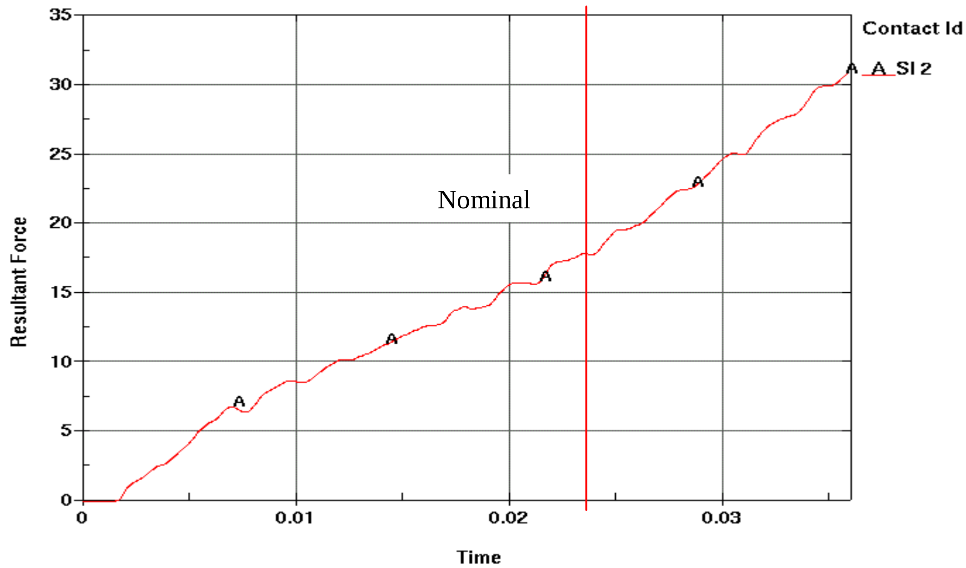
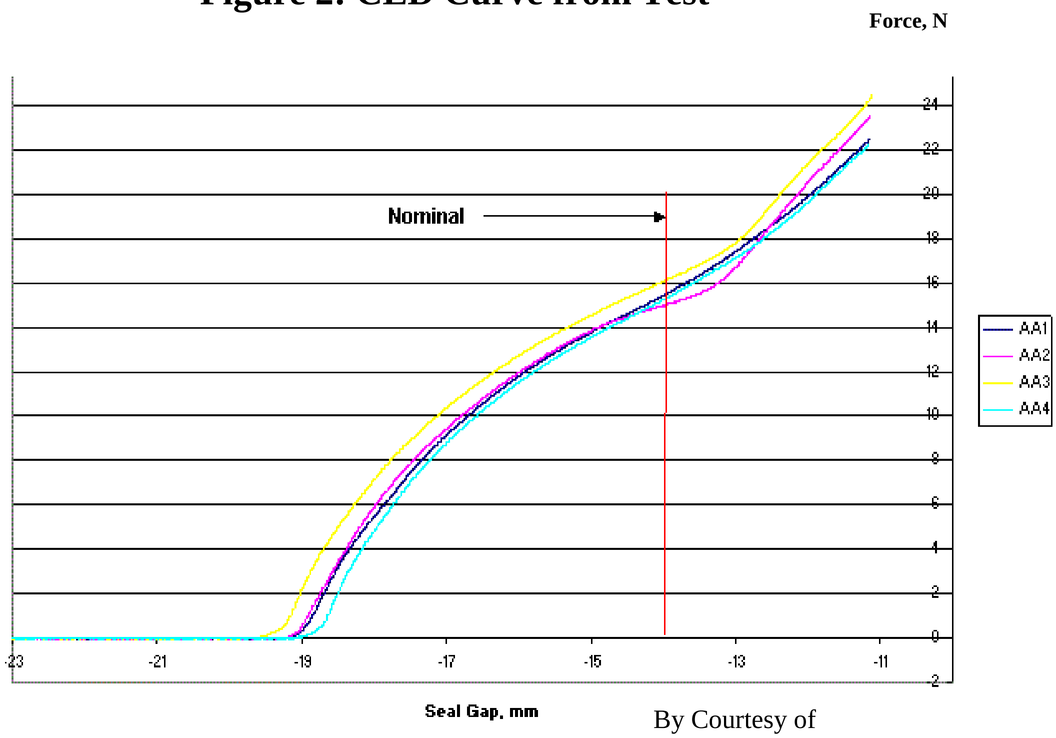


Figure 2: CLD Curve from Test



By Courtesy of
SaarGummi Americas

Figure 3: Energy Transformation from Analysis

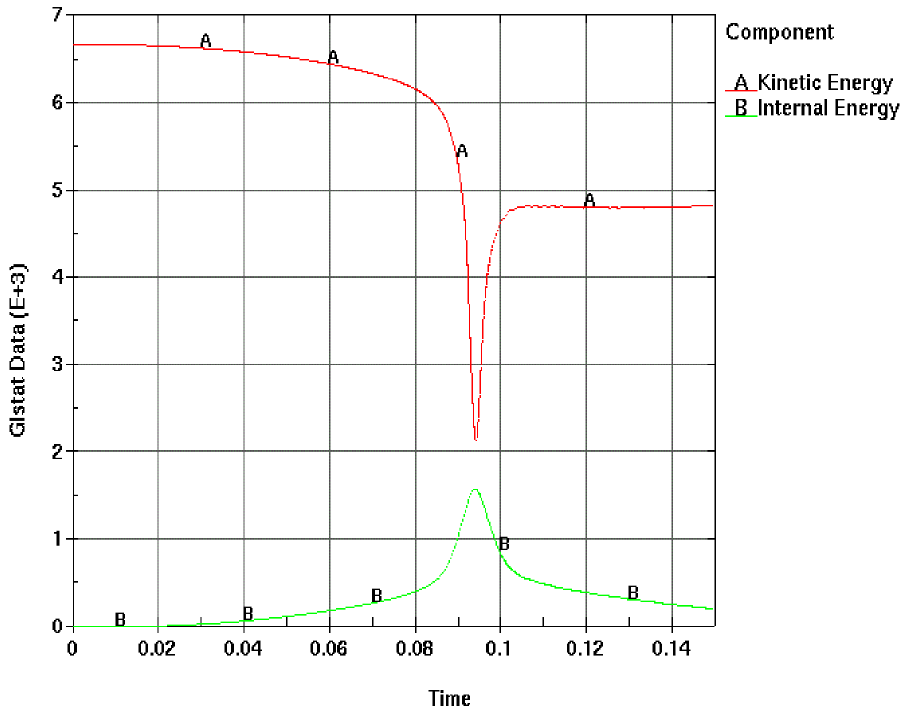


Table 1: Seal Strain Energy from Test

Test Conditions	Min. Required Energy (J)	Velocity (M/S)
With Primary Seal, All Doors Opened.	**2.5**	**0.56**
Without Primary Seal, All Doors Opened	**0.75**	**0.24**

Contact Pressure and Contact Area

Contact pressure and contact area directly influence door seal performance. To investigate contact pressure and contact area on the sealing surface is necessary. The compression force is a resultant of the integration,

$$F = \int_A p(\tilde{x})dA \qquad [1]$$

Where $p(\tilde{x})$ is the contact pressure distribution and A is contact area. It is important to control contact pressure distribution and contact area. This analysis could provide contact pressure and contact area information through out the whole seal and also on the time bases. This result holds the promise of further investigation of the relationship between seal performance and contact pressure and area.

It is important to evaluate contact pressure and contact area meeting the engineering requirement at early design stage. These two derivatives could be controlled by modifying input variables such as material property, cross section geometry, attacking angle and the shape of the indenter.

Water Leakage and Wind Noise

Water leakage and wind noise are the two major problems regarding to the door seal performance. Finding the root cause of water leakage and wind noise is the first step to resolve the problem.

Water leakage happens when the pressure outside of the vehicle overcomes the pressure at the sealing surface. To generate adequate contact pressure at the sealing surface could prevent water leakage problem. This does not only require a rational door seal system design but also a well controlled manufacturing process. Process error could completely jeopardize the performance and functionality of the door seal system even with a rational design.

Wind noise is generated by the presence of an unsteady fluid flow. Presence of the unsteady motion in a fluid medium and the vibration of the structure, which is coupled with a fluid medium, are the two main sources of sound. As a sound wave propagates, it disturbs the fluid for its equilibrium state. These disturbances are nearly always small. The pressure in a fluid medium at position *x* and time *t* has the mean and fluctuating parts, and can be written as:

$$p(x,t) = \overline{p}(x) + p'(x,t) \qquad [2]$$

where $\overline{p}(x)$ is the mean pressure and $p'(x,t)$ is the fluctuating pressure. The fluctuating part of pressure causes sound generation.

The door seal system primary function is to prevent water and dirt from entering the passenger compartment. Insulating the passenger compartment from exterior noise due to wind, traffic and other noise is another important function. Noise transmitting with zero net flow and aspiration are the two basic mechanisms to induce noise. Noise transmission with zero net flow is caused by the seal vibration response to the fluctuating pressure action on the exterior side of cavity. Aspiration is caused by the flow of air past through gaps between seal and the sealing surface. So, the low wind noise level could be benefited from no gaps between seal and the sealing surface and reduced the fluctuating pressure.

The functionality and performance of a door closure system includes: secure latch, no water leakage, low wind noise and proper closing effort. To get a fully functioned and a well performed system needs to have an excellent subsystem design combination and a less error process. Generally, a high contact pressure at the sealing surface is good for water sealing and isolating noise from exterior. There will be no gaps for water and noise to leak through into passenger compartment. However, high contact pressure will cause greater closing effort and reduce the fatigue life of the seal. Therefore, an uniform medium pressure is perfect. The uniform contact pressure through out the whole seal is based on the uniform seal margin. Therefore, control manufacturing process error appears to be very important. The bigger of the seal margin variances, the more of the chances for water leakage and wind noise penetration. To accurately predict water leakage and wind noise problems by using analytical method is still under investigation. More research work needs to be done definitely.

SUMMARY

It has been an encouraging experience to exercise LS–DYNA into a new territory. The analysis result shows the possibility to derive more information for door seal system engineers to get a better understanding of the door sealing system performance and functionality. Currently, activities are still underway to expand the capability and reliability of the analysis method.

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