Analyzing Elastomer Automotive Body Seals Using LS-DYNA

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Abbreviations:

BT – Biaxial Tension
CLD – Compression Load Deflection
PT – Planar Tension
SS – Simple Shear
UT – Uniaxial Tension
UC – Uniaxial Compression
VC – Volumetric Compression

Keywords: Automotive Body Seal, Elastomer, Elastomer Foam

ABSTRACT

Several different elastomer automotive body seals (weatherstrips or weather seals) are analyzed using explicit solver of LS-DYNA. The results are compared with those obtained from non-linear finite element analysis (FEA) solvers widely used for elastomer analysis as well as the experimental results. It is found that properly modeled LS-DYNA can be a very good tool for elastomer body seal analysis, especially for the analysis with potential instabilities, such as snap-through, loss-of-contact, severe slip-stick, and complicated contact problems.

INTRODUCTION

The most widely used elastomer seals in automobiles are body seals, which are installed mainly to help providing a comfortable vehicle interior environment and seal between the movable parts of the vehicle (Figure 1). The functions of the body seals are multifold. An effective design of automotive body seal should have good weatherability, sealability, durability, etc. to perform its duty as body sealing for vehicles under different harsh environments. Both dense elastomer and its foam are widely used in body seal design.

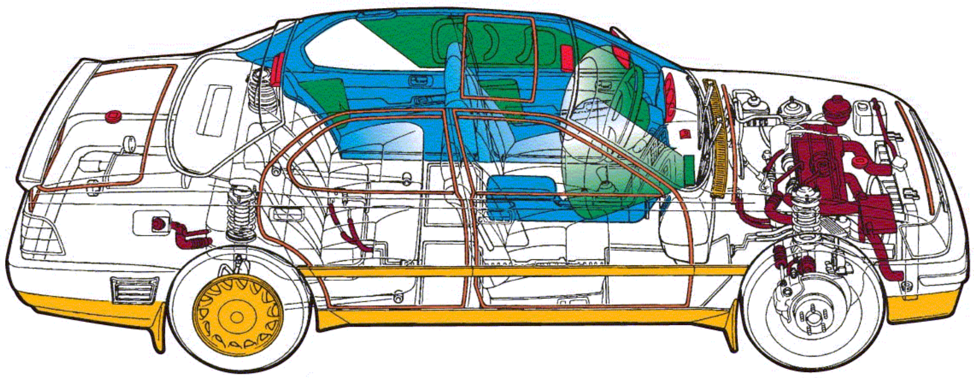


Figure 1. The representative of automotive body seals and other function parts in a car (copyright© TG North America Corporation).

To shorten the product development time and improve the seal performance, Finite Element Analysis (FEA) is widely used in engineering design of elastomer body seals. This also drives the theoretical development of elastomer elasticity, especially the phenomenological theory of elasticity [1]. For most elastomer FEA, deviations come mainly from elastomer material modeling, including material sample preparation, testing, model selection and model parameter determination. The detailed discussion about elastomer and its foam material modeling can be found in references [2 – 4].

In the present paper, the application of LS-DYNA on body seal analysis is discussed. Available testing results as well as the analysis results from nonlinear implicit solver are used to compare the analysis results from explicit solver. The nonlinear implicit solver in the current paper refers to Abaqus/Standard. For LS-DYNA, the explicit solver is always employed in the current paper, and the explicit solver refers to LS-DYNA explicit solver except stating explicitly.

APPROACH

Elastomer Material Testing and Models

Depending on the elastomer part and its serving conditions, different material testing methods may be employed for elastomers. The tests for elastomer and its foam include uniaxial tension (UT), uniaxial compression (UC) / biaxial tension (BT), and planar tension (PT) / simple shear (SS) testing. The volumetric compression (VC) test, in general, will be needed for elastomer foam. For body seal analysis, it generally involves different stress states. Therefore, it is generally recommended to get all the above testing data for material model fitting to avoid out-of-range physically unrealistic behavior due to the unreasonable extrapolation from limited types of testing data [3 – 4].

In the current study, the Ogden rubber model is always employed for elastomers. Because LS-DYNA does not have the capability to fit the elastomer model with different types of testing data, to facilitate the comparison, the same elastomer model parameters determined from the non-linear implicit solver with different types of testing data are used directly. For elastomer foam, both Blatz-Ko (BK) foam model and low-density (LD) foam model in LS-DYNA are used. The tested initial shear modulus is used as input for the Blatz-Ko model, whereas for low-density foam model, the tested Secant tensile module at 10% strain is used instead of the initial modulus from the tangent of the tensile stress-strain curve.

Why Explicit Solver

Under most circumstances, static analysis is widely employed for body seal analysis to access the seal behavior for both static and quasi-static applications. Sometimes, the dynamic behavior of the body seal is considered to access the seal performance under certain situations. In this case, the dynamic simulation with explicit solver will be employed, especially for high speed and short duration event, such as slamming the vehicle door to see the response of the seals. Due to the easy convergence of the explicit solver, it is found that it can also be a very good tool for general body seal analysis under static and quasi-static conditions, especially for seals with contact instabilities and very complicated contact conditions.

Models

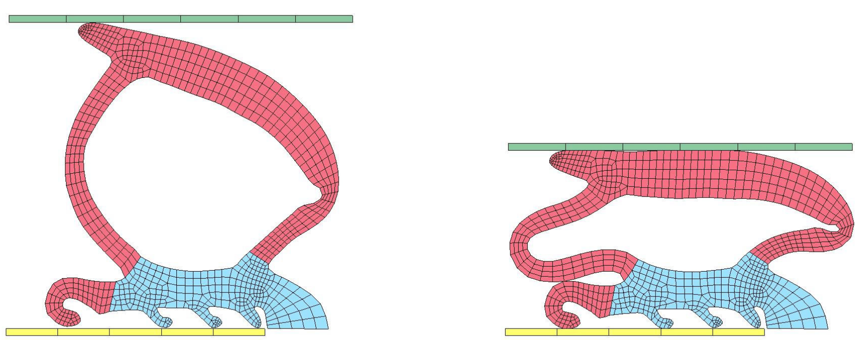
Both 2D and 3D seal problems are analyzed in the current study using LS-DYNA. Due to relative large deformations encountered with elastomer seals, to prevent the hourglass effect, the fully integrated elements instead of reduced elements are used. Proper mass scaling is always used to shorten the analysis time, which has found to have little effect on the desired results if properly selected.

RESULTS AND DISCUSSION

2D Seal Analysis

Most of the seal analyses are 2D problems that are widely used to access the performance of the extruded seal under working conditions. These problems are easily solved with implicit nonlinear solvers except for some cases either with severe slip-stick contact or snap-through problems. The general 2D seal analysis using LS-DYNA will be discussed in this section.

Figure 2 shows body seal A made of both elastomer and foam. The element is directly translated from the implicit solver to facilitate the comparison. The predicted compression load deflection (CLD) curves for body seal A are shown in Figure 3. The tested CLD curve and the predicted CLD curve from implicit nonlinear solver using the first order foam model fitted with both UT and UC data are also plotted in the figure for comparison. It is obvious from Figure 3 that the predictions from explicit solver with different foam models show good correlation with the testing results and the prediction from implicit solver.



(a) (b)

Figure 2. Body seal A. (a) Contact position; (b) Deformation at design position.

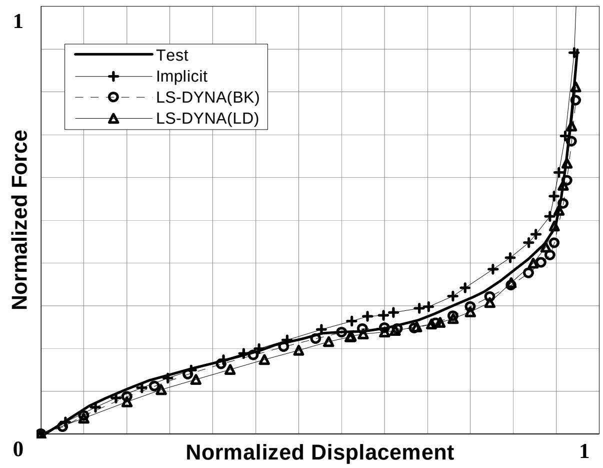


Figure 3. CLD curves for body seal A.

The CLD curves for body seal B are shown in Figure 4. The results are similar to the predictions from the implicit solver except the slipping position and the slipping behavior. The result from the implicit solver shows earlier slipping and a more abrupt slip than the corresponding results from LS-DYNA. These are mainly attributed to the difference in handing the contact algorithms and the friction between the contact surfaces. The difference between the testing and predictions may be that in real testing, the friction coefficient may vary depending on the surface quality and the contact pressure for foam materials, whereas in the simulation, a constant friction coefficient is used. In general, both implicit and explicit solvers with different foam materials predict the slipping of the seal relative to the closing door with reasonable accuracy. The deformations of the body seal B at 1 mm beyond design position from both explicit and implicit solvers are shown in Figure 5, which shows the relative positions of seal to the door after slipping (Figure 4). It is obvious that the deformation shapes ararly identical for both solvers.

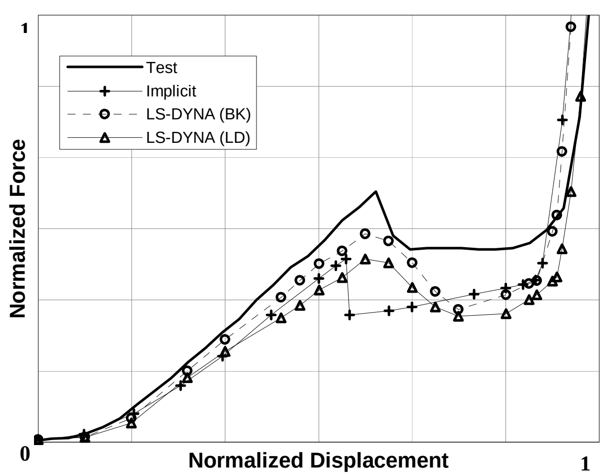
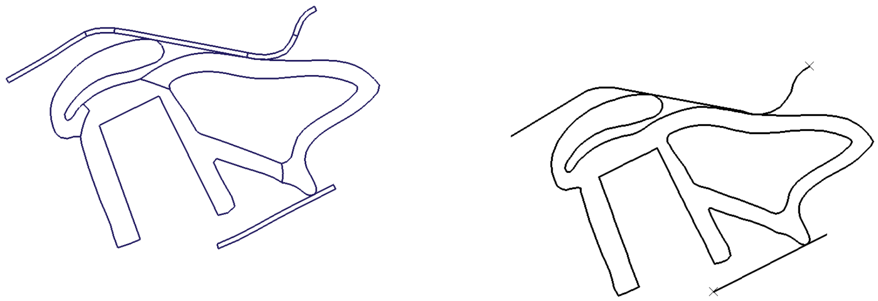


Figure 4. CLD curves for body seal B.



(a) (b)

Figure 5. Seal B at 1 mm beyond design position. (a). LS-DYNA; (b). Implicit solver.

The predicted CLD curves for body seal C using both explicit and implicit solvers are shown in Figure 6. The predictions are close to the testing results before position A (Figure 6). Then in the testing, the slipping happens between the door and the body seal at position A, and the CLD curve actually lowered slightly and increase again afterwards. The prediction from implicit solver shows no sudden slipping in the analysis, whereas the predictions from explicit solver show delayed slipping. The original seal shape and the seal deformation after contact slipping from LS-DYNA are shown in Figure 7. One of the reasons for the difference between the testing and analysis might arise from the fact that the contact surface behavior in testing and simulation is different. The different foam models implemented and the difference in handling the surface friction in implicit and explicit solvers might mainly account for the difference between the analysis results. In addition, the artificial damping used in implicit solver, which is implemented to overcome the contact instability, might also contribute the results for seal C.

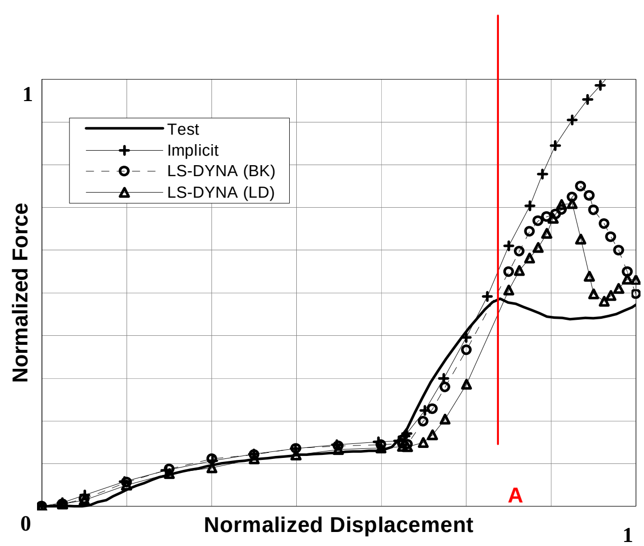
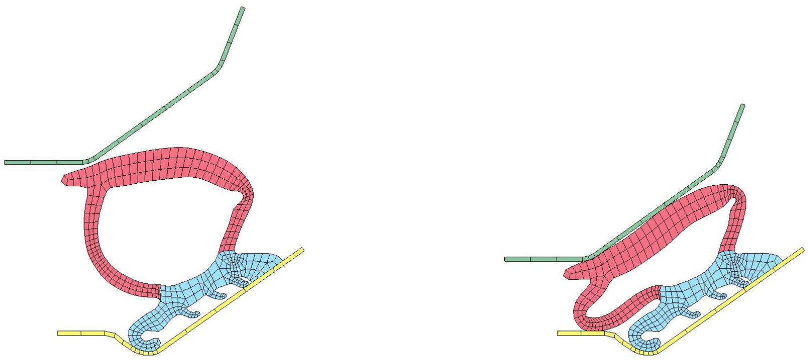


Figure 6. CLD curves for body seal C.



(a)

(b)

Figure 7. Shapes of body seal C using LS-DYNA. (a). Original shape. (b). Seal shape after contact slipping.

2D Seal Analysis with Contact Instability

Due to the large deformation and the hyperelastic material behavior of the elastomer body seal, the contact instabilities, such as loss of contact, snap-through and slip-stick, often happen during the analysis. For implicit solver, often the artificial damping or other techniques are employed to overcome the difficulty. However, for severe contact difficulties, the above-mentioned artificial manipulation may still not work. Under such conditions, the explicit solver shows its advantage over implicit solver.

One of the problems of contact instability for body seal analysis is to analyze the mounting (insertion) and dismounting (extraction) forces of the seal. Figure 8 represents the seal deformation for most of the body seals during dismounting process. Only the mounting portion of the seal and its metal carrier is modeled here. Because the sudden flipping over of the grippers as well as the releasing of the grippers from flange during dismounting process, the implicit solver is generally very difficult to successfully handle the analysis. However, for explicit solver like LS-DYNA, this problem can be trivial. Two sets of constraints can be used in the analysis, the fixed and movable horizontal mounting processes. The fixed mounting process fixed the relative horizontal position between the seal and the flange according to the final mounted position during the insertion and extraction processes, whereas for the movable mounting process, the seal can move relative to the flange in horizontal position depending on the resisting force the seal receives from the grippers during the process. In general, the movable mounting process will use less force in mounting and dismounting processes and is close to real mounting and dismounting processes of the seal. The mounting and dismounting forces of the seal for movable mounting process are shown the same figure.

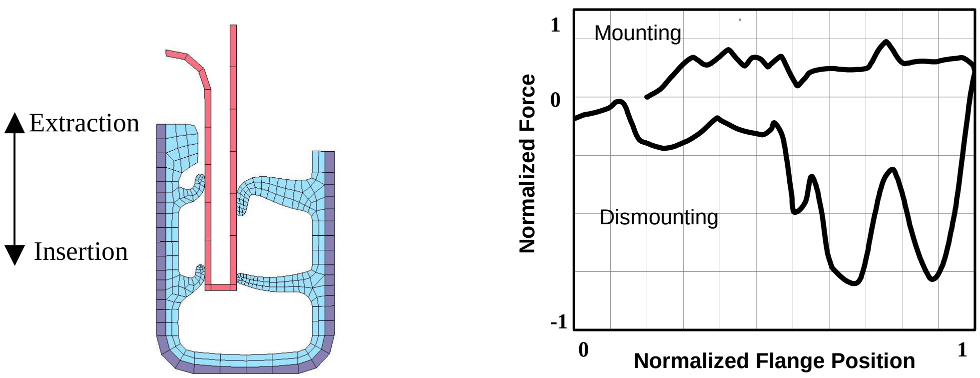


Figure 8. Typical seal deformation during dismounting process and CLD curve for mounting and dismounting processes.

Figure 9 shows the mounting and dismounting forces of another seal. For test using the fixed horizontal mounting process, the results of the maximum mounting and dismounting normalized forces of the seal is 0.5 and -0.72 respectively, which corresponding to the analysis result (A) very well.

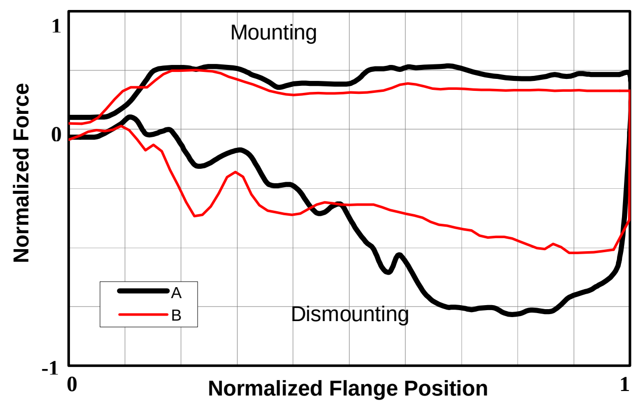


Figure 9. Mounting and dismounting forces of a body seal. A - fixed horizontal mounting process; B - movable horizontal mounting process.

3D Seal Analysis

3D seal analysis without contact, such as bending or cornering the seal, in general can be easily fulfilled using implicit solver. The purpose of the analysis is mainly to see the cross-section deformation after bending (Figure 10). For 3D analysis with contact, some of the problems can be solved easily with either implicit or explicit solver, such as the elastomer boot seal (Figure 11) and pressing the cornered body seal using relative flat surface. However, for 3D complicated contact problems, especially for problem with contact instability, the effort of trying to obtain a converged solution using implicit solver is not trivial.

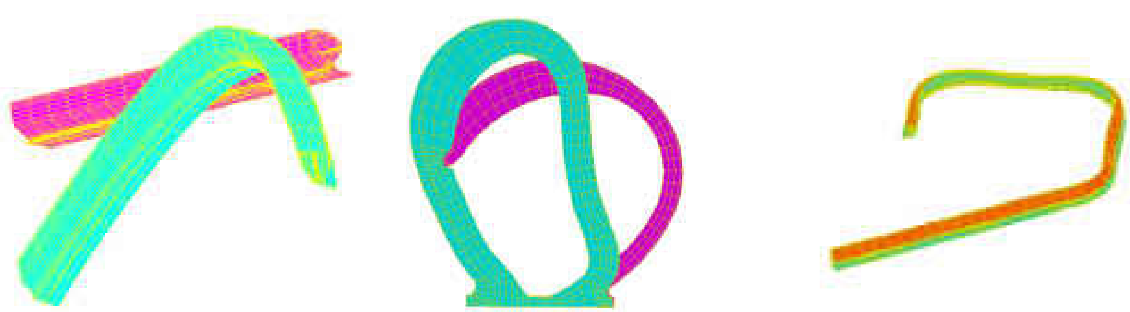
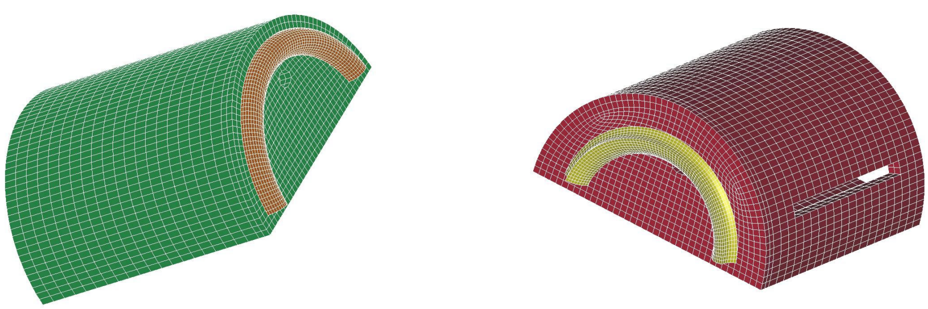


Figure 10. Bending or cornering the body seals.

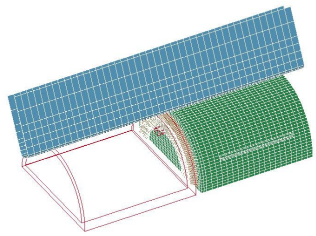
Figure 11. The shrink fitting and bending of a boot seal using LS-DYNA.

A simple molded elastomer foam seal is analyzed using LS-DYNA (Figure 12) to show the advantage of explicit solver. The seal consists of two parts. Both are hollow sections with ending cap at one end. Mating beads are designed on the ending caps (Figure 12, (a) and (b)), which will be compressed when two parts of the seal contact with each other after installing the seal. During application, the seal will be compressed by the glass, and the bead deformation as well the seal deformation as a whole will be critical for the seal performance (Figure 12, (c) and (d)). To access the bead performance, the beads need to be modeled using small solid elements to represent the detailed bead geometry. However, when such bead contacts with each other, the implicit solver will have a very hard time to find a solution to satisfy all the contact constraints and the runtime will be huge. For real seal design, the geometry will be far more irregular and complex as the example shown here. As the consequence, the real seal will involve complicated contact situations as well as contact instabilities, which often make the implicit solver impossible to solve such problems. The analysis starts with a shrink fit first, which can be simulated either using *CONTACT_SURFACE_TO_SURFACE_INTERFERENCE or just bring into contact and compressed the seal from both opening ends. Then the glass is pushed from the contact position to the design position, which involves significant deformation and contact changes of the seal, especially in the bead contact area.

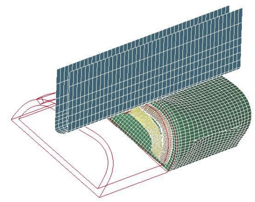


(a) (b)

Figure 12. Simulation of the shrink fit and press of the molded body seal.



(c)



(d)

In summary, LS-DYNA is a good tool for elastomer body seal analysis, especially for seals with complicated contact environment and contact instabilities in applications. The analysis capability of LS-DYNA for elastomer seal can be improved if more appropriate element type and elastomer material model-fitting routine are implemented, especially the element formulations that are suitable for nearly incompressible materials, and the elastomer material model-fitting program for multiple types of testing data.

CONCLUSION

Properly modeled, the LS-DYNA explicit solver can not only be used to simulate the dynamic behavior of the body seal behavior, but also employed for the quasi-static and static behaviors of the seal in reasonable accuracy. It is very effective in solving the problems with contact instability and complicated contact situations.

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