MODELING AND SIMULATION OF VEHICLE AIRBAG BEHAVIOUR IN CRASH

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Abstract: *Since safe transportation is one of the biggest concerns of vehicle manufactures***,** *occupant safety in vehicle accidents becomes a great challenge.*

The severity of the crash reflects the energy absorption of the car's structure during the accident and also has a close relationship with the amount of energy absorbed by the restraint system. Among components involved in restraint system, airbags are the most complex ones. The simulation and modelling of this system due to the nonlinear behaviour of the passenger and the vehicle add more complexity to its design and fabrication. Airbag system, which is a subsystem of the restraint system, is very important due to the nature of its multi-physical problem and the direct connection with passenger safety.

Therefore, in this paper, different approaches to develop airbag dynamics equations has been reviewed. Further a fast design and simulation method for airbag parameters in the concept design phase by an impact problem has been investigated to contribute to a comprehension of the relation between occupants and airbags.

Keywords: VEHICLE CRASH, RESTRIANT SYSTEM, AIRBAG, LS-DYNA

1. Introduction

Occupant safety is one of the principal objectives in the design of vehicles. Numerous innovations have appeared aimed at increasing safety in vehicles [1–3]. As is known, airbags, like safety belts are now devices designed to provide protection to the users of vehicles during crash events, minimizing the loads necessary to adapt their movement to the movement of the car [4, 5]. The airbag acts to cushion any impact with vehicle structure and has positive internal pressure, which can exert distributed restraining forces over the head and face. Furthermore, the airbag can act on a wider body area including the chest and head, thus minimizing the body articulations, which cause injury [6]. These safety elements can so reduce the death rates on the roads, and its protection effects have been widely approved [7, 8]. Thus, new types of airbag products are being developed to handle different collision scenarios.

Airbags have been in construction since the late 1940s, when they had first been manufactured and investigated by automobile engineers. The first airbag to be installed in a vehicle appeared in 1971, in the 831 Mercury models that were manufactured by Ford [9], followed by General Mo- tors offering frontal airbags as an optional extra between 1974 and 1976 [10]. In the 1980s, airbags were being mass- produced and by the 1990s they were accepted as an effec- tive supplemental restraining system, along with seatbelts.

Airbag is a primary component of the occupant restraint system, and its protection is widely accepted and analyzed [11]. NHTSA pointed out in a recent data report of traffic accidents that barrier/sled-certified airbags reduce about 20% fatality risk in frontal crashes of cars [12]. Braver et al [13], used Poisson marginal structural model to calculate standardized mortality rate ratios (MRRs), and found that advanced airbag features appeared protective for some occupants, but further study is needed.

While a vehicle is crashing heavily in the front, the forward movement of the front passengers can be perceived as an acceleration process towards the instrument panel starting with a zero speed in a reference coordinate system on a moving vehicle. During this process, airbags are inflated to tolerate parts of the initial kinetic energies of occupants, and compressed to absorb these energies [14]. Meanwhile, the gas in airbags discharges from vents due to the high pressure of airbag chamber compared with the atmosphere pressure, and this drastic venting process releases the energies absorbed by airbags. Based on the above overview, the mechanics relationship between occupants and airbags can be regarded as a simplified model, in which an impactor impacts an airbag with vents on at a given speed.

As an elementary module test method to investigate the performance of airbags, the drop tower test has been widely used in the product development phase of airbags [15–16]. Generally, before suitable airbags matches a certain vehicle, many times of drop tower test could be conducted by suppliers. This process can not only test the reliability of an airbag’s deployment process, but also verify the correctness of preliminary defined parameters.

Traditionally, airbags have been simulated using the control volume (CV) approach. In the CV model, the pressure inside the airbag is calcu- lated using the mass flow and temperature curves obtained from a tank test. This pressure is assumed to be uniform inside the airbag, and thus a uniform force is applied on all the surfaces of the airbag, including those surfaces which are yet not unfolded. CV approach is hence analogous to a lumped parameter model in which the flow of inflating gases inside the airbag is not discretized. The effect of the gas jet from the inflator is not taken into account in these models. To overcome this shortcoming, jetting is added to CV models to add a momentum to the airbag in the direction of the jet from the inflator [17-18].

In this paper, first the the governing equation on airbag dynamics has been investigated, after that a specified airbag has beed simulated under development and drop test by using LS-dyna.

2. Modelling

2.1. System equation

Different approaches in modeling of an airbag can be used. In a drop tower test, the basic mechanics relationship between the impactor and the airbag is expressed as follows [19]:

$$Mg - (P - P_{atm})A_e = Ma \qquad (1)$$

Another model has been used for an external airbag. As shown in Fig. 1, in this model airbag will work like a static air spring and so there is a necessity to know the spring coefficient and the damping coefficient for the external airbag.

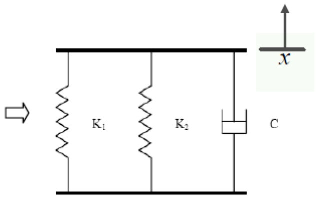

Fig. 1 *Air spring – damper/spring model.*

$$F_x = P.A_e \qquad (2)$$

$$K = \frac{dP}{dx}.A_e + P.\frac{dA_e}{dx} \qquad (3)$$

$$K_{x1} = \frac{dP}{dx}.\frac{A_e}{\dot{x}} \qquad (4)$$

$$K_{x2} = P.\frac{dA_e}{dx} \qquad (5)$$

By assuming an inviscid flow, the damping coefficient can be found as follows:

$$C = \frac{F}{\dot{x}} = \frac{\rho.g\left(\frac{{v_B}^2 + {v_A}^2}{2g} + \frac{32\mu L v_B}{\rho g d^2}\right).A_e}{\dot{x}} \qquad (6)$$

Based on the original dynamics model used to develop the airbag system for the Mars Pathfinder, another governing equation can be developed as follows:

$$M\ddot{x} + (P - P_{atm})A_{FP} = Mg \qquad (7)$$

In this model the airbags hit the ground and A_{FP} shows the area of the airbags which is in contact with surface.

2.2. Geometry

There is a tendency to assume a two-dimensional design to analysis the airbag behavior. In Fig. 2 a schematic of an airbag system is shown.

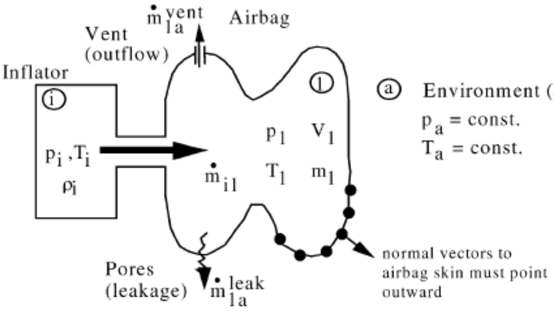

***Fig. 2** Airbag schematics*

In this paper, a three-dimensional analysis in regards to volumetric changes in airbag has been studied. A predefined airbag geometry is shown in Fig 3. Relations of volume changes are divided in two sections, V_1 shows the volume of the cylindrical volume in the middle and V_2 is related to torus around the cylinder.

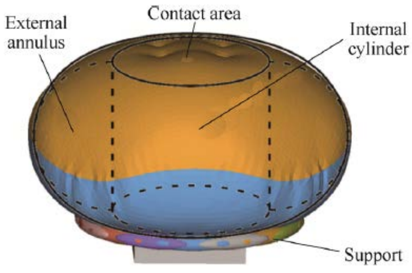

***Fig. 3** Airbag geometry*

$$V_2 = \int_{l/2}^{l+X/2} 4\pi x\sqrt{\left(\frac{X}{2}\right)^2 - \left(x - \frac{l}{2}\right)^2}\,dx \qquad (8)$$

$$V_1 = \pi\left(\frac{l}{2}\right)^2 X \qquad (9)$$

$$V = V_1 + V_2 \qquad (10)$$

According to Wang and Nefske, the relationship between the pressure (P_2) and the volume (V_2) of the airbag will be expressed as:

$$V_2 = V_{20}(1 + c_\beta(P_2 - P_{atm})) \qquad (11)$$

c_β is bag stretch factor and P_2 and V_2 are pressure and volume of airbag [20]

2.3. Ventilation

For the leakage or venting in the airbag, the Bernoulli equation can be used. It is assumed that the flow between location inside the airbag and location outside the airbag is inviscid, incompressible, free from heat transfer, and steady. Thus the Bernoulli equation between these two locations is derived according to head loss from inside and outside of the airbag after traveling through the vents:

$$H = \frac{32\mu L v_B}{\rho g d^2} \qquad (12)$$

Also standard gas dynamics equations can be used to determine the conditions required for the airbag venting mechanism by using a standard nozzle flow equation to relate the flow velocity through the vent:

$$\frac{dw}{dt} = C_D A_{th} P_{atm}\left(\frac{1}{RT}\right)^{1/2}\left[\frac{2\gamma}{\gamma - 1}\left(\frac{P}{P_{atm}}\right)^{\gamma-1/\gamma}\right]^{1/2}\left[\left(\frac{P}{P_{atm}}\right)^{\gamma-1/\gamma} - 1\right]^{1/2} \qquad (13)$$

Another approche is to assume a vent on an airbag is a circular hollowed-out region, which acts as a channel for the gas in the airbag chamber exhausts from the inside to the outside. Thus, the vent area directly affects the exhausted gas mass of an airbag. Based on the momentum theorem, mass of the exiting gas can be found as follows:

$$h = \sqrt{\frac{P - P_{atm}}{\rho}} \qquad (14)$$

$$m = m(t) - 2\int_0^t \rho A h\,dt \qquad (15)$$

2.4. Solution algorithm

A time stepping scheme is employed where at each time increment, the change in airbag geometry is calculated based on the position of the supported mass as shown in the Fig. 4. This is then used to obtain the pressure, volume, and mass of the operating medium, which is in turn used to determine conditions for venting of the airbag.

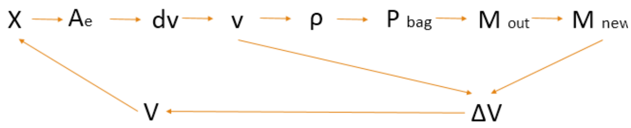

Fig 4. *Overview of iterative process*

3. Simulation

In the area of numerical simulations involving the use of airbags to absorb impact energy, passively or actively, accurate definitions of airbag leakage parameters play a crucial role in predicting the response of impacting objects. LS-DYNA is a software package for dynamic analysis and study of fluid structure interactions can widely be investigated.

Base on the geometry of a common driver airbag, the basic test conditions are described as follows: the diameter of the airbag is 610 mm, two vents on the airbag with the same diameter of about 30 mm, two straps in the airbag have the same length of 200 mm, the volume of the airbag chamber is about 45 L when the inflator has just finished its inflating process, the mass of the impactor is 4.8 kg with initial velocity of 14 m/s^2.

The impact problem has been imported in LS-dyna solver and the graphical view is shown in Fig. 5.

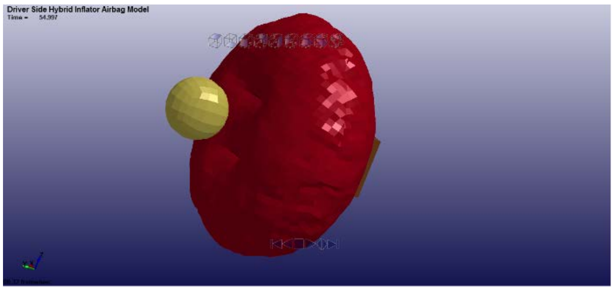

Fig. 5 *Graphical view of main LS-dyna simulation window*

Inflator mass flow pressure rate is dependent on the inflator function, but a common inflator is selected [19] and imported in software as Fig. 6:

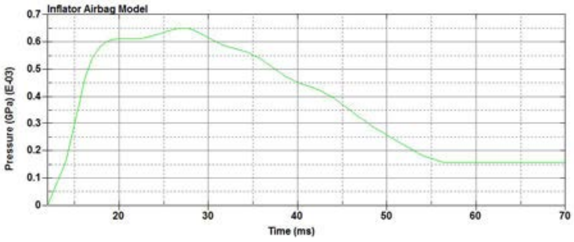

Fig. 6 *Mass flow pressure*

4. Result and Discussions

The airbag system is part of the passenger car restraint system. Therefore, the exact design of the airbag is very important. In this article it has been tried to review on different mathematical modelling and Ls-dyna simulation.

As of that, the results generated by coding in Matlab and Ls-dyna has been shown in Fig. 7 and Fig. 8.

From analytical approach, Fig 7. shows the acceleration changes of the impactor after dropping with initial acceleration (g) and contacting the airbag surface.

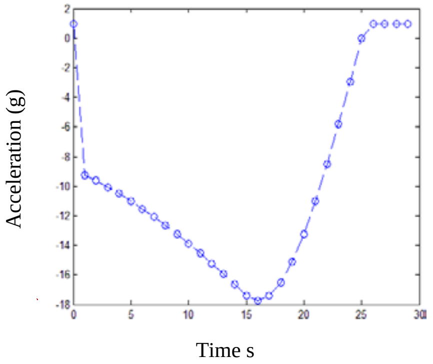

Fig. 7 *Impactor acceleration*

The same drop test has been simulated in Ls-dyan and acceleration changes of impactor is shown in Fig. 8.

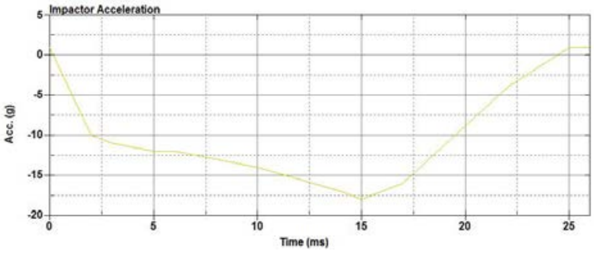

Fig. 8 *Impactor acc. (Ls-dyna)*

5. Conclusion

Since in the crashworthiness studies the head acceleration is one of the important parameters to determine the occupant injury, in this paper investigation of the acceleration of the impactor has been chosen as an important factor.

By comparing the results developed for the impactor acceleration from analytical and simulation, it was cleared that the results showed a similar trend almost same extreme points.

It should be noted that the proposed theoretical model cannot solve the situation in which the impactor contacts the airbag before it is fully inflated.

Since ventilation has a great impact on the airbag behavior, on the premise of reasonable simplifications and assumptions, the momentum theorem (which was proposed by formula 14 and 15) did not reflect a good relation between different design parameters and the impactor response. On the other hand, Bernoulli and dynamic gas equations showed better results.

In this paper three different approaches to analytically solve an impact problem has been studied. In all of them an impactor has been dropped on a fully developed airbag and the acceleration of the impactor has been investigated. After that in order to compare the accuracy of the results, a simulation with the same scenario has been developed in Ls-dyna.

5. Symbols and Signs

P	Pressure
h	Velocity (Gas flow)
V	Volume
ρ	Density
M	Mass
T	Temperature
d	Vent diameter
C	Damping coefficient
H	Head loss
v	Impactor velocity
K	Coefficient
V_{20}	Volume of fully Inflated airbag

6. Reference

1. Zhang, H., CAE-based side curtain airbag design. In: SAE 2004-01-0841, SAE World Congress, 8–11 March 2004, Detroit, Michigan, 8–11 March (2004)

2. Soongu, H., A study on the modeling technique of airbag cushion fabric. In: SAE 2003-01-0512, SAE World Congress, 3–6 March 2003, Detroit, Michigan, 3–6 March (2003)

3. Canaple, B., Impact model development for the reconstruction of current motorcycle accidents. Int. J. Crash 7, pp. 307–320 (2002)

4. Freesmeier, J.J., Butler, P.B., Analysis of a hybrid dual-combustion-chamber solid propellant gas generator. J. Propuls. Power 15, 552–561 (1999)

5. Schmitt, R.G., Butler, P., Freesmeier, J., Performance and CO production of a non-azide airbag propellant in a pre-pressurized gas generator. Combust. Sci. Technol. 122, pp. 305–350 (1997)

6. Gabauer, D.J., Gabler, H.C., The effects of airbags and seatbelts on occupant injury in longitudinal barrier crashes. J. Saf. Res. 41, pp. 9–15 (2010)

7. Crandall, C.S., Olson, L., Sklar, D.P., Mortality reduction with air bag and seat belt use in head-on passenger car collisions. Am. J. Epidemiol. 153, pp. 219–224 (2001)

8. Teru, I., Ishikawa, T., The effect of occupant protection by controlling airbag and seatbelt. In: Proceedings of the 18th International Technical Conference on the Enhanced Safety of Vehicles. NHTSA, Nagoya, Japan (2003)

9. Thompson, K.M., Segui-Gomez, M. and Graham, J.D., Validating analytical judgements: the case of airbag's lifesaving effectiveness, Reliability Eng. System Safety 66, pp. 57–68. (1999)

10. Chan, C.-Y., Crash Sensing in Automotive Airbag Systems, Warrendale, Society of Automotive Engineers (2000)

11. Greenwell, N K. Evaluation of the certified-advanced air bags[R]. Washington, DC: National Highway Traffic Safety Administration, Report No. DOT HS 811 834.

12. Kahane, C J., Injury vulnerability and effectiveness of occupant protection technologies for older occupants and women. Washington, DC: National Highway Traffic Safety Administration, Report No. DOT HS 811 766.

13. Braver, E. R., Shardell, M., Teoh E. R., How have changes in air bag designs affected frontal crash mortality. Annals of Epidemiology, 20(7): pp. 499–510 (2010)

14. Shi, L., Cao, L., Weixiong, Y., Test and simulation study on the performance improvement of SUV airbag. Chinese Journal of Automotive Engineering, 2(5): pp. 334–340 (2012)

15. Keun, L., Hyun, L., Hyung, L., Validation methodology on airbag deployment process of driver side airbag, 21th Enhanced Safety of Vehicles (ES) Conference, Stuttgart, Gernany, June 15–18, Paper No. 09-0363 (2009)

16. Bok, L., Gu, H., Parametric study on mid-mounted passenger airbag cushion using design of experiments[R]. SAE Technical Paper, (2003).

17. Cirak, F., Radovitzky, R., 'A new Lagrangian Eulerian shell fluid coupling algorithm based on level sets', Proceedings of the 44th AIAA/ASCE/ASME/AHS Structures, Structural Dynamics, and Materials Conference, Norfolk, Virginia, USA, (2003).

18. Marklund, P., Nilsson, L., 'Simulation of airbag deployment using a coupled fluid structure approach', 7th International LS-DYNA Users Conference, Detroit, MI, USA, (2002).

19. Zhang, J., Jin, Y., Xie, L., and Chen, C., Establishment and Validation for the Theoretical Model of the Vehicle Airbag, Chinese Journal Of Mechanical Engineering, Vol. 28,No. 3, (2015)

20. Wang, J.T., Nefske, D.J., A New CAL3D Airbag Inflation Model, SAE Technical Paper Number 880654, (1972)