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Research on Airbag Parameters Matching in the Vehicle Crash Simulation

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Abstract: Vehicle safety airbags can protect occupants from vehicle collisions, but there are still some shortcomings, thus need to be constantly improved. In occupant restraint system simulation, the establishment of a reasonable airbag model determines whether the simulation results are consistent with the actual test results. The aim of this study is to establish a precise airbag model for vehicle occupant restraint system by using MADYMO. The study is based on two parts, Firstly, the linear impact component test and correlation study were investigated. In this part, the effect of airbag parameters on correlation results were discussed, a suitable airbag model was built, the correlation results were compared to test data. Secondly, a full frontal sled test model correlation was conducted and compared to the test data to verify the airbag model which is precise for security simulation research of the occupant restraint system. The validation of this methodology was performed through comparing the simulation results with test results of various test setups and airbag designs. The results indicate that the airbag parameters have a good consistency with the actual test results, thus improve the accuracy of the test results. The study provides a method for the development of the restraint system and simulation of engineering practice.

Keywords: airbag model; parameters matching; Madymo; Vehicle Crash

1 Introduction

Automobile traffic accidents cause huge casualties and economic loss for the society worldwide. It is estimated that from 2015 to 2020 road traffic accidents will lead to 200-300 thousand fatalities and more than 1 million people injured every year [1]. Vehicle safety becomes more and more important in recent years. The airbag which is mainly used to prevent secondary collision between occupants and interior part can effectively reduce passenger casualties.

Airbags have been in construction since the late 1940s, when they had firstly been manufactured and investigated by automobile engineers. The first airbag to be installed in a vehicle appeared in 1971, in the 831 Mercury models which were manufactured by Ford [2], followed by General Motors offering frontal airbags as an optional extra between 1974 and 1976 [3]. In the 1980s, airbags were being mass produced and by the 1990s they were accepted as an effective supplemental restraining system, along with seatbelts [4].

In the past the research on vehicle safety systems were real crash tests and made the car manufacturers or suppliers focus on different methods. One of the earliest studies on airbag modeling was conducted by Irish et al. [5] in 1971, the study developed a series of equations to mathematically model the motion of the airbag during occupant interaction. In 1988, Wang and Nefske [6] investigated and developed a generalized analytical airbag inflation model for the CAL3D occupant simulation program. The early airbag models for simulation assumed a uniform pressure and temperature within the airbag, and did not consider bag slap and transient pressure forces on the occupant during airbag inflation, thus could not be used for out-of-position (OOP) occupant analysis. The study of Mu et al. [7] in 1999 showed that the fluid/structure coupling is the most accurate method to model OOP interaction. The next year Mu [8] put forwarded ten constraint programs, for example, multistage gas generator, split type airbag, hollow airbag housing, retractable type steering column, some of those programs could reduce OOP thorax injuries. In 2004, Haufe and Weimar [9] performed a study on airbag simulation, the article compared three different modeling techniques: the arbitrary Lagrangian-Eulerian

(ALE) technique, the control volume (CV) method without jetting effects and the CV method with jetting effects in two separate simulations. The comparison showed that the result of using ALE technique is closer to actual experimental data. Zhang et al. [10] made evaluation and comparison of CFD integrated airbag models in LS-DYNA, MADYMO and PAM-CRASH, all three CFD integrated airbag models in the study showed good correlation of both airbag deployment kinematics and pressure distributions.

Although airbags can effectively prevent occupants from the secondary collision, they can cause harm of their own accord, a deploying airbag is most likely to cause injuries or fatalities when inflated in the presence of an OOP small adult driver who is positioned near to the steering wheel [11], the high temperature generated during the airbag deployment may burn occupants.

Nowadays virtual crash simulations, in which high performance computers simulate collisions, substitute or support real prototype crashes. Security simulation research especially OOP occupant analysis of occupant restraint system needs to establish a precise airbag model, in particular the accurate simulation of airbag inflatable deployment process [12]. The choose of airbag parameters such as vent hole, fabric, airbag opening time determines whether simulation results are consistent with the actual test.

The aim of this article is to establish a precise airbag model for security simulation research of occupant restraint system using MADYMO. The benefit of MADYMO is the combinations of multi-body dynamics and finite element analysis in one simulation [13]. The study mainly contains two parts, the first part is linear impact component test correlation which is conducted to build a suitable airbag model, in this part, we analyze influence of change of airbag parameters on the result, and summarize their influence law, thus guidance model improvement and adjustment, the results give a conclusion that airbag material, vent hole characteristics and seam parameters could be used in the following simulation studies. The second part, we make a full frontal sled test model correlation, and compared to the test data to verify the airbag model which is precise for security simulation research of the occupant restraint system.

2 Linear impact component test correlation

2.1 Linear impact component test

The linear impact component test is to obtain dummies acceleration and force distribution during collision. In this test, an impactor is used for simulating the real body. The impactor with a weight of 33 kg, according to an average human torso, is impacted against the deploying airbag. The speed is around 4-6 m/s. All parameters for this test are chosen with respect to real frontal crash conditions and test experience.

2.2 Linear impact component test model build up

The airbag housing for the driver side was fixed in the steering wheel which is also attached to the support of the test environment. During the impact the impactor plate center should be in the center of the airbag cushion. Together with the filling time which is commonly set to 25-30 ms (depending on the airbag type), the initial distance between plate and steering wheel can be defined as:

$$d_{initial} = thick + vel_{imp} * t_{fill} \qquad (1)$$

Where $d_{initial}$ is initial distance, vel_{imp} is impactor velocity and t_{fill} is filling time.

The control volume (CV) method is used to simulate the deployment of the airbag, it regards airbag as a expanding control volume, the inflating gas is assumed to behave as an ideal gas with constant specific heats, and also, that the temperature and pressure are uniform. The total gas mass flow in the chamber is the result of the inflator-supplied gas mass flow (m_s), the inflowing gas mass flow (m_i) and the exhausted gas mass flow (m_{ex}) [14]. The formula for the mass flow change is:

$$m = m_s + m_i - m_{ex} \qquad (2)$$

Where m is total gas mass flow. As the isothermal expansion is expected from the inflator gas, the temperature at exit plane and supply temperature are assumed to be equal:

$$T_s = T_{exit}\left(\frac{p}{p_{exit}}\right)^{\frac{n-1}{n}} \qquad (3)$$

Where T_s is supply temperature, T_{exit} is temperature at exit plane, p is uniform pressure inside of the airbag chamber, p_{exit} is pressure at exit plane and n is polytropic constant [12, 13].

For the fabric the material isoline is declared which stands for isotropic linear elastic characteristics. Force which is measured at the center of the plate and the steering wheel support is calculated based on penetration and material properties. The linear force-penetration law is declared as:

$$F_c = \Psi \cdot K \cdot \frac{A^2}{V} \cdot \lambda \qquad (4)$$

Where Ψ is penalty factor, K is bulk modulus, A and V respectively stand for element area and volume, λ is penetration.

In MADYMO, the model consists of four systems such as impactor, airbag, steering wheel and the reference space, as shown in Figure 1. To creating the mesh of airbag cushion, we choose three-node linear membrane element (MEM3), this kind of element without the hourglass mode and can better describe the geometrical characteristics of the fabric, the element feature is elastic isotropic [13]. The airbag consists of 2, 659 nodes and 5, 056 elements.

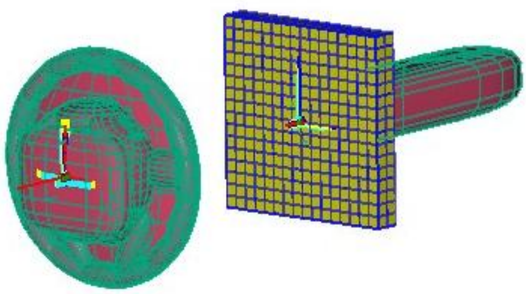


Figure 1. Linear impact component test simulation model.

Table 1. Airbag basic parameters.

E-modulus	Poisson's ratio	density	thickness	Permeability coefficient
200MPa	0.2034	785kg/m^3	0.3mm	0

The initial metric method (IMM) is used to set up folded airbag model. The IMM needs two meshes, one is initial mesh (the status of the cushion inside of the airbag housing), and the other one is reference mesh [12]. A mapping between the two configurations is established to calculate the strains and stresses with respect to the reference configuration. In the reduced state only contact, pressure, and IMM (damping) forces are active. When an element reaches its reference size, normal material properties are used to calculate internal stresses and strains [16].

To describe the gas outflow, two different hole materials are created. One is for the outflow through the actual vent hole and the other one for the gas loss due to seam and connection leakage. Furthermore to limit the deployment range of the airbag, eight straps are used connecting two nodes at the front and at the back of the airbag cushion. The straps are ordered clockwise, with no mass but with a defined stiffness as 1000 N/m and length as 360 mm. The inflator is defined by eight circular jets, these jets stand for the direction of the gas flow into the airbag chamber. Gas in the inflator is 20% oxygen and 80% nitrogen. INFLATOR defines the temperature-time, mass flow-time relationships. The set of basic parameters are shown in Table1.

2.3 Linear impact component test correlation

The correlation is done in two steps, first a parameter variation is accomplished to see the effects of each variable, and the following step is to adjust parameters to get the suitable airbag model.

2.4 Parameter variation

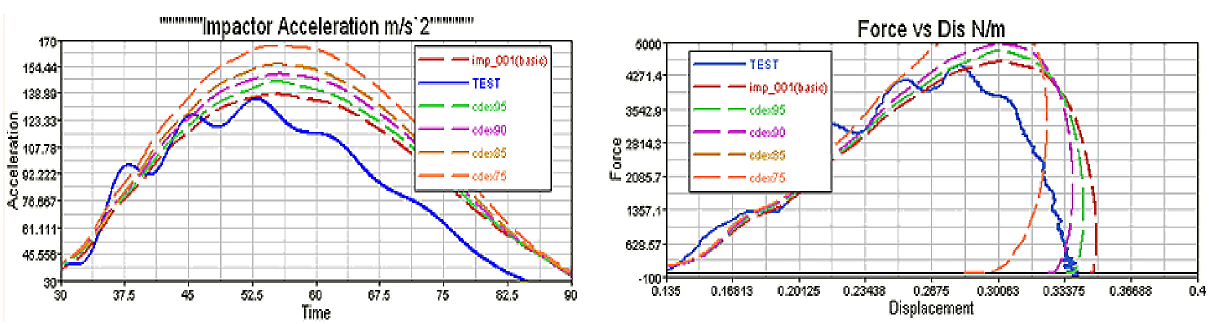
This procedure mainly gives an outlook on the influence of parameters change to the simulation model. To see the effects of the adjusted parameter, the other variables are fixed as the basic value during the changing of the selected one.

For the six variation parameters are chosen, divided by the parts of the airbag system into vent hole, fabric, airbag housing and inflator. The vent hole size is defined as 45 mm. The parameter variation is shown in Table 2 .

CDEX of vent hole is a coefficient which describes the ratio between actual vent hole size and simulation hole element size, this factor is used to display the outflow of the gas through the hole. CDEX for leakage is used to describe the outflow of the gas through the fabric seam. When the airbag cushion contacts the impactor plate, the pressure inside the cushion rises and causes the vent hole to open. This point of time is vent hole opening time. The airbag permeability which describes the outflow of the gas directly through the airbag fabric is defined through a factor. Airbag cover opening time is defined which enables the airbag to deploy freely in the surrounding space. Influence of such parameters on impactor acceleration and force vs. displacement are shown in Figures 2-7.

Table 2. Parameter variation.

	Vent hole			fabric	airbag	inflator
	CDEX vent hole	CDEX leakage	Vent hole opening time	permeability	Airbag cover opening time	Inflator temperature
base	0.8	1	0.01	0.00001	0.001	0.985
1	0.8	1.5	0.005	0.00001	0.001	0.7
2	0.95	1.25	0.0075	0.0001	0.00125	0.75
3	0.9	1	0.01	0.001	0.0025	0.8
4	0.85	0.75	0.0125	0.0125	0.00375	0.85
5	0.75	0.5	0.015	0.02	0.005	0.9



(a) **(b)**

Figure 2. CDEX vent hole parameter variation results.

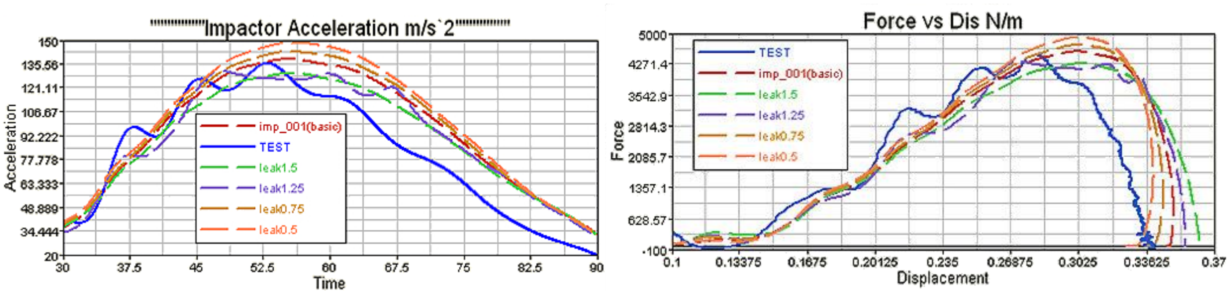


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Figure 3. CDEX Leakage parameter variation results.

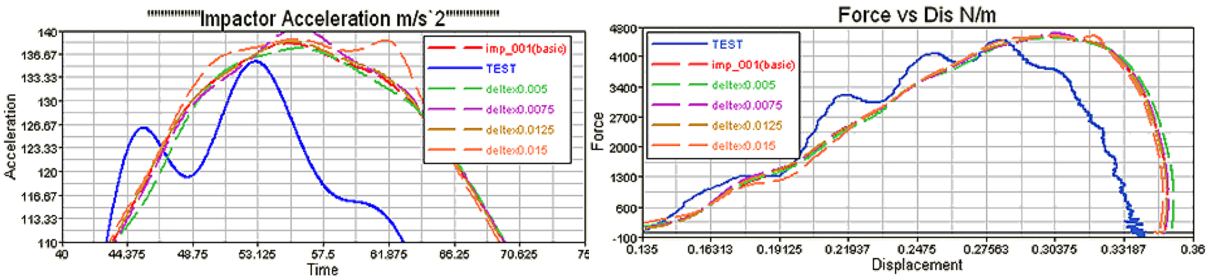

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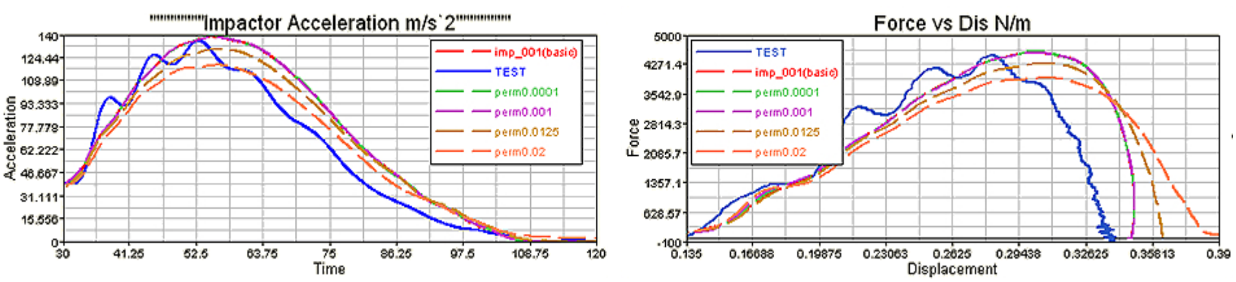
Figure 4. Vent hole opening time parameter variation results.



(a) **(b)**

Figure 5. Permeability parameter variation results.

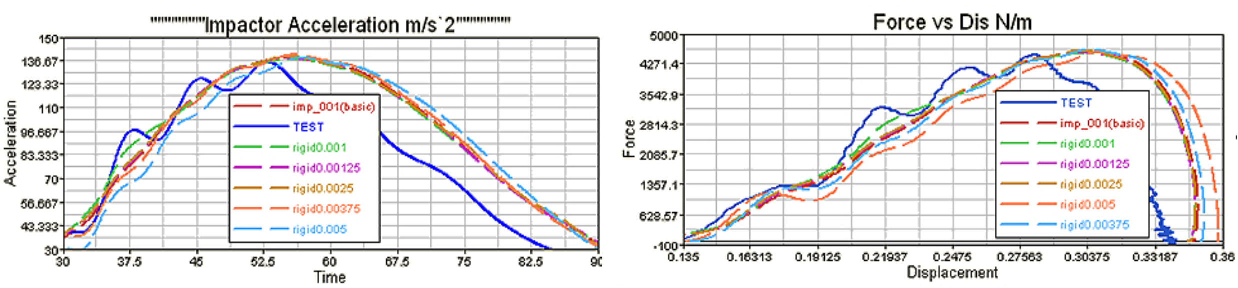


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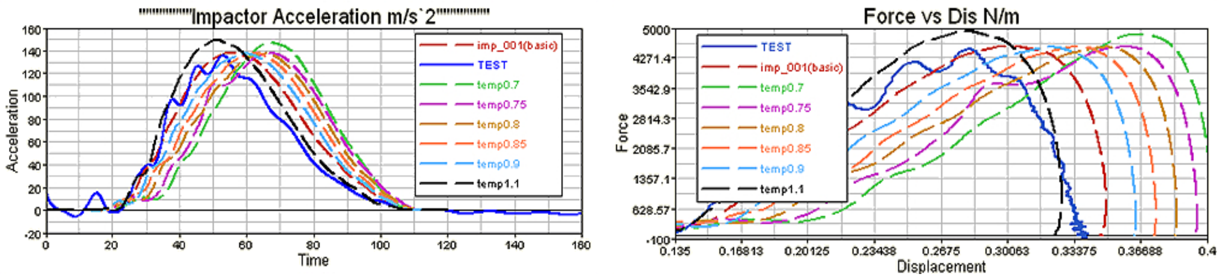
Figure 6. Airbag cover opening time parameter variation results.



(a) **(b)**

Figure 7. Inflator temperature parameter variation results.

From Figure 2, we can see that a reduction of the CDEX lead to a higher pressure inside of the airbag and as a consequence to a higher deceleration of the impactor. A lower impactor displacement goes hand in hand with higher force values. In conclusion a strong downscaling of the CDEX result in a negative effect on the simulation functions for deceleration and force vs. displacement. Figure 3 shows that small the change of leakage coefficient has small effect on simulation functions, the scale factor for the correlated model would be between 0.75 and 1.25 to achieve the best results for slope and peak of the deceleration and energy function. As shown in Figure 4, increasing the opening time which has positive effect as the displacement can be reduced effectively with low increase of the contact force. Figure 5 shows an increased permeability results in lower pressure as more gas could flow out of the cushion. The impactor deceleration would be decreased and the plate would move further into the softer cushion. In Figure 6, the later opening of the airbag cover hinders the airbag from deploying on time which leads to a higher impactor plate displacement, the total energy is increased with the delay of the cover opening. Summing up the earliest opening time for the airbag cover is considered for the correlated model. According to the Figure 7, depending on the downscaling factor, the deceleration peaks are shifted to later time stages.

In conclusion the parameter variation demonstrates the influence of different parameters to the correlation process. Parameters such as CDEX vent hole and permeability mainly influence the vertical course of the simulation functions while vent hole opening time, air bag opening time and inflator temperature adjust the horizontal position basically.

2.5 Adjustment procedure

This step is to find optimal matching parameters. Through the above results, we summarize that the laws of change of parameters, after multiple debugging and finally achieve the optimal airbag parameters' matching values, as shown in Table 3. The impactor acceleration and force vs. displacement curves are displayed in figure 8.

Table 3. The optimal airbag parameters.

CDEX vent hole	CDEX leakage	Vent hole opening time	Permeability	Airbag cover opening time	Inflator temperature
0.8	1.12	0.02	0.002	0.001	1

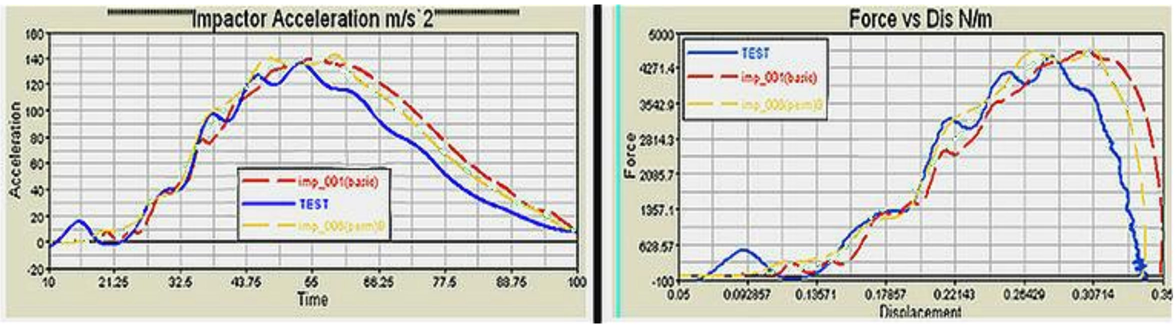


Figure 8. Correlation result for liner impact.

3 Full frontal sled test model correlation

3.1 Test full frontal sled test

In the full frontal sled test (Figure 9), sleds represent a vehicle equivalent system to reduce the high costs of car crash tests. The component is fixed on the sled and decelerated over a specific braking mechanism. The test is performed with two 50th percentile male occupants. The test speed is around 64 km/h and the buck has no pitch or angle.

3.2 Full frontal sled test simulation model set up

The simulation model is established in MADYMO (Figure10), the basic structure of the system model is similar to the linear impact model as also the master and include file system is used, the results of airbag parameters before-mentioned are used in this part. The dummy is the hybrid III 50th percentile male in USNCAP RH seating position, and is linked via a free joint to the reference space but has no connection to the interface system. For the positioning of the dummy, variables are used in the control analysis time element.

The contacts between all the systems need to be defined suitable to improve computational efficiency and save time. Feet to the acceleration pedal, footrest and toe board are all FE-FE contacts, the contacts between the rests of the dummy parts to interior surfaces are MB-MB and all contacts with the seat pan and the airbag system are MB-FE. An exception is the windscreen and airbag cushion contact which both are FE elements [16-17]. For each contact, friction functions are defined. A range of material properties are utilized to accurately model the dummy, as well as detailing the various instruments that are placed on the dummy to record the required data during testing [4].

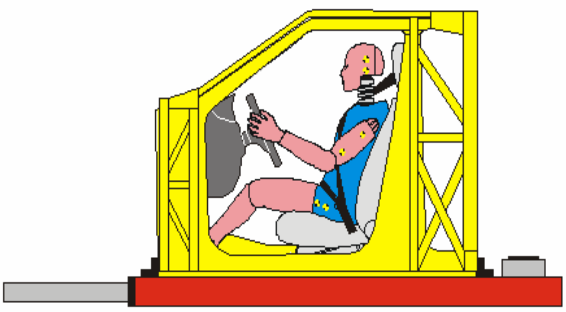


Figure 9. Full frontal sled test model.

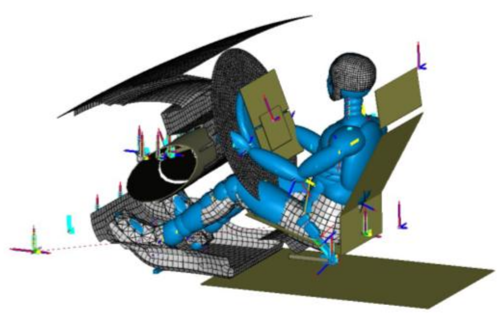
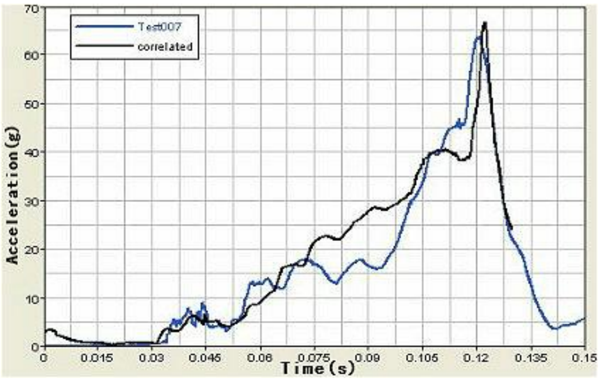


Figure 10. Full frontal sled test simulation model.

3.3 Full frontal sled test correlation

The graphs below (Figures 11-14) shows a comparison between the full frontal sled test and correlation result on head, thorax, pelvis acceleration and shoulder belt force. Test results and the correlation obtained corresponding curves can match well, peaks and peak time is nearly the same. We can make a conclusion that the correlation model can accurately simulate the real vehicle test, as well, it verifies the validity of the airbag model we have designed described earlier.



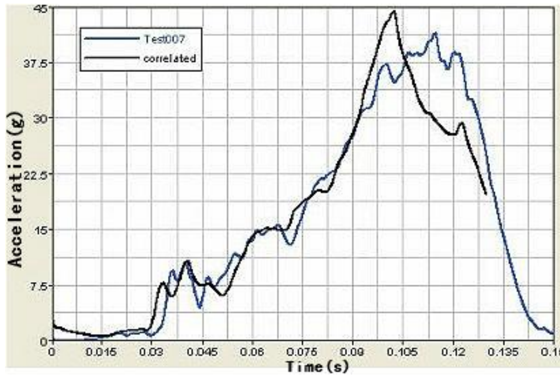


Figure12. Thorax acceleration of dummy. **Figure11. Head acceleration of dummy.**

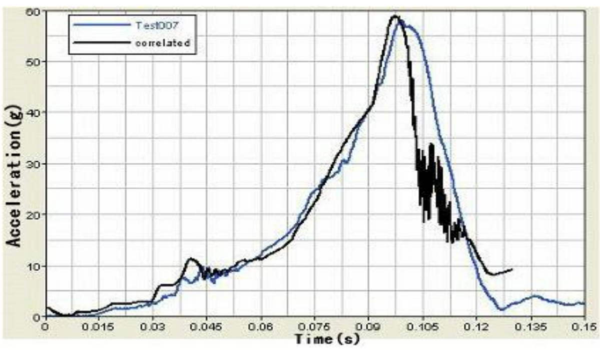


Figure13. Pelvis acceleration of dummy. **Figure14. Shoulder belt force of model.**

4 Conclusions

The literature first review summarizes the advances and accomplishments of vehicle safety airbag. The establishment and verify of the airbag model are described in detail in this paper. In the linear impact component test correlation, we focus on the modeling of airbag system, the change of airbag parameters lead to different simulation results, after adjustment we achieve the optimal airbag parameters component: CDEX vent hole is 0.8, CDEX leakage is 1.12, the vent hole opening time is 20 ms, permeability factor is 0.002, airbag cover opening time is 3 ms and the inflator temperature is 1000 K. The full frontal sled test model correlation is then conducted to verify the airbag model which is precise for security simulation research of the occupant restraint system.

The results obtained in this study show the airbag parameters have a good consistency with the actual test results, thus improve the accuracy of the test results. The study provide a good airbag model for further collision simulation experiment, and have a certain reference value for the research of passengers protection in the vehicle crash.

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