The Recent Progress and Potential Applications of Corpuscular Method in LS-DYNA®

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Abstract

The corpuscular method is a coarse-grained muti-scale method developed for gas dynamics simulation. It is based on the kinetic molecular theory, where molecules are viewed as rigid particles obeying Newton's laws of mechanics. Each particle in the corpuscular method represents a group of gas molecules. The only particle-particle and particle--fabric interactions are perfectly elastic collisions. The corpuscular method has been applied to airbag deployment simulation. This paper describes the recent progress of corpuscular method in LS-DYNA®; its application to airbag deployment simulation and other gas related process.

Introduction

In recent years there have been many airbag-related injuries that due to the deployment of an airbag interacting with an out-of-position (OOP) occupant [1]. To develop a numerical method that could model the OOP occupant interaction is thus important. Up until today, the dominating method to simulate airbag deployment in automotive safety society is the control volume (CV) approach. The CV approach assumes uniform pressure and temperature within the vas. This assumption makes the CV approach unable to correctly model OOP effects including highly transient gas dynamics and thermodynamics process of the airbag. Thus the CV approach is inappropriate for Out-of-Position-Safety (OOPS) analysis in which the airbag-occupant interaction occurs before the bag is fully inflated.

On the other hand, the kinetic molecular theory (KMT) has been used to investigate the behavior of gases for many years [2]. This atomic theory is based upon the following assumptions:

1. A gas consists of a collection of small particles traveling in straight-line and obeying Newton's Laws.
2. There is a thermo-dynamical equilibrium, i.e. the molecules are in random motion.
3. The average distance between the molecules is large compared to their size
4. The only molecule-molecule and molecule-structure interaction are perfectly elastic collisions. There are no attractive or repulsive forces between molecules.

The macroscopic physical properties of gases, such as pressure and temperature, can be related to their composition at a molecular level. KMT can accurately describe the properties of ideal gases, however, the application of the KMT to airbag deployment simulation is not straightforward due to their high computational cost. For example, in a typical kinetic molecular simulation, the characteristic time scale can be pico-seconds and the length scale can be nano-meters, making a realistic airbag simulation impossible.

To bridge the huge gap between the length scales and time scales that can be studied in atomistic simulation and those that are relevant for industrial process, Dr. Olovsson has proposed the corpuscular method to allow the study of airbag deployment simulation[3]. Corpuscular method is a coarse-grained method that based on KMT, i.e., many molecules are grouped together as a particle. For an efficient contact treatment, the particles are given a spherical shape. The particle-particle and particle-structure interaction are purely elastic collision. Each particle contains translational energy, as well as spin energy. The balance between translational energy and spin energy is determined directly from the heat capacities.

By grouping many molecules as one particle, corpuscular method reduces the degree of freedom of the system by several orders of magnitude. Combined with the increased critical time step, this method makes it possible for simulation of macroscopic systems and longer events. However, letting each particle represent many molecules leads to dispersion and to a noisy particle-fabric contact pressure.

The benchmark study of the CPM method has been performed by Lian et al. [4]. This paper is intended to introduce several new features of CPM method and its application

Initial Air with Particles

When initial air inside the bag is considered (IAIR=1), the CPM method uses control volume (CV) formulation to model the initial air inside the bag and uses particles to model the inflated gas. The air temperature is assumed equivalence to the average particles temperature. Energy is transferred between particles and air to ensure this balance. This mixed approach may encounter problems for tube shaped airbag as shown in Figure 1. When particles are shot into airbag at location *A*, the airbag is expanded and the volume is increased. As CPM uses CV formulation to simulate the initial air, the pressure applied from the initial air will drop simultaneously all over the bag, thus the pressure applied to the parts *B* which is far away from inflator will also drop, making the airbag more difficult to be opened. Figure 2 shows the initial drop of part pressure at location B.

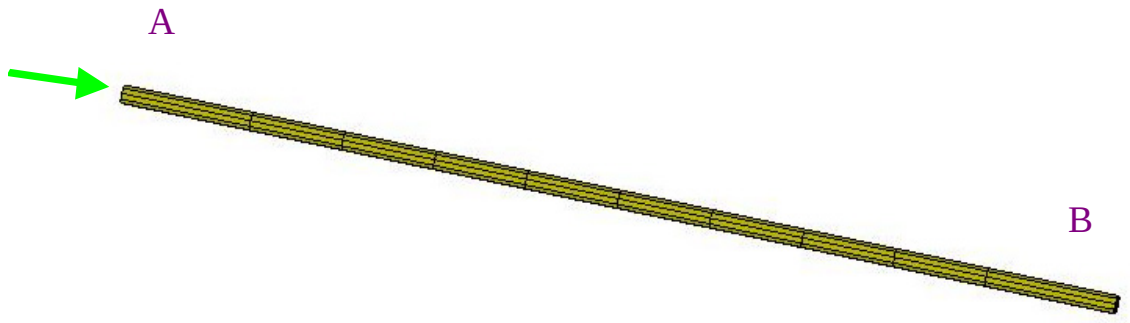


Figure 1. Long Tube Model

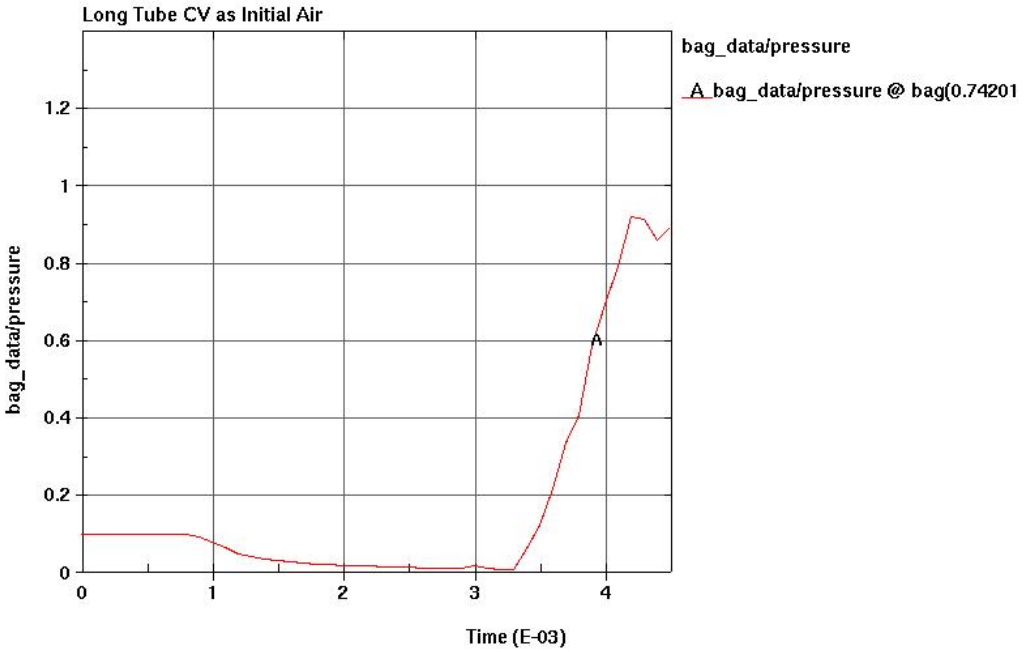


Figure 2. Pressure Time Histories for Mixed Method

To overcome this problem, we have added a new option to simulate initial air with particles. When IAIR =2, new particles are generated and positioned close to airbag inner surface. It is strongly recommended that one do relaxation simulation to let initial particles to reach their thermal equilibrium state before normal analysis. Figure 3 shows the pressure time histories at location B when using particles to simulate initial air. The pressure time histories comparison between mixed method and particle method is shown in Figure 4.

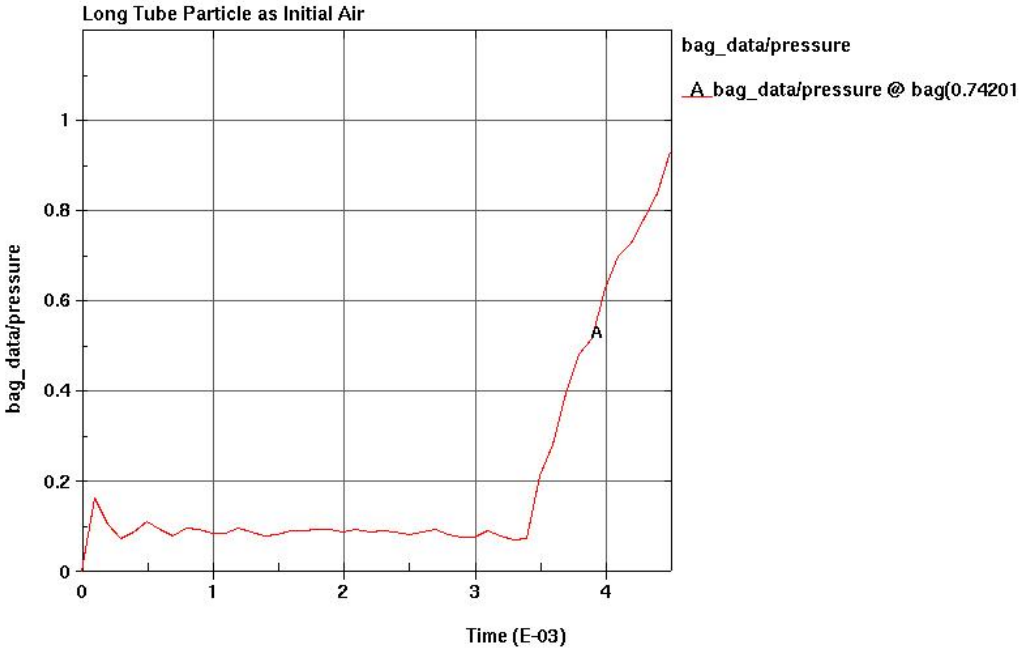


Figure 3. Pressure Time Histories for Particle Method

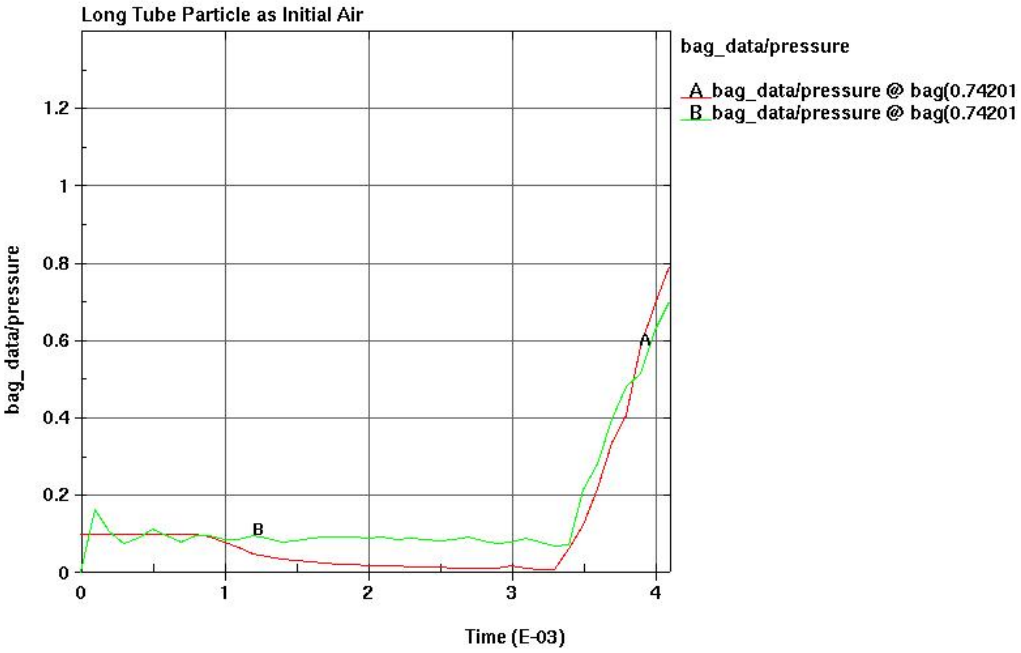


Figure 4 Pressure Time Histories Comparsion

Application to Door Impact Process

With the addition of using particle to model initial air, the application of CPM method may not limited to airbag deployment simulation, it can also be applied to other gas related process. Figure 5 shows the model set up for a door. This model simulates the process that a rigid ball impact on a door. The air inside door is modeled by 200,000 initial particles.

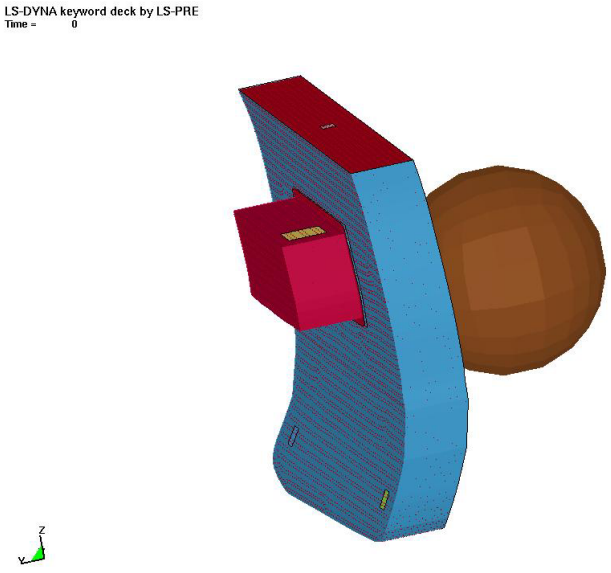
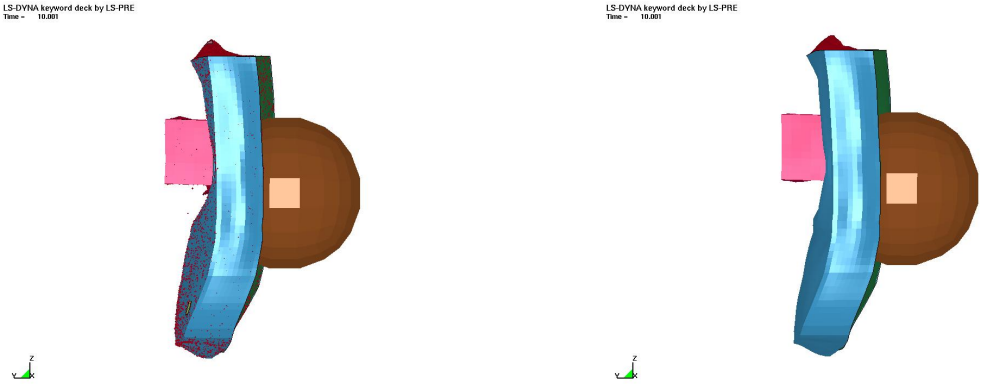


Figure 5 Rigid Ball Impact onto a Side Door

An ALE model was also created to simulate this process. Figure 6 show the deformed shape at time=10ms for CPM model and ALE model.



(a) CPM Model (b) ALE Model

Figure 6. Deformed Configurations

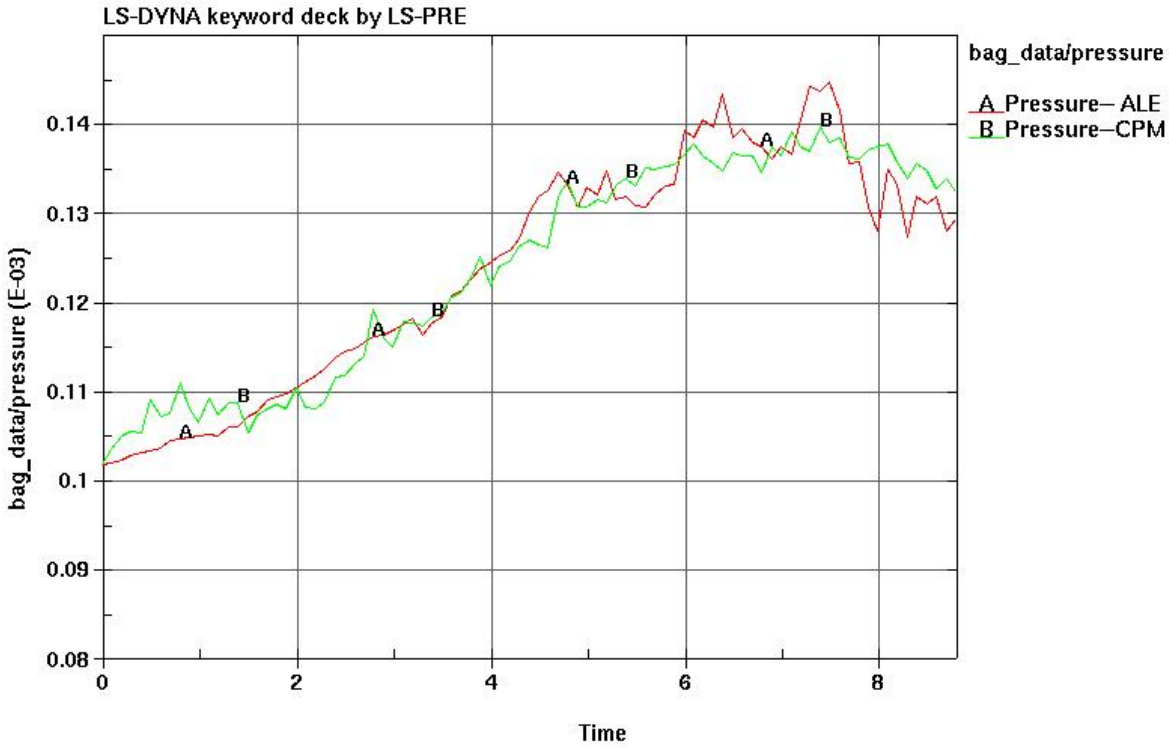


Figure 7. Press Time Histories

Figure 7 shows the pressure time histories comparison between ALE model and CPM model with NP=200,000. The result shows good agreement between these two models. The CPU time for a 10ms CPM run with time step size 0.874μs was 57 minutes, while the CPU time for the ALE run with element size 10mm and time step size 0.933μs was 2 hours and 49 minutes. It should be noted that this ALE model is a rather coarse model and does not consider the modeling of wind sill; otherwise, the element size of ALE model has to be reduced at least by several folds and the CPU time will increase tremendously.

Multiple Chambers Simulation

Recently advanced airbags are divided into several chambers to control expansion shape and speed. The airbag can expand in a predetermined order at a predetermined speed to optimally protect a passenger. To have multiple chambers capability is necessitous.

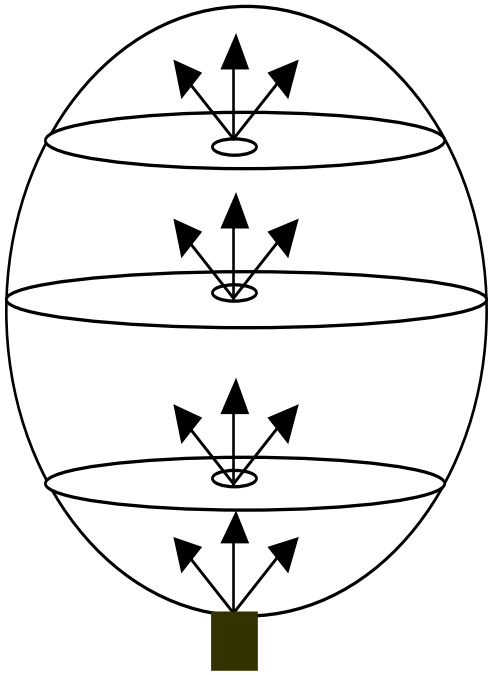


Figure 8. Multiple Chambered Airbag

When using particles to model initial air, the particles are evenly distributed to each segment of airbag. However, this approach may lead to unreasonable particles distribution for certain problems like multiple chamber or folded airbag. A typical model is shown in Figure 9. In this model, this size of chamber B is much smaller than the size of chamber A, thus the particle density in chamber B is much higher than in chamber A, leading to a large initial pressure difference between chamber A and chamber B as depicted in Figure 10.

Figure 9. Multiple Chambered Model

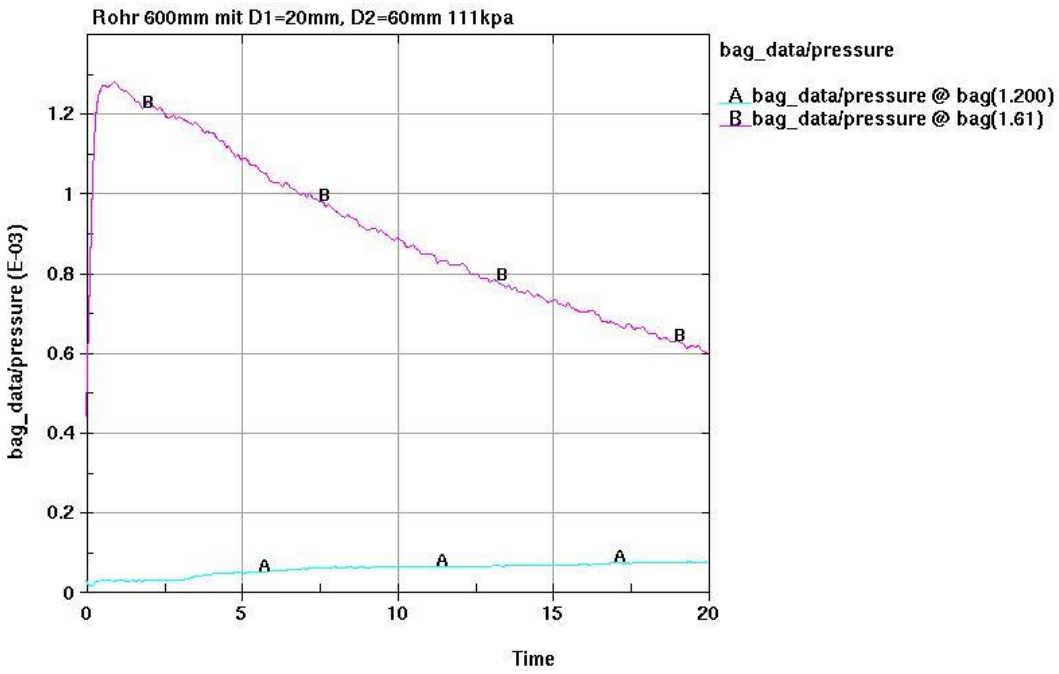


Figure 10. Pressures of Multiple Chambers

A new key word *DEFINE_CPM_CHAMBER is introduced to solve this issue. The number of particle in each chamber is determined by its volume. As such, the particle distribution is more reasonable as shown in Figure 11, and the initial pressure distribution is much better as shown in Figure 12

Figure 11. Multiple Chambered Model

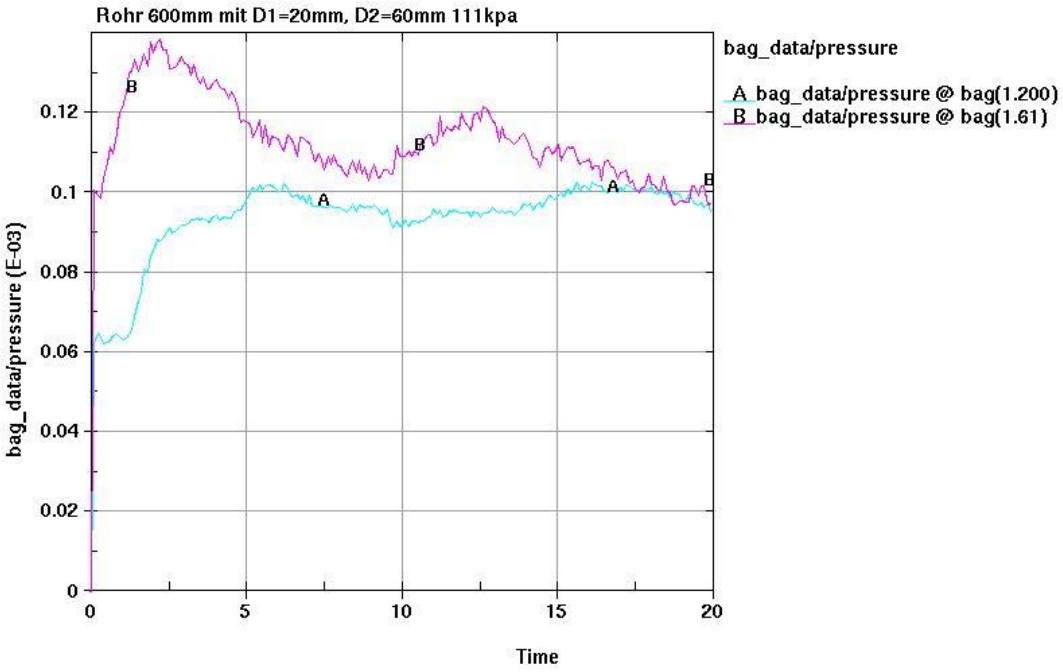


Figure 12. Pressures of Multiple Chambers

Conclusion

CPM method is a coarse-grained method that bridge s the gap between kinetic molecular theory and those that are relevant for industrial process. As there is no need to solve field equations, this method is numerically simple and robust. The CPM method has proven to be a promising new method for airbag deployment simulation. Several new features of this method are introduced, including initial air with particles and modeling multiple chambers.

References

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