Airbag Inflator Models in LS-DYNA®

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Abstract

New inflator models for the automotive air bag are developed for the pyrotechnic and hybrid inflation modes. Several propellant examples including Sodium azide(NaN_3), Azodicarbonamide($C_2H_4N_4O_2$), and Guanidine nitrate($CH_6N_4O_3$) are designed for users. To control the gas compositions into the airbag and the flame temperature in the combustion chamber, we modified an existing chemical equilibrium code, PEP(Cruise,1973) and provide a user-friendly code for users to develop their own propellant models. The inflating process is modeled by applying basic conservation laws to the several sub-sections of the inflator. Unlike existing inflator models, a new theoretical approach in a LS-DYNA model is provided. Advantages and disadvantages are discussed for the pyrotechnic and the hybrid models. In addition, we make available detailed descriptions of keyword files with comprehensive examples for the propellant ingredient control, cold and heat flow setup, and output file format options, which can be used to continue the air bag simulation with LS-DYNA's ALE, SPH, and CESE airbag simulation capabilities.

Introduction

The modeling zones of the pyrotechnic inflator generally consist of the propellant, combustion chamber, gas plenum, and discharge tank [1-3]. Propellant grains including igniting material are contained and confined to the combustion chamber, which is completely sealed from the rest of the inflator by a thin rupture disk, so that the pressure of the combustion chamber is maintained until it reaches a desired value. With rapidly increasing pressure and temperature due to combusting propellant grains, the high pressure in the combustion chamber causes the rupture disk to open. Then, the filter screen between the combustion chamber and the gas plenum captures the condensed phase slag and also cools the hot gas by permeating through the wide surface area heat sink. When the combustion gas fills in the gas plenum and the pressure in it exceeds a certain specified value, another rupture disk opens and the product gases exhaust into the discharge tank. Since the pressure, temperature and mass flow rate in the discharge tank caused by the performance of the inflator characteristics are the crucial factor in designing an airbag, the purpose of the simulation model is to provide accurate information concerning the combustion of the gas.

Recently, O'Loughlin et al. [4] published a U.S. patent for a heated gas inflator (HGI) that avoids several drawbacks for the conventional pyrotechnic inflator: 1) variable performance depending on the ambient condition, 2) disposal of un-burnt propellants, and 3) toxicity of the combustion products.

The HGI consists of an igniter, pressurized initial mixture chamber, and the discharge tank including exit nozzle. The common fuel is hydrogen with oxygen and the diluting gases are typically helium, nitrogen and argon. Initially, the canister chamber in the HGI is filled with pressurized fuel and mixture gases. By triggering with an electric signal, the igniter initiates the combustion, which propagates through the canister and eventually generates strong detonation waves in the downstream direction. Then, a rupture disk having the same purpose as in a pyrotechnic inflator breaks open and allows gas to flow into the discharge tank or airbag.

Theoretical Models

Pyrotechnic and Hybrid inflator

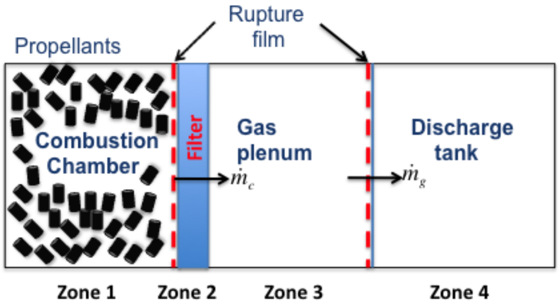


Figure 1 Schematic of the multi-zone inflator model.

As shown in Fig.1, the current model is a typical zero-dimensional and multi-zoned approach. In each zone, the volume averaged properties are assumed so that there is no spatial variation within cells. For example, the density of the combustion gas from zone 1 to zone 2 can be considered to be uniform, i.e., $\rho \neq \rho(x,y,z)$. Moreover, the basic assumptions of the model are the same as in reference [1]. Based on the laws of the isentropic flow, the mass flow rate of the gas phase can be calculated from zone to zone. However, it is not possible to evaluate the mass flow rate of the condensed phase and thus, it is assumed to be proportional to that of the gas phase under well mixed assumption between two phases in each zone. Therefore, separate governing equations of each phase are used. In addition, it is also assumed that the gas and condensed phases are composed of multiple species with temperature-dependent thermodynamics variables, i.e. $c_p = c_p(T)$. Due to this assumption, it is justified that the gas phase is treated as a thermally perfect gas, which is typical in combustion simulation and condensed-phase species are treated as incompressible with temperature-dependent thermodynamic properties. Under these assumptions such that the specific heat coefficient, c_p, is given by a polynomial of the temperature, it should be noted that there is no explicit equation for the temperature calculation. Instead, the temperature must be determined by solving an implicit equation constructed from the conserved variables. As a result, the energy equation should not be solved directly for the temperature. To reduce the amount of the propellant and both the temperature and the particulate content of the generated gas, the pressurized inert gas or combustible gas mixture is stored in the gas plenum, which is called a hybrid inflator. There are two hybrid models; cold flow and heat flow model in the gas plenum. The main purpose of the cold flow is to reduce the combustion temperature and additionally, a portion of the unwanted gaseous species produced by the propellant combustion is diluted. By contrast, the heat flow model can monitor the production of some toxic species in the gas plenum due to complex chemical reactions. Calculation of the production rate of participating species requires that the detailed mechanism of elementary reactions be provided. Thus, the heat flow model involves the finite rate chemical reacting equation system in the gas plenum, where it is necessary to solve a stiff ordinary equation system corresponding to the species involved in combustion.

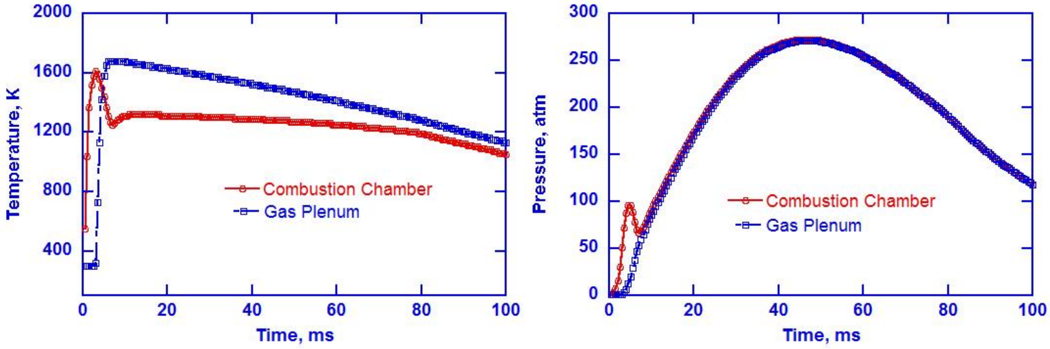
Heated Gas Inflator

Recently, to avoid the disadvantages of the pyrotechnic and hybrid pyrotechnic inflators, TRW introduced the heated gas inflator (HGI) or combustible gas mixture inflator which excludes completely the use of solid propellant. It relies on the combustion of the gaseous mixture of fuel and oxidizer such as a lean hydrogen/air mixture. Initially, the gas is stored at high pressure (200 ~ 500 bar) to generate the required amount of gas. Since the major products of combustion are water vapor, nitrogen and oxygen, it is claimed to be a clean inflator. In addition, it is easy to recycle and lighter than the pyrotechnic-type inflators. However, the gas should be maintained slightly higher than the lean limit of combustion, but lower than that of detonation. Theoretical model of HGI is the same as nominal chemically reactive flow with multi-dimensional and complex geometry. In most cases, although the flows are highly compressible and viscosity can be neglected, the general conservation governing systems are used without loss of generality.

Results and Discussion

The amount of mass of the product species generated from the solid propellants combustion was assumed to be proportion to the species mass fractions, which can be determined using a thermochemical equilibrium code [5]. The code originally was designed for calculation of thermodynamics properties in the combustion chamber and exhaust to apply to a rocket thrust performance analysis. These properties include flame temperature, chemical composition, enthalpy, etc. Upon obtaining the output of the program, the principal species making up over 99 percent of the total mass fraction were considered for use in the inflator input and the remaining minor species were neglected.

Figure 2(a) shows the temperature profiles in the combustion chamber and gas plenum. Due to the initial energy release from the igniter and propellants, the temperature increases quickly. When the interior rupture film bounding the combustion chamber wall breaks, gas and condensed phase species flow from the combustion chamber to the gas plenum, resulting in an increase of the temperature in the gas plenum. Initially, due to the existing N_2 and O_2 gases at standard conditions in the gas plenum, the maximum temperature of the gas plenum is a little higher than the temperature of the combustion chamber.

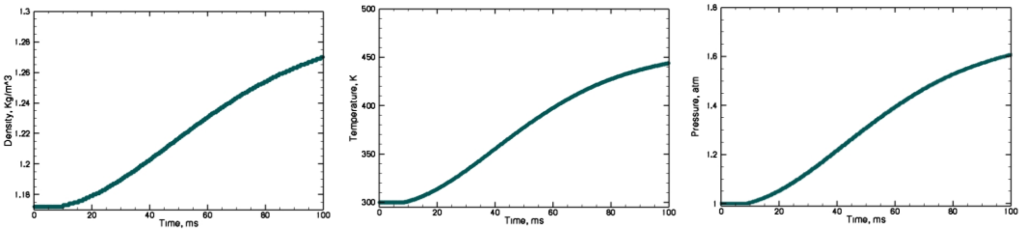


(a) Temperature (b) Pressure

Figure 2 Temperature and pressure profiles in the combustion chamber and gas plenum with time.

Figure 2(b) shows the pressure profiles both in the combustion chamber and the gas plenum. Due to the rapid energy release from the solid propellants, high pressure breaks the interior rupture film. Thus, a certain amount of gas flows into the gas plenum. Due to the sudden discharge of gas, the temperature in the combustion chamber shows a sharp decrease as can be seen in the temperature profile in Fig. 2(a). After this, a steady-state combustion mode is reached for the remaining period of time. Again, due to the initial condition in the gas plenum, the maximum pressure and the curve profile are similar to that in the combustion chamber.

Figure 3 shows the typical thermodynamics properties such as the density, pressure, and temperature as a function of time in the discharge tank in the pyrotechnic inflator simulation. With an initial delay time after which the gas flow arrives at the discharge tank, all variables are moderately increased until reaching their convergence values. The maximum pressure is about 1.6 atm and the corresponding temperature is approximately 400K, which is suitable for the airbag deployment process.



(a) Density (b) Temperature (c) Pressure

Figure 3. Thermodynamics properties at the discharge tank (zone 4).

Conclusions

In this study, we have demonstrated the performance of different inflator models: a pyrotechnic, hybrid inflator and a compressed, heated gas inflator. Descriptions of theoretical and mathematical models are provided. For the model validation purpose, the results between the numerical simulation and an experimental data set were compared, showing excellent agreement. With the development of these validated inflator models, we strongly believe that the present work should find more applications in designing advanced inflator models and predicting airbag performance.

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