

Research on Method of Evaluation of Energy in Gas Generators Using Variable Volume Tank Pressure Measurement Device

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ABSTRACT

To date, fixed volume tank pressure measurement devices have been employed in the evaluation of the performance of the gas generators (inflators) used in airbags, etc. However, these measurement devices are limited in accurately gauging inflator characteristics as the volume changes. This research project therefore built a variable volume tank pressure measurement device⁽³⁾ to enable measurement data to be obtained as internal volume changes with increasing tank pressure. This device was used in tests, and measured values were input into a predictive equation to define an index (inflator work) for the evaluation of inflator performance. The new measurement device has made it possible to evaluate energy in an inflator and has enabled the development of a new performance evaluation index (inflator work) and method.

1. Introduction

Fixed volume tank pressure measurement is one of the methods for evaluating the performance of the gas generator used in air bags, etc. This method of measurement has been employed, because it facilitates the manufacturing control of inflators.

J. T. Wang reports that knowing only the tank pressure curve (pressure measurement results obtained by fixed volume tank pressure measurement) is insufficient to determine the capability of an airbag⁽¹⁾. Many other performance evaluation methods of the inflator are being studied^{(1),(2)}. However, these evaluation methods mainly use the fixed volume tank pressure measurement device and not only are the theoretical and experimental equations complex, but also the measurement method is not simple. Therefore, it is not widely used as a method for evaluating the performance of the inflator.

Therefore, the work obtained due to the variation in the

volume of the tank was focused on, and it was considered that a method for evaluating the inflator performance can be constructed based on this work. As a result, a variable volume tank pressure measurement device⁽³⁾ with built-in flat disk piston capable of sliding within the tank was devised.

This research attempts to define the performance evaluation index of the inflator by substituting the pressure difference and the volume difference obtained as a result of the sliding of the internal piston accompanying the increase in tank pressure in this device, into the predictive equation based on the Energy Conservation Law.

Based on this assumption, the variable volume tank pressure measurement device was manufactured.

2. Definition of Measured Value Symbols

Figure 1 shows the conceptual drawing of the variable volume tank pressure measurement device. Measured value symbols are defined as shown below.

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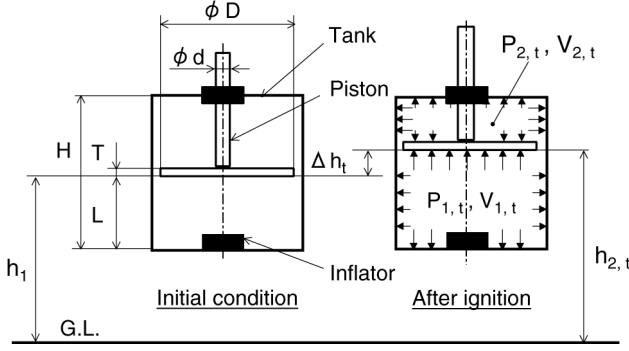


Fig. 1 Conceptual drawing of variable volume tank pressure measurement device

- D : Flat disk diameter (m) of flat disk piston
 d : Shaft diameter (m) of flat disk piston
 T : Thickness of flat disk (m) of flat disk piston
 m : Mass (kg) of flat disk piston
 H : Overall internal height of tank (m)
 $P_{1,t}$: Pressure in tank (Pa) on the lower side of disk surface of flat disk piston (hereafter referred to as "lower side of disk surface")
 $P_{2,t}$: Pressure in tank (Pa) on the upper side of disk surface of flat disk piston (hereafter referred to as "upper side of disk surface")
 $P_{1,0}$: Atmospheric pressure (Pa) in tank on the lower side of disk surface
 $P_{2,0}$: Atmospheric pressure (Pa) in tank on the upper side of disk surface
 $\Delta P_{1,t}$: Pressure difference (Pa) in tank on the lower side of disk surface
 $\Delta P_{2,t}$: Pressure difference (Pa) in tank on the upper side of disk surface
 $V_{1,t}$: Volume (m^3) of tank on the lower side of disk surface
 $V_{2,t}$: Volume (m^3) of tank on the upper side of disk surface
 $\Delta V_{1,t}$: Volume difference (m^3) in tank on the lower side of disk surface
 $\Delta V_{2,t}$: Volume difference (m^3) in tank on the upper side of disk surface
 h_1 : Height (m) from the ground line to the lower side of disk surface at the initial position of flat disk piston
 $h_{2,t}$: Height (m) from the ground line to the lower side of disk surface after sliding of flat disk piston
 Δh_t : Height difference (m)
 Δt : Time difference (s)
 L : Height (m) from the bottom surface in tank to the lower side of disk surface
 Δw_t : Flat disk piston local work (J)
 W_t : Flat disk piston total work (J)
 Δw_t^* : Inflator local work (J)
 W_t^* : Inflator total work (J)
 $\Delta w_{\kappa,t}^*$: Inflator local work (J) applying ratio of specific heat κ
 $W_{\kappa,t}^*$: Inflator total work (J) applying ratio of specific heat κ
 The subscript t in the symbols used in the equations mentioned above shows the measurement values that vary with time.

3. Predictive Equation for Variable Volume Tank Pressure Measurement Device

3.1. Flat Disk Piston Work

Here, flat disk piston work is defined as the work generated by the sliding of the flat disk piston due to the

increase in pressure in the tank when gas is generated by the inflator. If the heat issued and received in the system in Fig. 1 is ignored, the flat disk piston local work can be determined from the external work created by the system and the combination of the increased energy inside the system (Energy Conservation Law). The time integration of the flat disk piston local work is the total work of the flat disk piston.

$$\Delta w_t = P_{1,t} \cdot \Delta V_{1,t} - P_{2,t} \cdot \Delta V_{2,t} - mg \cdot \Delta h_t + \frac{1}{2} m \cdot \left(\frac{\Delta h_t}{\Delta t} \right)^2 \quad (1)$$

$$\sum_{t=0}^N \Delta w_t = W_t = \sum_{t=0}^N \left\{ P_{1,t} \cdot \Delta V_{1,t} - P_{2,t} \cdot \Delta V_{2,t} - mg \cdot \Delta h_t + \frac{1}{2} m \cdot \left(\frac{\Delta h_t}{\Delta t} \right)^2 \right\} \quad (2)$$

3.2. Inflator Work

The inflator work is assigned by dispersion of Eq. (1).

$$\begin{aligned} \Delta w_t = & P_{1,0} \cdot \Delta V_{1,0} + (\Delta P_{1,1} \cdot \Delta V_{1,1} + \Delta P_{1,2} \cdot \Delta V_{1,2} + \dots + \Delta P_{1,t} \cdot \Delta V_{1,t}) \\ & - P_{2,0} \cdot \Delta V_{2,0} - (\Delta P_{2,1} \cdot \Delta V_{2,1} + \Delta P_{2,2} \cdot \Delta V_{2,2} + \dots + \Delta P_{2,t} \cdot \Delta V_{2,t}) \\ & - mg \cdot \Delta h_t + \frac{1}{2} m \cdot \left(\frac{\Delta h_t}{\Delta t} \right)^2 \end{aligned} \quad (3)$$

Every member that forms the second and fourth member in Eq. (3) is the inflator local work. The inflator local work is defined as the amount of energy that expresses the phenomenon of the generation of gas generated by the inflator per unit time.

Assuming that the gas generated from the inflator is ideal gas, the inflator local work can be defined as shown in the following equation.

$$\Delta P_{1,t} \cdot \Delta V_{1,t} \approx \Delta P_{2,t} \cdot \Delta V_{2,t} \quad (4)$$

By applying the conditions assumed in Eq. (4), a general equation for the total work and the inflator local work was formulated. The total inflator work is the measured value that expresses the total amount of energy that can be assigned by the inflator to a restraint device until a specific time stage.

$$\Delta w_t^* = \Delta P_{2,t} \cdot \Delta V_{2,t} \quad (5)$$

$$\sum_{t=0}^N \Delta w_t^* = W_t^* = \sum_{t=0}^N (\Delta P_{2,t} \cdot \Delta V_{2,t}) \quad (6)$$

The reason for formulating a general equation for inflator work using the term on the right side of Eq. (4) is to reduce the compressibility effects of the air that exists in the tank.

If the ratio of specific heat κ is applied to Eqs. (5) and (6),

$$\Delta w_{\kappa,t}^* = \Delta P_{2,t} \cdot \Delta V_{2,t}^{\kappa} \quad (7)$$

$$\sum_{t=0}^N \Delta w_{\kappa,t}^* = W_{\kappa,t}^* = \sum_{t=0}^N (\Delta P_{2,t} \cdot \Delta V_{2,t}^{\kappa}) \quad (8)$$

then Eqs. (7) and (8) are used to compare inflators with different gas components.

The predictive equations assigned in Eqs. (5) to (8) are the equation of state of gas consisting of pressure difference and volume difference obtained by the sliding of the flat disk piston.

4. Variable Volume Tank Pressure Measurement Device

Figures 2 and 3 show the conceptual drawing and photo of the variable volume tank pressure measurement device. The variable volume tank pressure measurement device consists mainly of the cylindrical tank and the flat disk piston.

The inflator is positioned on the bottom surface of the tank and at the center of the tank in the normal direction.

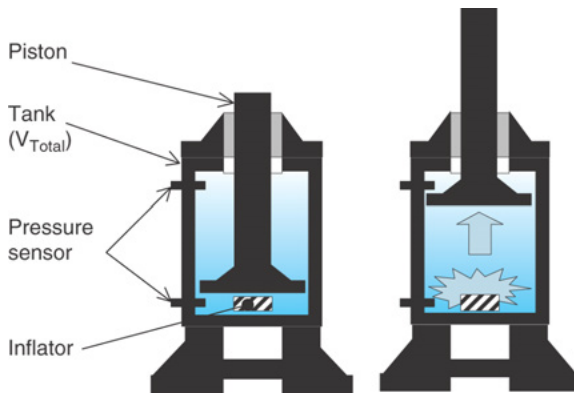


Fig. 2 Structure of variable volume tank pressure measurement device

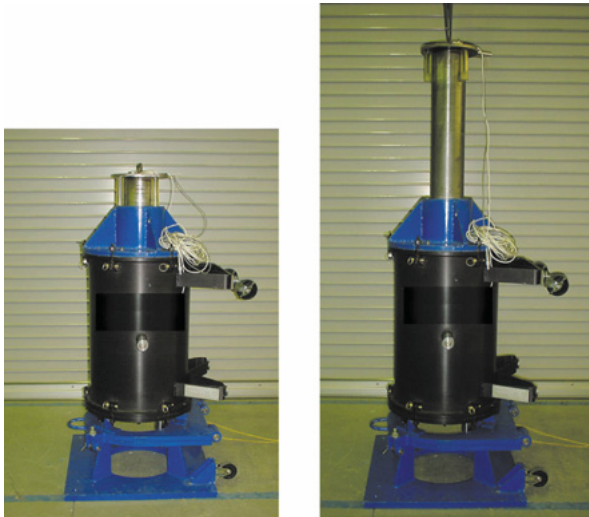


Fig. 3 Picture of variable volume tank pressure measurement device

5. Experiment

5.1. Overview of the Variable Volume Tank Pressure Measurement Device

The total tank volume V_{Total} of the variable volume tank pressure measurement device used in the experiment was taken as $0.054 \text{ [m}^3\text{]}$.

5.2. Experimental Conditions

5.2.1. Measurement method

The measurement of pressure on the upper and lower sides of the disk surface in the variable volume tank pressure measurement device was performed using two pressure sensors installed on the outer surface of the cylindrical tank at arbitrary positions in the normal direction. The position of installation of the pressure sensor was arbitrary, because the flat disk piston built in the tank is considered to slide while maintaining equilibrium between the pressures on the upper and lower side of disk surfaces.

The change in the volume of the variable volume tank pressure measurement device was calculated from the slide displacement of the flat disk piston.

5.2.2. Inflator used in the experiment and the experimental conditions

1) Dual ignition pyrotechnic inflator

- Simultaneous ignition (First and second stages 0 (ms))
- Delay ignition (First stage 0 (ms), second stages 20 (ms))
- Delay ignition (First stage 0 (ms), second stage 40 (ms))

The settings of 20 and 40 (ms) for the experimental conditions in the delay ignition are optional settings used for validating the gas generation phenomenon.

2) Single ignition pyrotechnic inflator

- The experiment was performed thrice for inflators with the same inflator specifications.

6. Validation and Observations of Experimental Results

6.1. Validation of Experimental Results

Figures 4 to 7 show the measurement results of internal pressure in the variable volume tank pressure measurement device. The vertical axis shows the pressure on the upper and lower side of disk surface in the tank and the horizontal axis shows the time from ignition of inflator.

All the measurement results in Figs. 4 to 7 show that the curves in the graph of pressures on the upper and lower sides of disk surface of the variable volume tank are in equilibrium. (Enveloped area in the figure.) This proves that the time integrated value of the pressure differences in the upper and lower side of disk surface is in equilibrium even when the inflator specifications and experimental conditions vary. Thus, the conditions assumed in the internal pressure equilibrium equation (4) proposed in this report were confirmed. Moreover, the validity of the manufactured variable volume tank pressure measurement device was also confirmed.

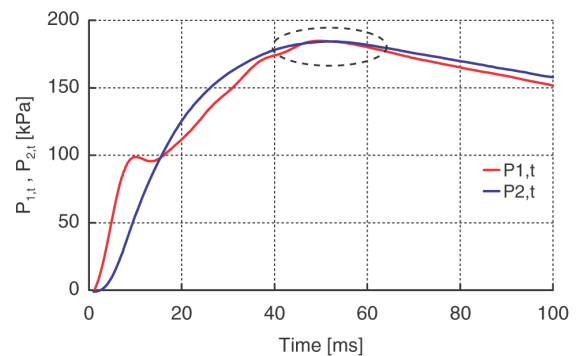


Fig. 4 Tank pressure (dual ignition pyrotechnic inflator, 0ms)

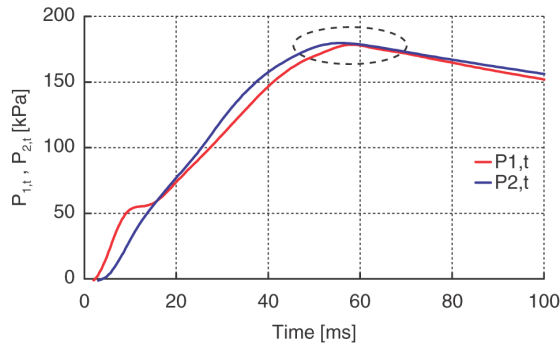


Fig. 5 Tank pressure
(dual ignition pyrotechnic inflator, 20ms delay)

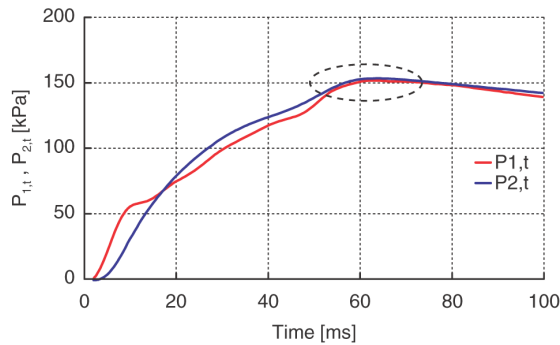


Fig. 6 Tank pressure
(dual ignition pyrotechnic inflator, 40ms delay)

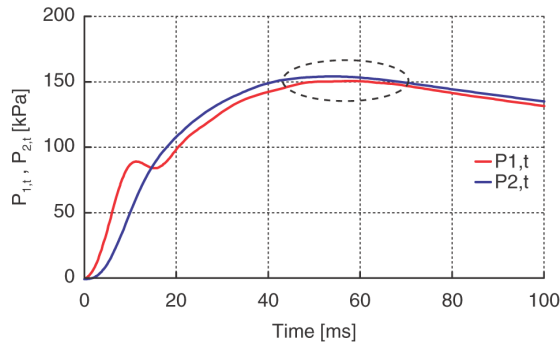


Fig. 7 Tank pressure
(single ignition pyrotechnic inflator)

6.2. Considerations

The inflator local work and the total work can be determined by substituting the pressure difference derived from internal pressure measurement results of the variable volume tank pressure measurement device and the volume difference, into predictive equation (5) and (6), or (7) and (8).

6.2.1. Dual ignition pyrotechnic inflator

Figures 8 and 9 show the calculation results of the inflator work. The vertical axis shows inflator work and the horizontal axis shows the time from ignition of inflator. The following can be understood from the results:

- (1) The graph for the local inflator work in simultaneous ignition is curved and the slope of time of local inflator work is higher than 20 and 40 ms in the secondary stage delay ignition.

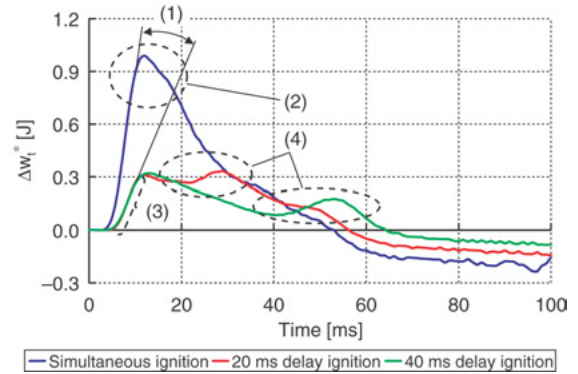


Fig. 8 Local inflator work
(dual ignition pyrotechnic inflator)

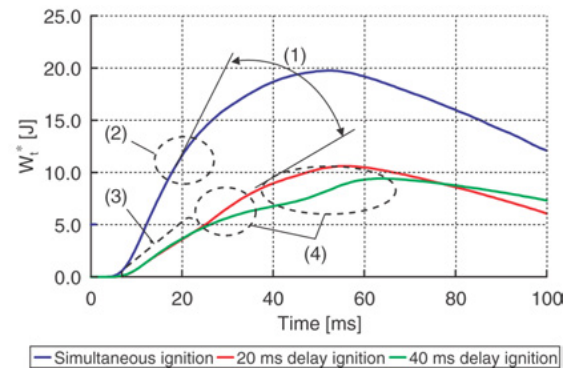


Fig. 9 Total inflator work
(dual ignition pyrotechnic inflator)

- (2) The local inflator work in simultaneous ignition deteriorates at stages earlier than the secondary stage delay ignition.
 - (3) The curve in the local inflator work graph at 20 and 40 ms of secondary stage delay ignition is consistent until it reaches the vicinity of the secondary stage delay ignition time.
 - (4) The increase in the local inflator work graph at 20 and 40 ms of secondary stage delay ignition can be seen from the vicinity of the secondary stage delay ignition time.
- These considerations are similar also for the total inflator work shown in Fig. 9.

6.2.2. Single ignition pyrotechnic inflator

Figures 10 and 11 show the calculation results of local inflator work when the experiments for single ignition were performed thrice and simultaneous ignition of dual ignition pyrotechnic inflators. The following can be understood from the results:

- (1) From the time slope and its maximum value for local inflator work and the curve of the graph, it can be seen that the dispersion of the inflator gas generation phenomenon was low when the predictive equation proposed in this paper was used.
 - (2) The differences in the local inflator work can be expressed by comparing the calculation results for the single and dual ignition pyrotechnic inflators.
- These considerations are similar also for the total inflator work shown in Fig. 11.

From the results for single and dual ignition pyrotechnic inflators mentioned earlier, it can be said that inflator work is

the amount of energy that expresses the gas generation phenomenon and the energy characteristics.

Consequently, the variable volume tank pressure measurement device with which this inflator work can be obtained is a measurement device that enables validation of the appropriate inflator performance evaluation index.

Acknowledgments

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References

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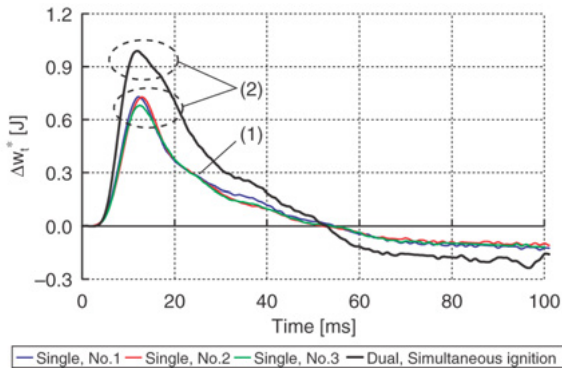


Fig. 10 Local inflator work
(single and dual ignition pyrotechnic inflators)

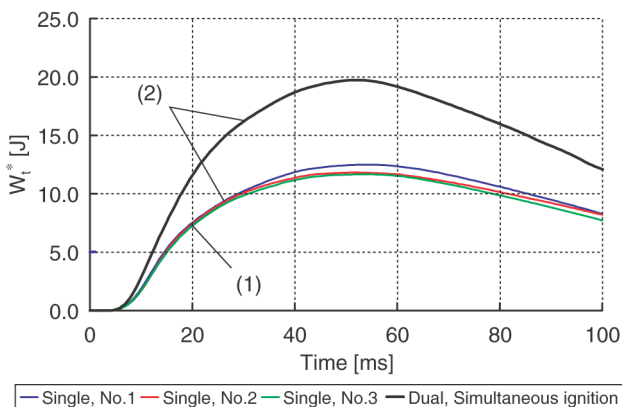


Fig. 11 Total inflator work
(single and dual ignition pyrotechnic inflators)

7. Conclusion

The goal of this research was to construct a method for evaluating the energy of the inflator considering the variable volume, for which a variable volume tank pressure measurement device with a built-in flat disk piston sliding in the tank was designed.

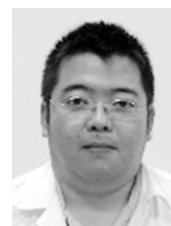
The inflator performance evaluation index was obtained from experiments using this device.

Henceforth, our endeavor will be to verify that this method of energy evaluation of the inflator can also express gas temperature and temperature conditions of the laboratory.

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