2014 5th International Conference on Chemical Engineering and Applications
IPCBEE vol.74(2014) © (2014) IACSIT Press, Singapore
DOI: 10.7763/IPCBEE. 2014. V74. 15

Experimental Investigation on Pyrotechnic Igniter for Solid Rocket Motor

Paisan Apinhapat [1+] and Narupon Pittayaprasertkul [1]

[1] Research and Development Department, Defence Technology Institute, Office of the Permanent Secretary of Defence Building, Changwattana Road, Pakkred, Nonthaburi, Thailand 11120

Abstract. Solid rocket igniters normally use pyrotechnic igniter compositions as a heat source to ignite the solid propellant. In this paper, thermodynamic properties of pyrotechnic pellet from Graphical User Interface Propellant Evaluation Program (GUIPEP) are used to calculate the suitable amount of pyrotechnic pellet quantity that produces a combustion pressure. This pressure must be higher than the critical pressure which is a reference level to continually burn a propellant. Pyrotechnic pellet composes of $BKNO_3$:Mg/Teflon: composite propellant in a ratio of 1:2:4 to increase series of heat and pressure generation. In the static test of rocket motor, various pyrotechnic pellet weights are used. The result shows pyrotechnic pellet weight with less than 45% wt. from ideal gas method calculation cannot increase the pressure to burn the propellant in 0.100 second. In contrast, pyrotechnic pellet weight with equal and higher than analytical calculation can increase the pressure to burn the propellant within 0.040 second.

Keywords: Igniter, pyrotechnic pellet, critical pressure, ideal gas

1. Introduction

Small and medium solid rocket motor typically use pyrotechnic igniter as a heat source to diffuse to the propellant grain. Heat convection from hot combustion gases and heat conduction from solid combustion products impact surface of solid propellant grain in rocket motor.

A static test of firing rocket motor usually uses normal free volume of combustion chamber inside rocket motor. The igniter provides heat to ignite the propellant and raise it to a self-sustaining combustion level. Energy release rate at the propellant surface must meet the time limit for 0.030sec. The main criteria of igniter design is to find suitable quantitative pyrotechnic pellet in the igniter. Effective firing of igniter for series of burning propellant grain in rocket motor depends on the pressure of combustion. When energetic material is ignited, hot gas in ignition and combustion process generates pressure. It must keep the pressure to be higher than critical pressure which is the reference value to make the combustion continue. Pressure from the combustion in ignition process depends on type and weight of energetic material in igniter [1].

2. Theory and Related Researches

The success of ignition in a rocket motor propellant depends on the combustion pressure. When ignition process starting, the pressure generated by hot gas must be higher than the critical pressure (P*) [2], which is the minimum pressure to ignite the solid propellant.

2.1. Critical Pressure

At low pressure, heat energy is very important in igniting the rocket motor propellant. The igniter size depends on pressure of the rocket motor. The critical pressure should reach the level that the propellant can

[+] Corresponding author. Tel.: + 662-9806200-207; fax: +662-9806198.
E-mail address: Paisan.a@dti.or.th.

be ignited and continuously burnt. There are several methods to calculate the critical pressure assuming that the nozzle is small or the end of the nozzle is closed, so the free volume in the motor become a closed system. The pressure from igniter combustion can be calculated based on the free volume in the closed system.

The critical pressure can be achieved by various methods such as experiences of making rocket motor propellant, igniter test, or using Von-Elbe equation [3] as shown below.

$$P^* = \left[C_1 \frac{2km}{c\rho b} \right]^{\frac{1}{1-n}} ; C_1 = \frac{A_s}{V} \rho RT ; b = \frac{r}{P^n} \qquad (1)$$

P* is critical pressure (atm),
k is propellant heat conductivity (cal/cm-sec-K),
n is propellant exponent,
c is propellant specific heat of solid (cal/g-K),
ρ is propellant density (g/cm^3),
A_s is surface area exposed to igniter combustion products (cm^2),
V is chamber free volume (cm^3),
R is propellant gas constant (cm^3-atm/g-K),
T is propellant flame temperature (K),
r is propellant burning rate (cm/sec),
P is chamber pressure at 1,000 psi (atm)

2.2. Pelleted Pyrotechnic

Pyrotechnic is a basic type of igniter used to ignite a small or medium rocket motor. The pelleted pyrotechnic is formed in a bulk of wire mesh or perforated metal basket. The energy output from ignition depend on the form, composition, quantity and density of the pellets. When controlled dimension with discrete pellets are used, a specific ratio of burning surface to chamber vent area is maintained to provide a greater control of the ballistic performance of igniter. There are 3 types of Pyrotechnic grain which are normally used. $BKNO_3$ has ease of ignition at very low pressures, and also produce high gas content and low sensitivity of burning rate to pressure. Al/K_2ClO_4 has high energy content but difficult to ignite at low pressures. Mg/Teflon generally characterized by very low pressure burning-rate exponent and low gas content, has energy output strong in the infrared region and energy content approximately equivalent to that of $BKNO_3$. Table I shows heat properties of pyrotechnic grain [4].

Table 1: Thermal Properties of Different Pyrotechnic Grain

Type	$BKNO_3$	Al/K_2ClO_4	Mg/Teflon
Burning rate ,mm/sec	43.2	9.9	10.2
Pressure exponent	0.32	~1	0.22
Heating value ,cal/g	1550	2490	2200

In general, the design criteria base on the comparison between weight of the pyrotechnic and free volume of the rocket motor [5]. The advantage of this method is fast and the calculation is not complicated. However, other methods use the surface area of the propellant, for example, Bryan-Lawrence that calculates base on the properties of rocket motor and heat flux method [6].

With less quantity of pyrotechnic, the pressure is raised up after the rocket motor is ignited. However, it is not enough to raise the pressure in the rocket motor's free volume to be higher than the critical pressure [7]. As a result, the ignition is not successful as shown in Fig. 1.

On the other hand, by using enough quantity of pyrotechnic, the pressure in the igniter is high and over the critical pressure which lead to the burning of rocket motor as shown in Fig. 2.

3. Calculation and Experiment

A model of rocket propellant is designed as a cylindrical annulus gear shape for initial burning area. Igniter is installed in the front end of a rocket motor as shown in Fig. 3. From equation (1), when all variables are defined, the critical pressure of each state can be determined. In this case, the calculated critical pressure of this rocket motor is 27.7 atm.

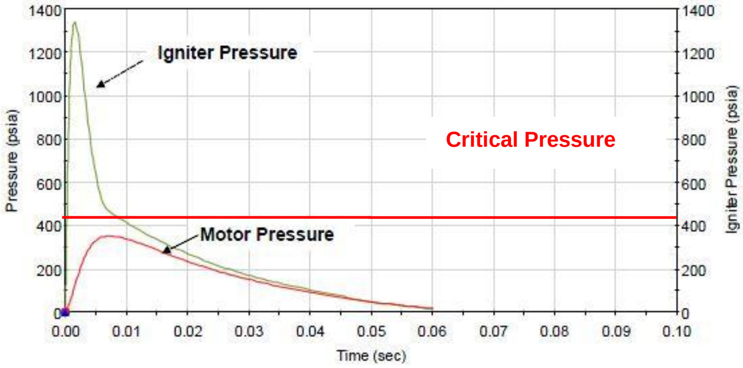

Fig. 1: Ignition at lower critical pressure

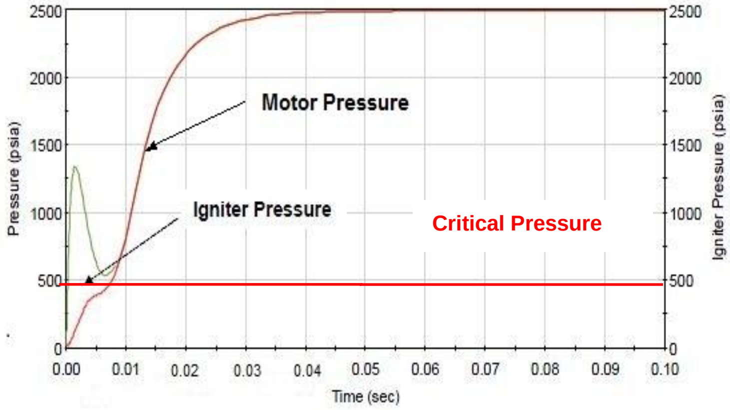

Fig. 2: Ignition at higher critical pressure

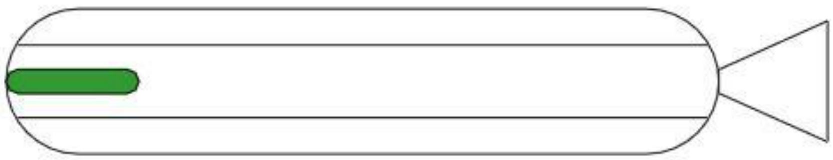

Fig. 3: Position of igniter case in rocket motor

Subsequently, the weight of pyrotechnic pellet is calculated base on thermodynamic properties from Graphical User Interface Propellant Evaluation Program (GUIPEP) [8] as shown in Fig. 4. This program calculates the enthalpy, entropy, C_p/C_v, specific heat, composition, mole and molecular weight of exhaust gas from the combustion of additional quantity of pyrotechnic pellet composition. Critical pressure from the above and chamber volume rocket motor is used to convert the volume of ideal gas at 1 atm. Then, volume of ideal gas is converted to the mole of exhaust gas. Next, mole of exhaust gas from GUIPEP program can be converted to the pyrotechnic weight.

The pyrotechnic pellet using in this study composes of BPN:MTV:composite propellant in a ratio of 1:2:4 to serially increase heat and pressure generation. From the above data, pyrotechnic pellet quantity using to generate the pressure to reach critical pressure is 145 grams.

Finally, the experimental investigation in a static test is using pyrotechnic pellet at various quantities to show the effect of pressure ignition in motor chamber.

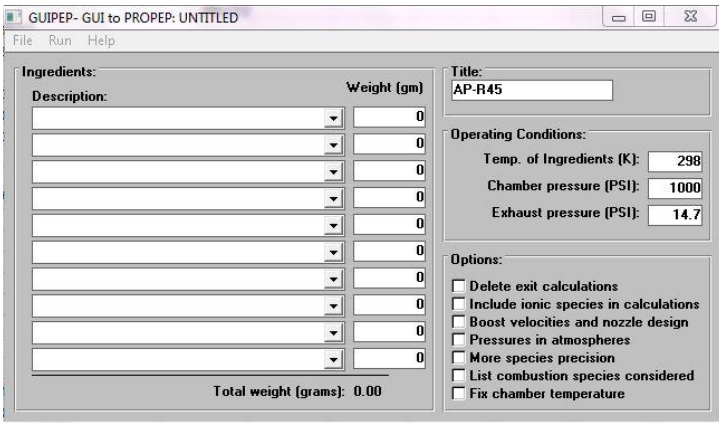

Fig. 4: GUIPEP program

4. Result

The experimental weight of pyrotechnic pellet at 59 grams, which is much less than the calculation weight (145 grams).

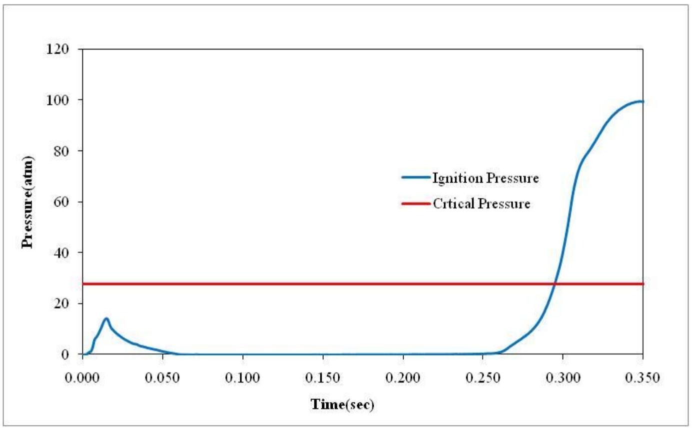

Fig. 5: Ignition pressure VS ignition time of pyrotechnic pellet 59 grams

From Fig. 5, the result shows that chamber pressure after ignition is less than the critical pressure and the ignition of rocket motor is delayed for 0.294 sec.

The experimental weight of pyrotechnic pellet at 145 grams, which is equal to the calculation weight.

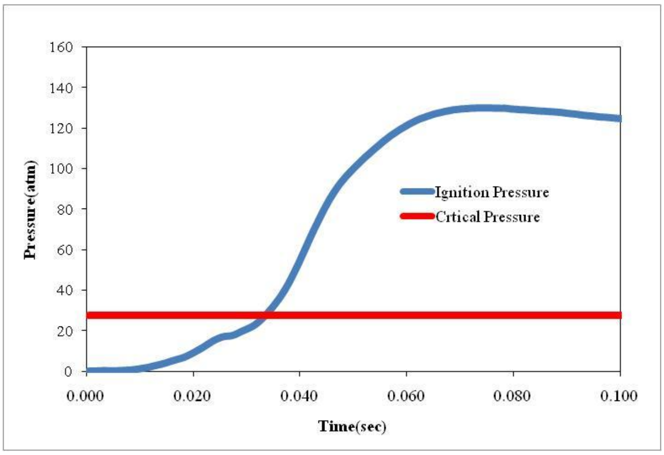

Fig. 6: Ignition pressure VS ignition time of pyrotechnic pellet 145 grams

From Fig. 6, the result shows that chamber pressure after ignition is higher than the critical pressure with the successful ignition of rocket motor in 0.033 sec.

The experimental weight of pyrotechnic pellet 175 grams, which is higher than the calculation weight.

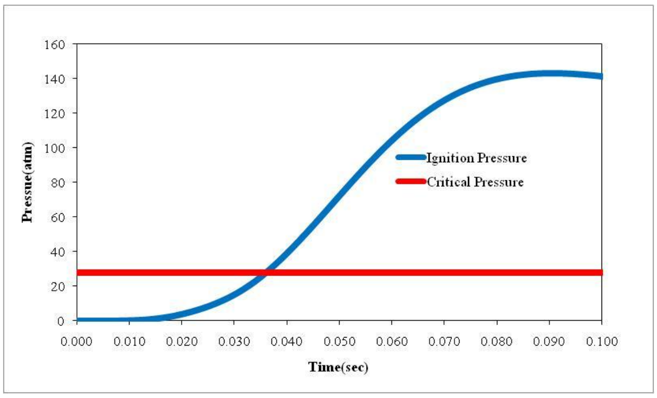

Fig. 7: Ignition pressure VS ignition time of pyrotechnic pellet 175 grams

From Fig. 7, the result shows that chamber pressure after ignition is higher than the critical pressure with the successful ignition of rocket motor in 0.036 sec.

5. Conclusion

From the experiment, Critical Pressure from Von-Elbe equation is recommended as a reference pressure to calculate the appropriate pyrotechnic weight.

The 45% of pyrotechnic pellet weight from the calculation can be used to ignite the rocket motor but use long ignition time to burn propellant for increasing chamber pressure continually (fail to meet required ignition time).

The 100% of pyrotechnic pellet weight and higher from the calculation in ignition system can be used to ignite the rocket motor to burn propellant for increasing chamber pressure continually.

6. Acknowledgements

This work was funded by the Operation Propulsion System Laboratory, Research and Development Department, Defence Technology Institute (Public Organisation), Nonthaburi, Thailand.

7. Reference

[1] Carr, C. E. and Thomas, M. J., *Factors Influencing BKNO3 Igniter Performance*, AIAA Paper No. 87-1985, June, 1987.

[2] Bryant, G. J. and Lawrence, Evan K.: *A Method for Predicting Ignition Energy Requirements of Practical Propellant Systems. Part III*, NAVORD Report 6134, Naval Ordnance Lab., Feb. 2, 1959 (Confidential)

[3] Von Elbe, G., *Theory of Solid Propellant Ignition and Response to Pressure Transients*, Bulletin of the Interagency Solid Propulsion Meeting, Vol. III, July, 1963.

[4] Robertson, W. E., *Igniter Material Considerations and Applications*, AIAA Paper No. 72-1195, November, 1972.

[5] Nachbar, D.; et all. *Aft-End Ignition Large Solid Rocket Program*. Final Report SSD-TDR-62-103, Aerojet-General Corp., Oct. 1962.

[6] Keller, R. B. Jr., ed., *Solid Rocket Motor Igniters*, NASA SP-8051, March 1971.

[7] Apinhapat P., et all; "Mass and Energy Balance Technique for Rocket Motor Igniter Design Criteria with a High Free Volume", The 44th International Annual Conference of the Fraunhofer ICT, Germany, Jun. 2013.

[8] http://www.nakka-rocketry.net/th_prope.html