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NEGATIVE DIFFERENTIAL PRESSURE BY IGNITION OF GRANULAR SOLID PROPELLANT

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This report deals with the results of experimental study for a negative differential pressure by ignition of granular solid propellants in a large calibre gun system. Experiments were performed using a combustion vessel with a rupture disk. The vessel was designed to investigate a negative differential pressure at the initial combustion of the propellants in a relatively simple manner. Internal volume of the vessel was approximately 9500cm^3, inner diameter was 148mm and the internal length of the vessel was 550mm. The rupture disk was 9mm thick steel, and the diameter was 115mm. The rupture disk was sheared at approximately 150MPa during combustion of propellants. A nineteen-perforation hexagonal triple base granular propellant with the grain size of 15mm and the web thickness of 2mm was used. 8.4kg of the propellants were charged tightly in the vessel. The Benite of 2mm diameter straight strands was used as the priming charge. In order to optimize the design parameters of the igniter, the effect of length of the primer, charge mass of the Benite, size of the flash holes. The mechanisms of generating the negative differential pressure were discussed by evaluating the using experiment data.

INTRODUCTION

In recent years, ignition to the propellant charges of large calibre guns by a short igniter become necessary in the case of the ammunitions that a tail part of projectile are deeply merged in the combustion chamber. However, it has been reported that a pressure wave was generated by a partial ignition of the breech side in granular propellants charge of a large calibre guns [1]. The pressure wave would cause a pressure gradient in the chamber, then may cause a damage of artillery not only influence on a ballistic performance. Differential pressure is often used in firing tests for an indication of the pressure gradient, namely, a uniformly ignition for propellants. Especially, restraining a negative peak of differential pressure (NDP) is important to avoid a destruction of artillery. A method of acquiring data by using actual projectiles and artilleries is the best when the primer of new ammunition is developed. However, a destruction of artillery would be caused by a large NDP, which is generated by a partial ignition. Authors have been conducting extensive work to establish an evaluation method of NDP without using practical projectiles and artilleries.

In this study, NDP in granular propellants was measured with a combustion vessel with a rupture disk. The effects of igniter length, the amount of igniter powder, and the size of flash holes of igniter were discussed.

EXPERIMENTAL SETUP

Figure 1 shows a schematic of combustion vessel that was designed for this study. The combustion vessel consists of a chamber, an igniter, a rupture disk, a breech plug, and disk plug. The vessel was designed to simulate the geometry and dimensions of the gun chamber, the internal volume of the vessel was approximately 9500cm^3, the internal diameter was 148mm, and the internal length of the vessel was 550mm. The rupture disk was made from steel with thickness and diameter of 9mm and 115mm, respectively. The rupture disk was designed to shear at approximate 150MPa by a combustion pressure of propellants, both combustion gas and residual propellants gush out to the outside after a shear of rupture disk. This structure, which consists of the rupture disk, enables to observe initial ignition phenomena without having an exceedingly strong chamber. In addition, expensive projectile and canon barrels are not necessary. Therefore, an experimental cost can be reduced.

Figure 2 illustrates an experimental setup in this study. Three piezoelectric gauges (PCB, Series 165M05) were installed along the side of combustion vessel: 1st gauge (P1) and 3rd gauge (P3) near the breech and the rupture disk, 2nd sensor (P2) at the middle of P1 and P3. An optical fiber cable was installed near the rupture disk, in order to measure a timing of the share of rupture disk. The optical fiber cable detects the flash from the combustion flame when the disk sheared, then an amplifier device converts the flash into an electric signal and send the signal for a data recorder.

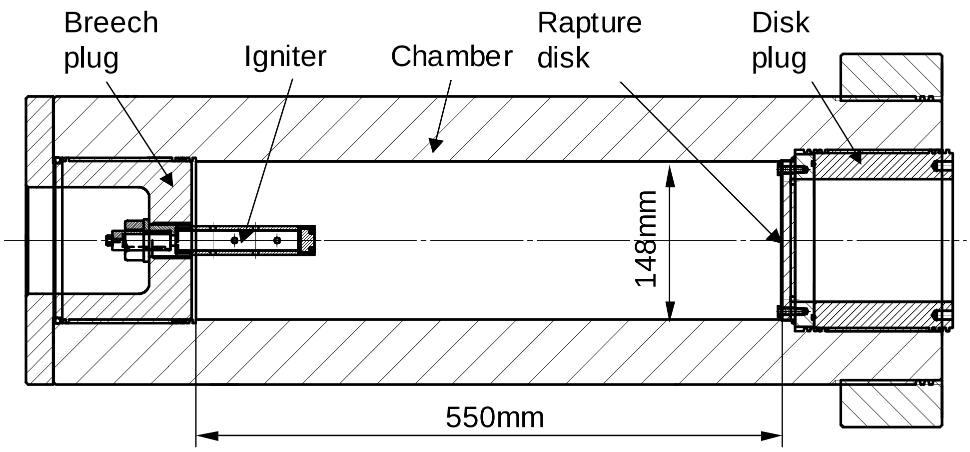

Figure 1. Cross-Sectional Schematic of Combustion Vessel

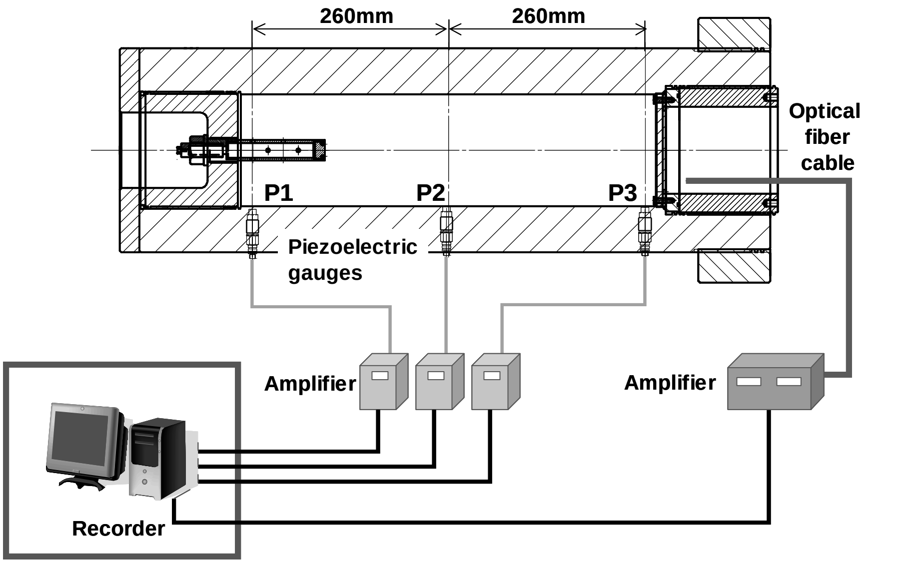

Figure 2. Experimental Setup

EXPERIMENTAL

In this study, eleven rounds of firings were conducted with various conditions at 21ºC temperature condition. The length of igniter tube, the diameters of the flash holes of igniter, and the charge mass of priming charge were changed as experimental parameters to research the effects for NDP, shown in Table 1. Figure 3 shows cross sectional schematic of igniter tubes, their inner length of 300, 200 and 100mm. These igniter tubes are made of steel. The inner and outer diameters were 19.4mm and 27.2mm respectively. The numbers of flash holes on the tubes were 28 for 300mm tube, 18 for 200mm tube, and 8 for 100mm tube.

Granular hexagonal 19 perforated triple base propellants are used for a main charge, which was charged tightly in the vessel. The mass of the main charge was 8.4 kg. Straight Benite was used for a priming charge. The length of Benite was fitted to the inner length of several igniters. The maximum charge mass of igniter powder were 65g for 300mm tube, 43g for 200mm tube, and 22g for 100mm tube. The characteristics of propellants are shown in Table 2.

Table 1 Experimental condition

Experiment No	1	2	3	4	5	6	7	8	9	10	11
Length of ignitor (mm)	300	200	100	100	100	100	100	100	100	100	100
Number of flash halls	28	16	8	8	8	8	8	8	8	8	8
Charge of ignitor propellant	65	43	22	22	22	16	16	16	11	11	11
Diameter of flash halls (mm)	5.0	5.0	5.0	7.2	8.8	5.0	7.2	8.8	5.0	7.2	8.8
Total area of flash halls (mm^2)	550	314	157	326	487	157	326	487	157	326	487

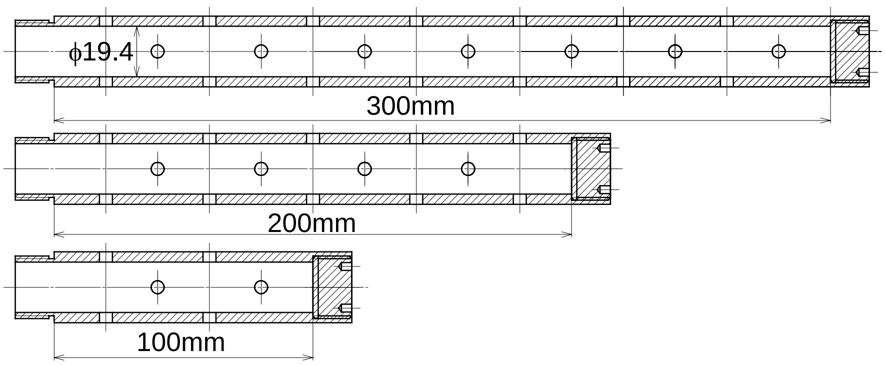

Figure 3. Igniter Tubes

Table 2 Property of propellants

	Main charge	Priming charge
Formulation	Triple base	Benite
Geometry	Hexagonal 19 perforated	Stick
Diameter	15mm	2mm
Length	15mm	-
Web	2.0mm	-
Density	1.68 g/cm^3	1.60 g/cm^3
Impetus	1026 J/g	554 J/g

RESULTS and DISCUSSIONS

Figure 4 shows Pressure-Time curves (PT curves) of P1, P2, P3, differential pressure (DP) curve, and an optical fiber sensor in the case of Experimental No.3. DP was obtained by subtracting pressure P1 from pressure P3.

In an initial stage of the curves, P1 increased gradually by the combustion gas of the propellant. After the increase of P1, P2 followed the behaviour of P1, while P3 increased rapidly at t=22.5ms in comparison. The most popular explanation for the cause of NDP is a generation of pressure wave in the chamber and a reflection of the wave on the rupture disk [2]. Partially ignited propellant bed gives ignition waves into the region of unignited propellants exist. The deferential pressure increases as the pressure wave propagates from the primer to the rupture disk. When the wave arrives on the rupture disk, the pressure of the wave increases rapidly by a reflection on the rupture disk. The increased pressure wave propagates to opposite direction from the rupture disk to the igniter. Consequently, the rapid pressure increase of both P2 and P1 are caused by a passage of the pressure wave. A signal of the optical cable, which increased at t=24ms indicated a shear of the rupture disk, and the rupture disk sheared at approximate 150MPa on P3gauge in this round. In spite of the shear of the rupture disk, all pressures (P1, P2, and P3) increased continually. It is considered that it took some time fore the sheared part of the rupture disk passed through the disk plug. All pressures increased until the part had finished passing. Although, the PT curves show a different behaviour with a general curves used by usual ammunition, the combustion vessel provided the good measurements for negative differential pressure.

Figure 5 shows the length of igniter vs. NDP, which results were obtained in round #1, #2 and #3. The NDP increased with shortening of the igniter tube. This is attributed to a decreasing of ignition area in the propellant bed.

Figure 6 shows the total area of flash holes (A_{fh}) of igniter vs. NDP, which were results of round #3 to #11. The symbols in Figure 6 indicate each mass of priming charge. In the case of A_{fh} =157mm^2, NDP were different for each mass of priming charges. Increasing the mass of priming charge caused increases of NDP. In contrast, in the case of A_{fh} =326mm^2 and 487mm^2, NDP were almost fixed value 20MPa regardless of the mass of priming charges.

According to above-mentioned results on the relationship between A_{fh} and the mass of priming charge, it can be judged that the increase of A_{fh} was effective in control of NDP. However, when its attention was paid to change of ignition delay time, A_{fh} had brought about the undesirable effect as shown in Figure 7. The ignition delay time increased with both increasing the A_{fh} and decreasing the mass of priming charge. Depending on a required performance of ammunition, the increase of this ignition delay may cause some troubles. Therefore, the determination of both the total area of flash holes and the mass of priming charge should be paid attention to the balance of both NDP and ignition delay time.

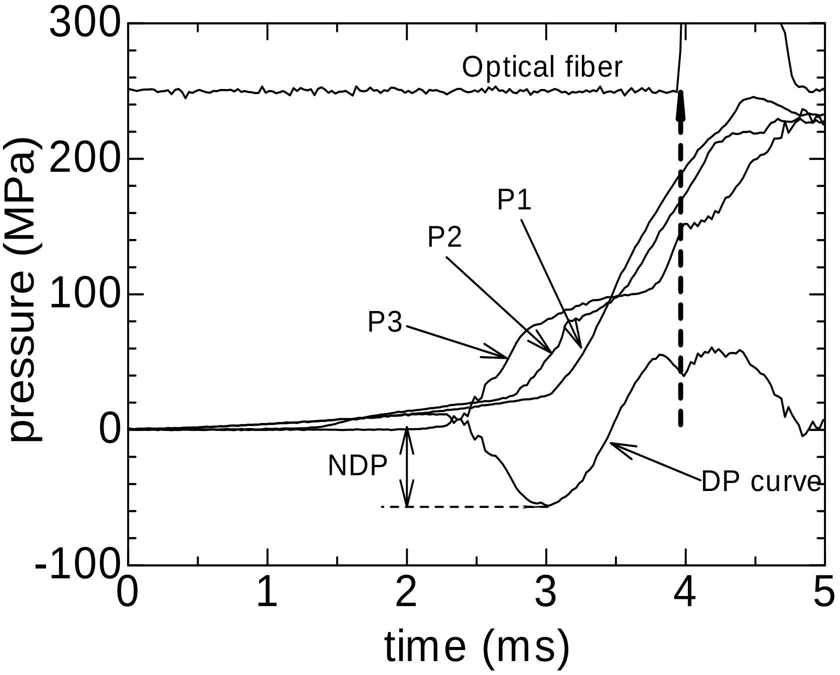

Figure 4. Typical Pressure–time curves
(Round #3, Length of igniter tube: 100mm, charge weight of ignition propellant: 22g)

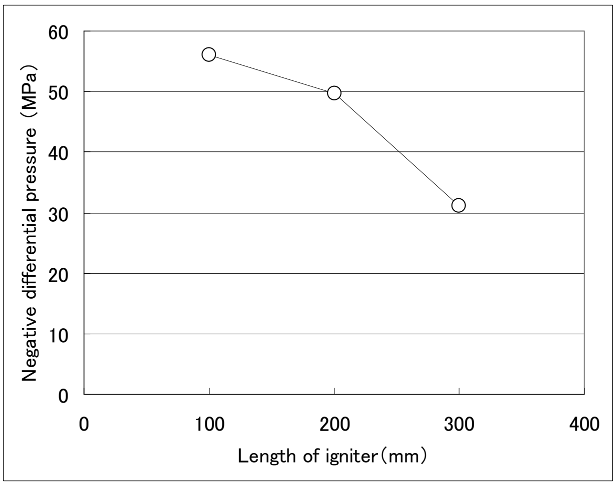

Figure 5 Length of igniter tube vs.
Negative differential pressure (NDP)

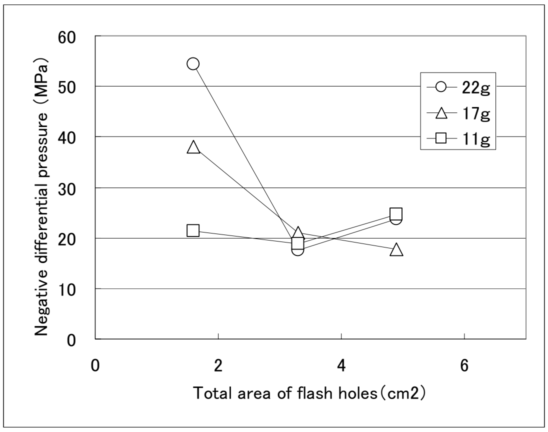

Figure 6. Total area of flash holes (A_{fh}) vs. Negative differential pressure (NDP) (Length of igniter tube: 100mm)

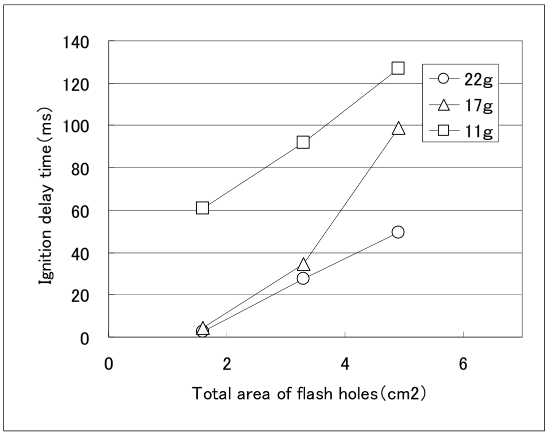

Figure 7. Total area of flash holes (A_{fh}) vs. Ignition delay time (NDP) (Length of igniter tube: 100mm)

Additionally, it was investigated if some parameters are associated with the NDP ant the ignition delay time. Figure 8 shows the relationship between the calculated maximum combustion gas flow of priming charge (MGF) and the NDP and the ignition delay time. The MGF used here were calculated results by a lumped parameter simulation, because it is so difficult to measure pressure in igniter tubes. It appears that MGF is linked with an increasing NDP and a decreasing ignition delay time. This relationship may be useful to estimate the NDP and the ignition delay time by calculated results for the igniter.

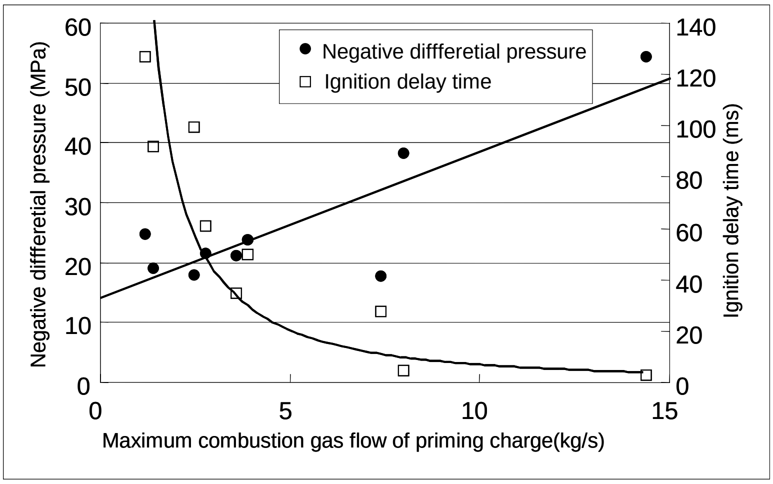

Figure 8. Calculated maximum combustion gas flow of priming charge vs. Negative differential pressure and Ignition time (Length of igniter tube: 100mm)

CONCLUSIONS

The experiments using a combustion vessel with a rupture disk were carried out in order to investigate a negative differential pressure (NDP) at ambient temperature conditions. The examination method using the combustion vessel provided detail information on the NDP in the cases of several ignition conditions. Consequently, it was found that the NDP increased with shortening of length of the igniter tube. For the effect of the total area of flash holes (A_{fh}) of igniter and the mass of priming charge, NDP were different for each mass of priming charge in the case of A_{fh} =157mm^2. Increasing the mass of priming charge caused increases of NDP. In contrast, in the case of A_{fh} =326mm^2 and 487mm^2, NDP were almost fixed value 20MPa regardless of the mass of priming charges. The ignition delay time increased with both increasing the A_{fh} and decreasing the mass of priming charge. From the above results, it is found that calculated maximum combustion gas flow of priming charge was linked with an increasing NDP and a decreasing ignition delay time.

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