



Study on the Initiation Capacities of Two Booster Pellets

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Abstract: The appearance of insensitive main charges has created new requirements in the booster pellets of the detonation train, specifically, the output of the booster pellet must be strong enough to initiate the insensitive main charge. Traditional cylindrical booster pellets have great difficulty in meeting the demands of the insensitive main charge for reliable detonation. A four-point-synchronous explosive circuit and an eight-point-synchronous explosive circuit were designed to initiate two booster pellets, designed on the basis of shock initiation theory and effective charge theory, as well as the shaped charge effect theory. The results show that booster pellet 1 and booster pellet 2, under multi-point-synchronous explosive circuits, can initiate standard main charge pellets with less explosive mass than an ordinary cylindrical booster pellet. The initiation capacity of booster pellet 2 is better than that of booster pellet 1.

Keywords: explosion mechanics, booster pellet, synchronous explosive circuit, initiation capacity, main charge

Introduction

The appearance of insensitive main charges has demanded new requirements for the explosive train of the booster pellet. These are firstly, that it has a large energy output, and secondly, that the insensitivity of the whole explosive train should be in accordance with the ammunition, which means that, in the face of threats in the battlefield environment, it should have the same “immunity” as the ammunition [1, 2].

The traditional cylindrical booster pellet has insufficient energy output to initiate reliably an insensitive main charge. Therefore, it is necessary to develop

a highly effective booster charge structure, to effect reliable initiation of the insensitive main charge using a small booster pellet. It is also necessary to study the technique of highly effective initiation and detonation transmission, in order to increase the initiation capacity of the booster pellet. Spahn [3] studied an initiation system with a booster explosive ring. The explosive device had a main charge explosive and a booster explosive ring, with the main charge explosive filling the space in the center of the booster ring. When the booster explosive was set off, shock waves converged on the space at the center of the ring, thus, initiating the main charge explosive. Spahn [4] also studied an embedded can booster. A can or plate was embedded in the main charge explosive and provided a high impedance surface which is shaped and oriented so that shock waves from the booster explosive strike the high impedance surface at normal incidence and are reflected back towards the booster explosive. This increases the pressure in the main charge explosive material between the booster explosive and the can or plate, thus, increasing the effectiveness of the booster explosive. Corley et al. [5] studied the initiation technology of a hemispherical booster explosive. Their results showed that the output of the hemispherical booster explosive was large for a small quantity using this technology. Menz et al. [6] designed an explosive AND/NAND logic element and a three-input-seven-output explosive logic element. Wilhelm et al. [7] invented a multi-point warhead initiation system. Kennedy et al. [8] invented a multi-directional initiator for explosives. However, there are few reports that have concentrated on the study of booster pellet structures and highly effective initiation systems.

In this paper, two highly effective booster pellets initiated by four-point-synchronous and eight-point-synchronous explosive circuits were studied experimentally.

Experimental

Experimental method

There are many methods to assess the initiation capacity of a booster pellet [9]. Two methods are used in this paper.

(1) The main charge varied-composition method. A composite explosive is designed as the main charge. The main charge containing different amounts of a desensitizer is directly initiated by the booster pellet. The critical initiation amount of the desensitizer represents the initiation capacity of the booster pellet required to initiate the main charge completely under these conditions.

(2) The main charge axial-steel-dent method. In this method, the main charge

in contact with the steel witness plate is directly initiated by the booster pellet. The depth of the dent represents the initiation capacity of the booster pellet.

Experimental devices

The experimental devices used to measure the initiation capacity of booster pellets 1 and 2 under multi-point-synchronous explosive circuits are shown in Figures 1 and 2 respectively.

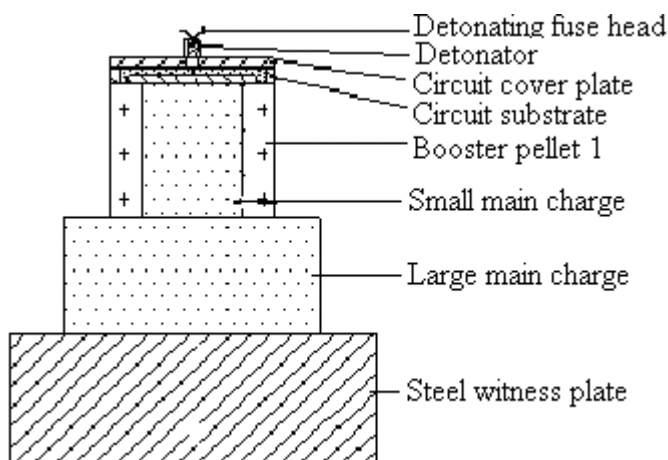


Figure 1. Booster pellet 1 under multi-point-synchronous explosive circuit.

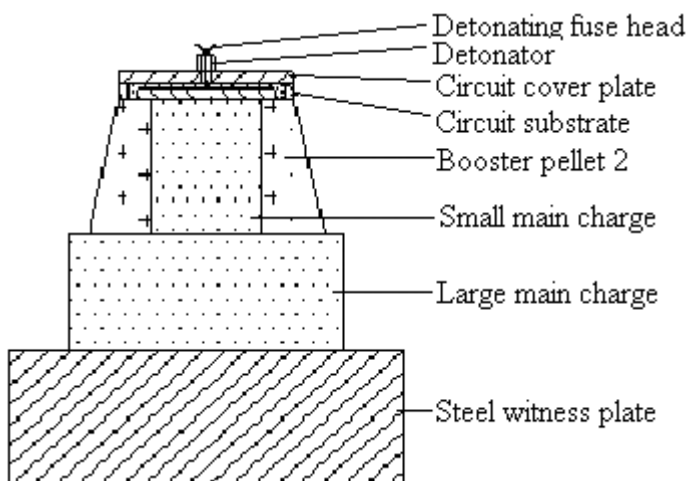


Figure 2. Booster pellet 2 under multi-point-synchronous explosive circuit.

Experimental conditions

(1) Selection of explosives

The explosive for the multi-point-synchronous explosive circuits must not only propagate the detonation wave steadily, but also have enough initiation capacity at a small charge diameter. It has also to have a good technological characteristic at a diameter of 1 mm or less. Ultra-fine HMX was selected as the circuit charge, because it has a small critical diameter, small particle size, large output energy, high detonation velocity, good thermal stability, good fluidity, and it can propagate a detonation wave well at under 1 mm charge diameter.

The plastic-bonded booster explosive PBXN-5 was used in the experiment. Since PBXN-5 is a new booster explosive with high detonation velocity and good thermal stability, it is a permitted booster explosive for use in in-line explosive train systems.

The main charge with varied compositions was designed to meet the experimental demand. The ingredients were nitroguanidine (NQ), polytetrafluoroethylene (PTFE) and graphite. NQ is the explosive component, PTFE is a desensitizer and graphite is used to lubricate and to eliminate static electricity. The content of the latter is generally small. The sensitivity of the composite explosive was adjusted mainly by changing the PTFE content. The critical amount of the desensitizer represents the initiation capacity of the booster pellet required to initiate the main charge completely under the conditions.

(2) Preparation of the base plates of the multi-point-synchronous explosive circuits.

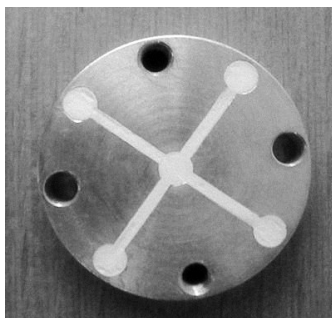


Figure 3. Four-point-synchronous explosive circuit.

The precision, press-loading charge method was used in the construction of the multi-point-synchronous explosive circuits. The processes of precision, press-loading charge of base plates were as follows. Firstly, a certain amount of explosive was accurately selected, it was then uniformly put into the groove

of the base plate, and it was finally pressed into the form using a special mould under pressure [10].

The charge densities of the multi-point-synchronous explosive circuits were between $1.36\sim 1.37\text{ g/cm}^3$. In this experiment, the charge was pressed under a pressure of 1.25 t using a screw press, with a holding time of 30 s. The charge obtained had a smooth surface, was uniform in density, and had good consistency. The base plate of the four-point-synchronous explosive circuit is shown in Figure 3. The base plate of the eight-point-synchronous explosive circuit is shown in Figure 4.

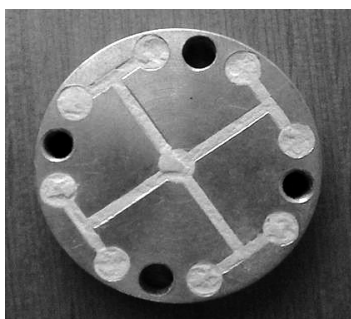


Figure 4. Eight-point-synchronous explosive circuit.

(3) Preparation of the cover plates of the multi-point-synchronous explosive circuits.

The steps for the press-loading charge of the cover plates were as follows. Firstly, a small explosive pellet with 3 mm length and $1.15\pm 0.01\text{ g/cm}^3$ density was produced, and put into the cover plate. The cover plate of the multi-point-synchronous explosive circuit is shown in Figure 5.



Figure 5. Cover plate of multi-point-synchronous explosive circuit.

(4) Preparation of the booster pellets.

All booster pellets were pressed by mould external positioning, and the densities were all 1.66 g/cm^3 . The diameter of the cylindrical booster explosive was 29.58 mm. The inner diameter, outer diameter and height of booster pellet 1 were 17.10, 28.94, and 20.00 mm respectively. The booster pellet 1 is shown in Figure 6. The inner diameter, upper outer diameter, lower outer diameter and height of booster pellet 2 were 17.10, 25.65, 32.11 and 20.00 mm respectively. The booster pellet 2 is shown in Figure 7.



Figure 6. Booster pellet 1.



Figure 7. Booster pellet 2.

(5) Preparation of main charge.

The density, diameter and height of the large main charge were 1.28 g/cm^3 , 42.30 and 36.50 mm respectively. The density, diameter and height of the small main charge were 1.28 g/cm^3 , 17.00 and 19.20 mm respectively. The small main charge and the large main charge are shown in Figures 8 and 9 respectively.

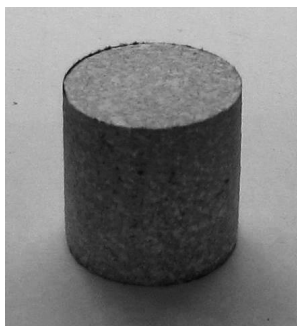


Figure 8. Small main charge.

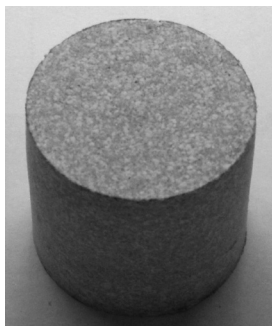


Figure 9. Large main charge.

(6) Selection of steel witness plate.

The steel witness plate was a general carbon steel (1045) with a size of $\Phi 120 \times 50$ mm.

Results and Discussion

Comparison of the initiation capacities of booster pellet 1, booster pellet 2 and the cylindrical booster pellet

The initiation capacities of booster pellets 1 and 2 under the multi-point-synchronous explosive circuits were measured using the main charge varied-composition method. The results were compared with the initiation capacity of the cylindrical booster pellet, also under multi-point-synchronous explosive circuits. The results are shown in Table 1. The experimental devices are similar to those mentioned above, but without small main charges.

Table 1. Results of initiation capacities of booster pellets by the varied-composition method

Main charge			Booster pellet		Initiation rate
NQ/PTFE/ Graphite	Mass (g)	Density (g/cm ³)	Shape	Mass (g)	
42/57/1	65.6	1.28	cylindrical	22.8	0/5
			pellet 1	14.2	0/5
			pellet 2	14.2	0/5
46/53/1	65.6	1.28	cylindrical	22.8	0/5
			pellet 1	14.2	5/5
			pellet 2	14.2	5/5
51/48/1	65.6	1.28	cylindrical	22.8	5/5
			pellet 1	14.2	5/5
			pellet 2	14.2	5/5

Table 1 shows that the initiation rate decreases with the increase of PTFE content. When the compositions of the main charge are NQ/PTFE/G = 46/53/1, the initiation rate of the 22.8 g cylindrical booster pellet is 0/5. However, the initiation rate of the 14.2 g booster pellet 1 is 5/5, and the initiation rate of the 14.2 g booster pellet 2 is also 5/5. Therefore, the initiation capacities of the booster pellets 1 and 2 are more powerful than the initiation capacity of a cylindrical booster pellet of the same densities.

According to the shaped charge effect theory [11], the output of the booster pellet is significantly affected by energy convergence. When the booster pellets 1 or 2 were initiated, the detonation products of the booster pellet converged to the central axis. The high-energy air flow, with high velocity and high pressure, converges near the bottom of the central axis. Therefore, the initiation capacity of the booster pellet is enhanced.

The energy density E was adopted to compare the degree of energy convergence among the booster pellets 1 and 2 and the cylindrical booster pellet. The energy density E is determined as follows [12]:

$$E = \rho \left[\frac{P}{(n-1)\rho} + \frac{1}{2}u^2 \right] = \frac{P}{n-1} + \frac{1}{2}\rho u^2 \quad (1)$$

where ρ , P and u are the density, pressure and particle velocity of the detonation wave front respectively, and n is the polytropic index. In Formula (1), the first item on the right is the potential energy term, and the second item is the kinetic energy

term. The kinetic energy can converge, but the potential energy has a dispersion function in the process of energy convergence. The degree of energy convergence of the booster pellets 1 and 2 is large, and so is their initiation capacity.

Further study on the initiation capacities of booster pellets 1 and 2

The initiation capacities of booster pellets 1 and 2 under multi-point-synchronous explosive circuits were studied using the main charge axial-steel-dent method. The composition of the main charge was NQ/PTFE/G=51/48/1. The results are shown in Table 2.

Table 2. Results of the initiation capacities of booster pellets by the main charge axial-steel-dent method

Shape	Mass (g)	Density (g/cm ³)	Average value of steel dent data (mm)	No.	Reducing amount compared with a cylindrical booster pellet (%)
Cylindrical	20.5	1.66	3.20	5	
Cylindrical	22.2	1.66	3.30	5	
Cylindrical	26.7	1.66	3.48	5	
Cylindrical	28.5	1.66	3.54	5	
Booster pellet 1 under four-point	14.2	1.66	3.21	5	30.7
Booster pellet 1 under eight-point	14.2	1.66	3.30	5	36.0
Booster pellet 2 under four-point	14.2	1.66	3.49	5	46.8
Booster pellet 2 under eight-point	14.2	1.66	3.55	5	50.2

The steel dent data under a four-point-synchronous explosive circuit are smaller than those under an eight-point-synchronous explosive circuit, which means that the output energies of the booster pellets 1 and 2 under an eight-point-synchronous explosive circuit are more powerful than those under a four-point-synchronous explosive circuit. There are two reasons for this. One is that the axial wave outputs of booster pellets 1 and 2 under an eight-point-synchronous explosive circuit are much smoother than those under a four-point-synchronous explosive circuit. The booster pellets 1 and 2 under four-point-synchronous explosive circuit were not exploded completely. A second reason is that the radial convergence pressures of booster pellets 1 and 2 under an eight-point-synchronous explosive circuit are larger, resulting in larger output energies to

the main charge.

Meanwhile, the experimental results also show that the initiation capacities of the booster pellets 1 and 2 under multi-point-synchronous explosive circuits are more powerful than the initiation capacity of a cylindrical booster pellet.

The small main charge was initiated by booster pellets 1 or 2 and then initiated the large main charge. When the booster pellets 1 or 2 were initiated instantaneously, the part near the primary explosive was initiated first, then, the edge part was initiated. So, when the small main charge was initiated instantaneously, the upper part of the small main charge was initiated first. However, the detonation velocity in the booster pellet was faster than that in the small main charge, so, the detonation wave from the upper surface of the small main charge reached the center of the small main charge later than that from the side. That is to say, that when the detonation wave from the upper surface reached the center, the central charge might have already been initiated by the detonation wave from the side. As a result, at the center of the small main charge, convergence resulting from the side detonation wave had happened. The mass of the booster pellet required to initiate the main charge was greatly reduced by the effect of detonation wave convergence.

The initiation process for the main charge contains two effects. One is the detonation wave effect produced by the booster pellet in the axial direction. The second effect is the effect of detonation wave convergence from the booster pellet in the radial direction. The effect of detonation wave convergence is dominant.

The initiation capacity of the booster pellet 2 is more powerful than that of the booster pellet 1, due to the contact area to the large main charge being different. The initiation capacity N is determined as follows [13]:

$$N = \frac{\alpha}{Z} \int_0^{t_c} p^2(t) dt \quad (2)$$

where, α is the area effect coefficient, Z is the shock impedance of the acceptor explosive, t_c is the time in which the shock pulse decays to p_c (p_c is the critical initiation pressure), $p(t)$ is the shock pressure between the initiation explosive and the acceptor explosive, and t is the action time. The initiation capacity N increases with an increase in the area effect coefficient α . The contact area to the large main charge of the booster pellet 2 is larger than that of the booster pellet 1, and so is its initiation capacity.

Factors influencing the experimental results

There are three main factors affecting the experiment results.

(1) Effect of booster pellet shape. The booster pellets 1 and 2 were designed using shock initiation theory and effective charge theory, as well as shaped charge effect theory. In these structures, the shock wave converges towards the central axis, so the shock wave pressure is enhanced and the initiation capacity of the booster pellet is increased.

(2) Effect of initiation method. The synchronization and uniformity of the initiation booster pellets 1 or 2 are enhanced ensuring synchronous detonation under multi-point-synchronous explosive circuits. So, the initiation capacity of the booster pellet is increased.

(3) Effect of initiation point numbers and synchronous initiation time deviation. The results of synchronization deviation under four-point and eight-point-synchronous explosive circuits are shown in Table 3. The initiation point numbers affect the output wave shape in two different ways, a positive effect and a negative effect. The positive effect is that the more initiation points there are, the better the shock wave converges, the better the shock wave outputs, and the greater the initiation capacity becomes. The negative effect is that the synchronization of a “one in eight out” synchronous explosive circuit is worse than that of a “one in four out” synchronous explosive circuit. Because, the more detonation points there are, the further the shock wave path is from the input end to the output end, more corners are present, the accumulated error is larger, and the synchronization deviation is larger. So, the initiation effect is perturbed.

Table 3. Results of synchronous initiation time deviation

Type of explosive circuit	Explosive charge	Explosive density (g/cm ³)	No.	Synchronization deviation (ns)
One in four out	HMX	1.36	3	32
One in eight out	HMX	1.36	3	46

Conclusions

The initiation capacities of two booster pellets were studied by the main charge varied-composition method and the main charge axial-steel-dent method. Several conclusions have been drawn as follows:

- The initiation capacities of the two booster pellets are much better than the initiation capacity of a cylindrical booster pellet with the same mass and the same density.
- The initiation capacity of the booster pellets 1 or 2 under an eight-point-synchronous explosive circuit is better than that under a four-point-

synchronous explosive circuit.

- The initiation capacity of the booster pellet 2 is more powerful than that of the booster pellet 1 under multi-point-synchronous explosive circuits.

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