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Numerical simulation of detonator impact initiation of hollow cylindrical charges

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Abstract: In order to determine whether the hollow cylindrical charge can be fully detonated when the detonator is eccentrically detonated, the HyperMesh-LS-DYNA joint simulation method was used to numerically simulate the hollow cylindrical charge through the ignition growth equation. The simulation results show that when the detonator is eccentrically detonated, except for the surface layer of the hollow cylindrical charge, all other parts are fully detonated. The research results indicate that detonators can fully detonate cylindrical charges under eccentric detonation conditions.

Keywords: Numerical simulation; Detonator impact initiation; Hollow cylindrical charges.

1. Introduction

Fuze is a control system that uses target, environmental, or command information to release insurance under predetermined conditions and detonate or ignite ammunition warhead charges at favorable times or positions. The main components of a fuze are the ignition control system, detonation sequence, safety system, and energy. As one of the core components of a fuze, the detonation sequence is used to transform the information output by the information sensing device or detonation command receiving device into the ignition of the pyrotechnic component, and gradually amplify the ignition energy, ultimately leading to a reliable detonation warhead. The composition of the detonation sequence is generally detonator detonating explosive booster warhead charge or detonator booster warhead charge. The reliable transmission of explosive trains plays an important role in the reliable initiation of warhead charges. Therefore, many scholars have conducted extensive research on explosive trains. The reliability of detonation sequence transmission has a significant impact on the reliable initiation of warheads. Li RC et al. proposed the Langley method to study the reliability of internal detonation sequence isolation in electromechanical fuzes. The research results show that this method can be used to guide the design of detonation isolation mechanisms and sequences in electromechanical fuzes . With the development of miniaturization technology for warheads, requirements have been put forward for the miniaturization design of fuzes. In order to meet the requirements of miniaturization development of fuzes, micro initiation sequences based on microelectromechanical systems are applied to micro miniature fuzes. In order to improve the safety of the fuze, the detonation sequence adopts an explosion-proof design, with a safety and isolation mechanism cavity between the micro initiator and the detonating explosive. Due to the small charge of the micro initiator, the detonation energy may not be able to reliably detonate the detonation column after attenuation through the cavity. To solve this problem, Xie RZ et al. used the cavity of the safety and isolation mechanism as the acceleration chamber, and used a micro detonator to accelerate and drive the flying plate to achieve the amplification of detonation energy, achieving the reliable detonation transmission function of the detonation sequence . Liu RQ et al. proposed a parameter for evaluating the effectiveness of flyers using both the velocity and kinetic energy of the flyers. The influence of factors such as charge structure, acceleration chamber diameter, and flyer thickness on the effectiveness of the flyers was studied through numerical simulation. During the detonation process, the completeness of the detonation sequence is the primary function of the detonation sequence, and there has always been a lack of quantitative indicators. Liu HB proposed a method for determining the completeness of the detonation sequence based on the initiation time to address the problem of insufficient quantitative characterization of the explosion completeness test criteria. The research results show that this method can quantitatively determine the completeness of the detonation sequence, providing a method for the quantitative characterization of explosion completeness. Due to the fact that the explosive components in the detonation sequence are arranged in a decreasing sensitivity and increasing intensity order, primary explosive components have the characteristic of low sensitivity. Therefore, there is a phenomenon of martyrdom explosion during the service processing. Xiao XD et al. conducted numerical simulation research on martyrdom explosion under shock wave action to address this phenomenon, providing certain reference value for the safety design of explosive trains.

In the study of references [4-8], each explosive element in the detonation sequence is designed to be concentric, which makes it easier to achieve reliable detonation of the detonation sequence. To address the issue of whether detonators can reliably detonate hollow cylindrical detonation propellants, this paper uses numerical simulation methods to study this issue. The numerical simulation uses the HyperMesh meshing tool to mesh the designed structure and perform relevant preprocessing settings, and submits it to the LS-DYNA solver for calculation.

2. Establish 3D model

Establish a 3D model of detonator detonator and hollow cylindrical booster in the 3D drawing software Inventor, as shown in Figure 1.

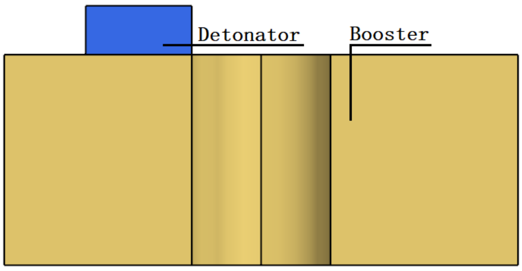


Figure 1. 3D model of detonator initiating explosive and cylindrical booster explosive

The model shown in Figure 1 includes detonator initiating explosive and hollow cylindrical booster explosive.

3. Numerical simulation

According to the structural design of hollow cylindrical booster detonator detonated by detonator charge impact, its structure is plane symmetry. In order to reduce the amount of calculation, the established finite element model is a half model; The fluid structure coupling algorithm is used in the simulation of detonator charge impact initiation of hollow cylindrical explosive, which means that the detonation wave after detonator charge initiation propagates in the air and impacts the hollow cylindrical explosive. Therefore, an air domain is added to the three-dimensional model shown in Figure 1, and the numerical simulation model is shown in Figure 2.

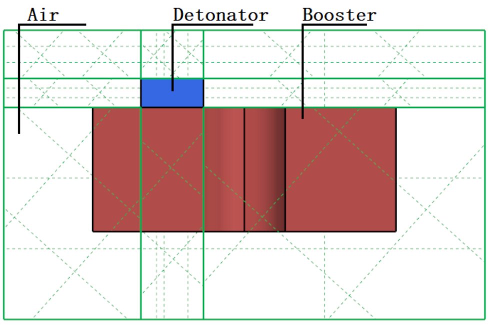


Figure 2. Simulation Model

3.1. Establishing a finite element model

Import the 3D model shown in Figure 2 into HyperMesh for mesh generation, and the resulting finite element mesh is shown in Figure 3.

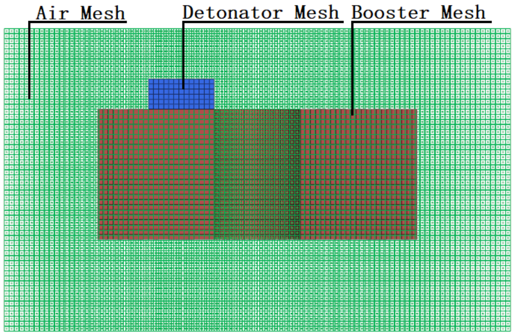


Figure 3. Finite element model for shock initiation

In Figure 3, a common node contact is used between the detonator grid and the air domain grid, and the hollow cylindrical booster grid is included in the air domain grid; The detonator grid and air domain grid use Euler elements and the multi material ALE algorithm; The hollow cylindrical explosive mesh adopts Lagrangian elements; The finite element model shown in Figure 3 contains a total of 330440 elements.

3.2. Material constitutive model and parameters

The material of the detonator charge is JH-14, and the material of the hollow cylindrical booster charge is PBX. The material constitutive model of the detonator charge is described using HIGH-EXPLOSIVE-BURN, and the corresponding state equation is described using JWL [9,10]. The expression of the explosive detonation product pressure P1 is shown in equation (1), and the material parameters are shown in Table 1.

$$P1 = a\left(1-\frac{\omega}{R_1 V}\right)e^{-R_1 V} + b\left(1-\frac{\omega}{R_2 V}\right)e^{-R_2 V} + \frac{\omega E1}{V} \quad (1)$$

In equation (1),a,b, R_1 , R_2 , ω *are constant*, $E1$ is the internal energy per unit volume， V is the relative volume.

Table 1. Material parameters of JH-14 explosive

Materials	**a GPa**	**b GPa**	**c GPa**	R_1	R_2	ω	**ρ (g.cm^{-1})**	**P_{CJ} GPa**	**D m/s**
Comp B	618.4	6.9	1.082	4.2	1.4	0.38	1.67	27.2	8186

The constitutive model of air materials is described using NULL, and the corresponding state equation is described using IDEAL_GAS. The parameters of air materials are shown in Table 2 .

Table 2 Air Material Parameters

Materials	ρ(kg/m3)	γ	Cp(kJ/kg*K)	Cv(kJ/kg*K)	$T(K)$	E0(Kj/kg)
air	1.225	1.4	1.005	0.718	288.2	2.068E5

Table 3. The ignition and growth parameters of the explosive

material	ρ_0(g/cm^3)	I(us^{-1})	b	a	x	G1
PBX	1.842	7.43E11	0.667	0	20	3.1
c	d	y	G2	e	g	z
0.667	0.111	1.0	400	0.33	1.0	2.

The constitutive model of the booster explosive is described using ELASTIC-PLASTIC-HYDRO, and the state equation is described using the Lee Tarver ignition growth equation IGNITION-AND_GROWTH-OF-REACTION-IN_HE (i.e., the trinomial term, ignition term, growth term, and completion term). This model is suitable for the shock initiation process of explosives [12,13] and can be used to simulate the shock initiation (or non initiation) and propagation of detonation waves of solid high-energy explosives. Its expression is shown in equation (2).

$$\frac{\partial F}{\partial t} = I(1-F)^b\left(\frac{\rho}{\rho_0}-1-a\right)^x + G_1(1-F)^c F^d p^y + G_2(1-F)^e F^f p^z \qquad (2)$$

Where F is the reaction fraction, which controls the release of chemical energy of the explosive during the simulated detonation process; T is time; ρ 0 is the initial density; ρ is the current density; P is the pressure; I, G_1, G_2, b, x, a, c, d, y, e, g, and z are constants.

The constitutive parameters of hollow cylindrical explosive materials are shown in Table 3

3.3. Boundary conditions

Set the symmetry plane of the finite element model as a symmetric constraint, and set the other five surfaces in the air domain, except for the symmetry plane, as non reflective boundaries; The detonation point is set by the keyword * INITIAL_DETONATION; The simulation time is 10us, and the time step is set to 1us.

3.4. Analysis of simulation results

Transform the preprocessed finite model into Submit the format of the K file to LS-DYNA to display the dynamic calculation program for solving calculations. Obtain the stress cloud map of the booster explosive as shown in Figure 4

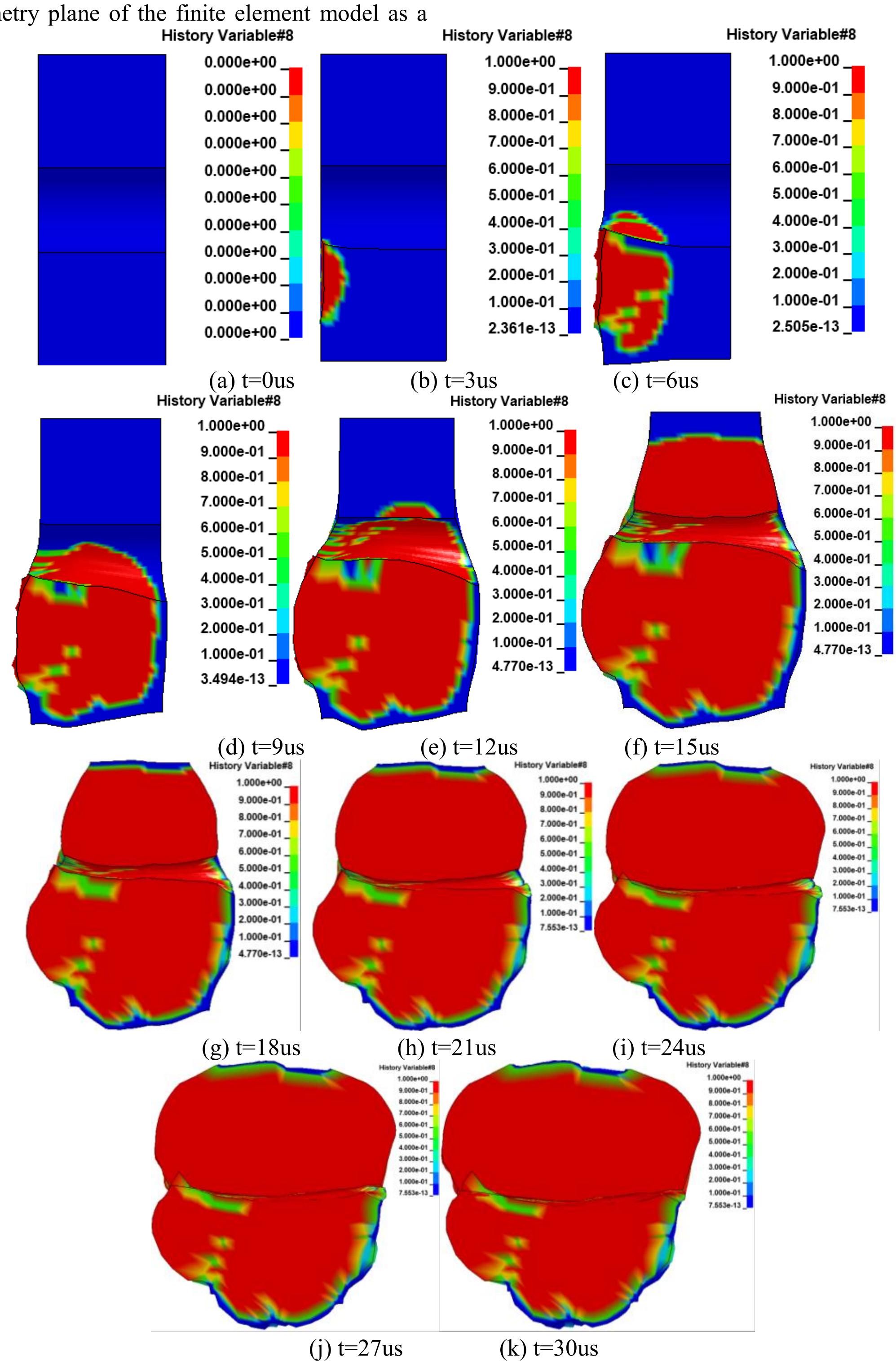


Figure 4. Stress cloud map of booster explosive

According to the stress cloud diagram of the hollow cylindrical booster shown in Figure 4, it can be seen that the symmetry plane of the charge is completely detonated.

In order to examine the internal detonation situation of hollow cylindrical booster, five profiles were established to examine the internal detonation situation of hollow cylindrical booster. The schematic diagram of the five profiles is shown in Figure 5.

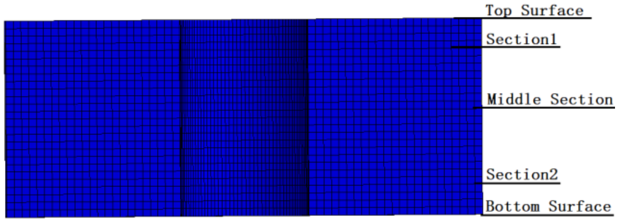
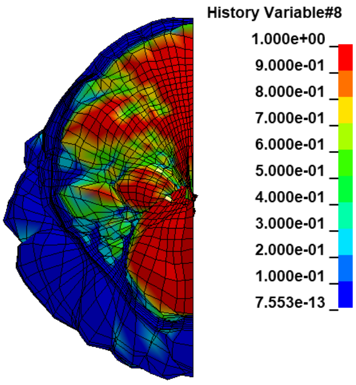
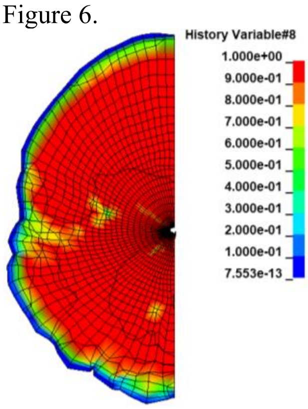


Figure 5. Section diagram

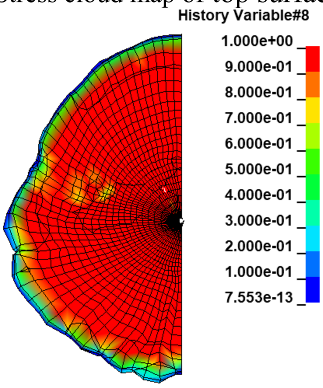
The pressure cloud map at the cross-section is shown in Figure 6.



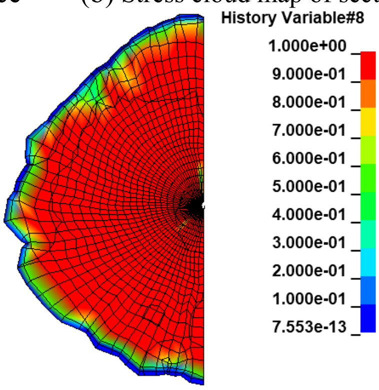
(a) Stress cloud map of top surface



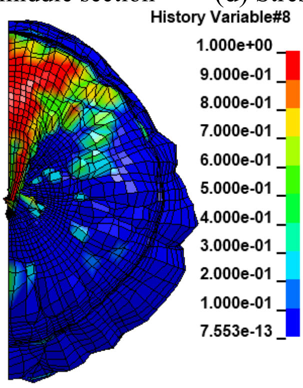
(b) Stress cloud map of section1



(c) Stress cloud map of middle section



(d) Stress cloud map of section2



(e) Stress cloud map of bottom surface

Figure 6. Pressure cloud map of each section

From Figures 5 and 6, it can be seen that except for the explosive on the surface of the booster, which has not been fully detonated, all other parts have been fully detonated (the red part indicates a reactivity of 1, and a reactivity of 1 indicates that the explosive has been fully detonated).

Select some units at the middle section to check their reactivity, and the selected unit numbers are shown in Figure 7.

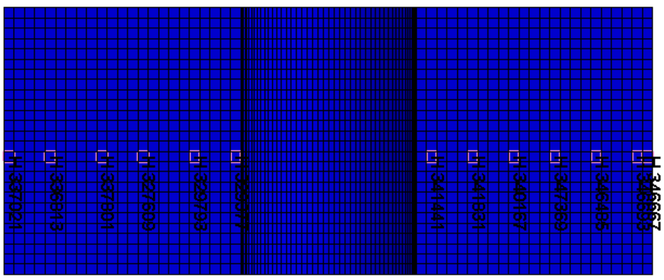


Figure 7. Selected Unit

The unit numbers from left to right are 337021, 336813, 337801, 327609, 329793, 329377, 341441, 341831, 340167, 347369, 346485, 346693, 346667.

The selected unit reactivity in Figure 7 is shown in Figure 8.

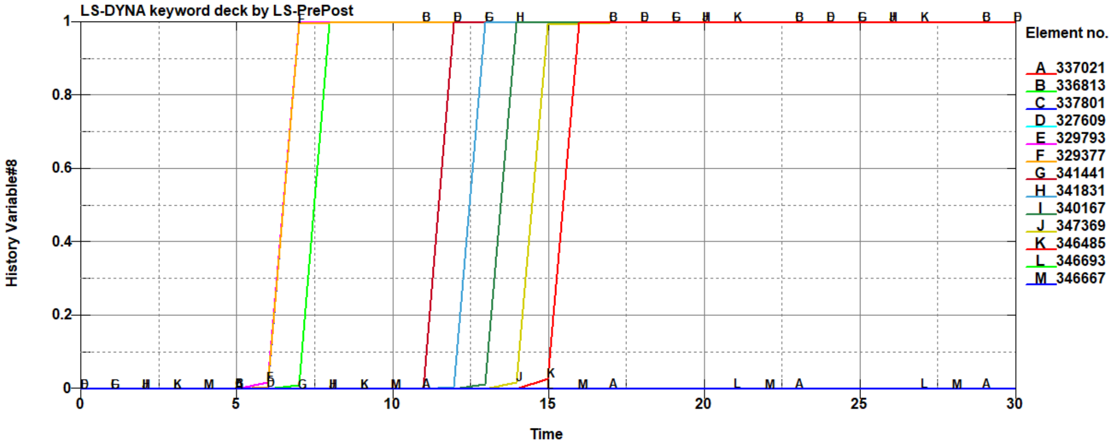


Figure 8. Reactivity curve

It can be seen from Figure 8 that the reactivity of all units except A (337021), M (346667), and L (346693) is 1. That is to say, except for the units at the edge of the booster that have not been fully ignited, their interiors have been completely ignited.

4. Conclusion

According to the stress cloud maps of the hollow cylinder shown in Figures 4, 6, and 8, as well as the stress cloud maps and reactivity curves at each section, it can be concluded that when the detonator eccentrically impacts the hollow cylindrical booster, it can completely detonate the hollow cylindrical booster.

References

[1] Li XF, Wang YB, Wu B. Fuze of Penetration Ammunition. National Defense Industry Press, 2015.

[2] Ma BH. Structure and Principle of Fuze，National Defense Industry Press,1983.

[3] He GL, Fan NJ. Analysis and Design of the Fuze Safe and Arming. National Defense Industry Press, 2016.

[4] Li RC, Xu PZ, Wang S, Liang T, Huang HD. Progressive Arming Test Method for Electromechanical Fuze Based on Langlie Method. Journal of Detection & Control, 2023, 45(1):105-112.

[5] Xie RZ, Chu EY, Dai XH. Design and Detonation Transfer /explosion Interruption Performance of Micro Initiation Train. ACTA ARMAMENTARII,2021,42(6):1178-1184.

[6] Liu RQ, Nie JX, Jiao QJ. Simulation Analysis of Influencing Factors of Flyer Driven by Small-size JO-9C Booster Explosive. ACTA ARMAMENTARII,2020,41(2):246-253.

[7] Liu HB. Explosion Completeness Judgment Based on High Explosive Train Initiation Time. Journal of Detection & Control,2022,44(5):58-63.

[8] Xiao XD, Xiao YC, Jiang HY. Numerical Simulation and Analysis of Fuze Explosive Trains under Shock Waves. CHINESE JOURNAL OF HIGH PRESSURE PHYSICS,2021, 35(5): 054202: 1-9.

[9] Chen JJ. Research on the Technology of a Single Soldier's Terminal Trajectory Correction Rocket Armor Breaking and its Fuze. Nanjing University of Science& Technology,2015

[10] Yang K. A Study on Determining the Detonation Parameters of Explosives through Underwater Explosion Experiments: Proceedings of the 12th National Academic Exchange Conference on Warheads and Destruction Technology, Guangzhou, 2011:1032-1035.

[11] Ding LL, Tang WH, Ran XW. Simulation Study on jet formability and damage characteristics of a low-density material liner. Materials, 2018, 11, 72.

[12] Yu QB, Zhong SW, Xiao YW. Numerical Simulation of Influence of Hit Position on Detonating Heavy Explosive Reaction Armor. Transactions of Beijing Institute of Technology, 2021, 41(2):151-157.

[13] Yu QB, Zhong SW, Wang J. Research on the Effect of Jet Action Conditions on Interference Duration of Heavy Reactive Armor. Transactions of Beijing Institute of Technology, 2022, 42(4):383-389.