Research on Overload Signal of New Impact Body Based on Air Cannon Test and Simulation

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Abstract. Air cannon simulation test method is a common method to generate high overload signal. In this paper, a new impact body model for air gun test is proposed. Based on the model, the impact dynamic theory is analysed, and the variation law of high overload signal in accelerometer due to multiple reflection and transmission of stress wave in the impact process is studied. The finite element model is established by using ANSYS / LS-DYNA software to simulate and analyse the impact process, and a test platform is built to verify the simulation. The test results and simulation results show that the impact body can generate a "W" shape high overload signal during the impact process, which also verifies the rationality of the theoretical analysis. The methods and conclusions of this paper have certain significance for the study of the new type of impact body and the high overload signal produced by the impact test.

1. Introduction

The hard target penetration fuze is the explosive point control system of penetration ammunition. This kind of fuze usually uses an accelerometer to sense and calculate the penetration target, and control the warhead to explode at the best explosive point position [1]. The anti-high overload performance of the hard target penetration fuze is an important indicator in each cycle of fuze design, testing, acceptance, and service [2]. Verifying the anti-overload performance of fuze by live ammunition test will greatly waste time and financial resources. Therefore, researchers have studied several high overload simulation test methods in practice. At present, the commonly used simulation test methods mainly include the Marshall hammer test method, Hopkinson rod test method [3], drop weight impact test method and air gun simulation test method [4]. The simulation test method of air gun is a method to obtain the equivalent high overload impact signal by using compressed air to push the test projectile to accelerate in the gun barrel and then hit the chopping block at high speed [5].

In the previous literature [6], the impact test of the impact body produced a high overload signal in the shape of a half sine wave. Researchers design different impact bodies according to different needs. Based on a new type of impact body structure, this paper establishes an equivalent model of the impact body. Through theoretical analysis, it is believed that the impact signal of the impact body will show up and down first, then low and then high during the impact process. The impact process of the new impact body model is simulated in ANSYS / LS-DYNA software. At the same time, a test platform is built to verify the simulation model and theoretical analysis.
2. Impact body model
The new impact body model is shown in Figure 1. Figure 2 shows the various parts of the impact body model, including the test projectile, the anvil and the gasket placed on the anvil. The test projectile includes a bullet head, a bullet body, a gland, a fixture and an accelerometer. Among them, fixture and accelerometer are equivalent to the fuze and accelerometer in practical applications respectively. The bullet head and the gland are threadedly connected with the bullet body, the accelerometer and the fixture are threadedly connected. The materials of each part of the new impact body are shown in Table 1.

The diameter of the test projectile is 130mm and the height is 200mm. The gasket is cubic, with a bottom side length of 100mm and a thickness of 2mm. The anvil is a cylinder with a bottom radius of 100mm and a height of 100mm.

| Part         | Material          |
|--------------|-------------------|
| Bullet head  | T10A steel        |
| Bullet body  | 7A04-T6 aluminum alloy |
| Gland        | 45 # steel        |
| Accelerometer| 45 # steel        |
| Fixture      | 7A04-T6 aluminum alloy |
| Gasket       | 45 # steel        |
| Anvil        | T10A steel        |

3. Analysis of Stress Wave Propagation in the Process of Impact
The propagation of stress wave is a complicated process, which will produce reflection and transmission at different interfaces [7]. The elastic wave propagation form of the material under uniaxial strain is [8].

\[
C_0 = \left( \frac{E}{\rho_0} \right)^{1/2}
\]  

In equation (1), \(C_0\) is the wave velocity, \(E\) is the Young modulus, \(\rho_0\) is the material density, \(\rho_0C_0\) is the material wave impedance, which is one of the basic parameters that characterize the mechanical properties of the material under dynamic load. The wave impedance of aluminum alloy is about 13.7 MPa·m\(^{-1}\)·s\(^{-1}\), the wave impedance of steel is about 40.5 MPa·m\(^{-1}\)·s\(^{-1}\).

In the process of stress wave propagation, when it enters another medium which in contact with it from one medium, reflection and transmission will occur simultaneously on the interface of different
media. The reflectivity and transmittance of elastic stress wave are determined by the wave impedance of different media. For the propagation of elastic stress waves in complex multi-layer materials medium, the attenuation research can refer to equation (2) [9]:

\[ \varepsilon_{i+1} = \frac{2\varepsilon_i}{1 + \beta_i / \beta^+_{i+1}} \]  

(2)

In equation (2), \( i \) is the number of layer, the outermost layer is 1, increasing by 1 from the outside to the inside. \( \beta_i \) is the wave impedance of the incident layer material, \( \beta^+_{i+1} \) is the wave impedance of the transmission layer material; \( \varepsilon_{i+1} \) is intensity of the stress wave in material of the transmission layer, and \( \varepsilon_i \) is intensity of the stress wave in material of the incident layer.

According to the basic theory of stress waves, when the wave impedance of the transmission layer medium is much smaller than that of the incident layer medium, the intensity of the stress wave in transmission layer medium will be much lower than the intensity of the stress wave in incident layer medium. When impact stress wave propagates from impact location to the accelerometer inside the fixture, the reflection and transmission of the stress wave will inevitably occur.

Since the structure of the accelerometer is smaller than that of the fixture, it is considered that most of the impact stress waves are transmitted into the accelerometer through the fixture, and the first high amplitude signal is generated. Then the stress wave reaches the interface between the fixture and the gland and reflects and transmits. The reflected stress wave enters the fixture again. The wave impedance of aluminum alloy material is very different from that of steel material. The gland material is steel and the fixture material is aluminum alloy. Therefore, the transmission coefficient of the interface between the gland and the fixture is small, which causes most of the shock stress waves to reflect as tensile waves. Part of the transmitted stress wave is transmitted through the air at the free end of the gland, and part of it is continuously reflected and attenuated at the gland. The tensile wave reflected at the interface between the fixture and the gland continues to propagate in the test projectile, which is opposite to the direction of the stress wave at the bullet head. After the two waves meet, the amplitude of the stress wave in the fixture and accelerometer is reduced, resulting in the reduction of overload signal. Then the tensile wave attenuates, and the stress wave on the head of the test projectile produces the second peak of the overload signal. finally, the impact process ends, and the overload signal tends to zero.

4. Impact simulation
Aiming at this new type of impact body model, ANSYS/LS-DYNA software was used to simulate the impact process. ANSYS/LS-DYNA is a very famous general explicit dynamics analysis program in the world [11], which can simulate various complex problems in the real world well, and is especially suitable for solving various high-speed, two-dimensional and three-dimensional nonlinear structures. Non-linear dynamic impact problems such as collisions and explosions. LS-DYNA software is equipped with various material dynamic constitutive models and effective contact nonlinear capabilities.

4.1. Material constitutive model
Investigate several materials in Table 1. In this paper, these materials all adopt the Johnson-Cook dynamic constitutive model. Johnson-Cook dynamic constitutive model is generally used to describe the strength limit and failure process of metal materials under large strain, high strain rate, and high temperature environment. The dynamic parameters of T10A steel, 7A04-T6 aluminum alloy, and 45 steel in the Johnson-Cook dynamic constitutive model are obtained through investigation [10], as shown in Table 2.
Table 2(a). Material Johnson-Cook constitutive model parameters.

| Material                  | RO (g cm\(^{-3}\)) | E (GPa) | PR  | A (MPa) | B (MPa) | T\(_M\) | T\(_R\) |
|---------------------------|---------------------|---------|-----|---------|---------|---------|---------|
| T10A steel                | 7.85                | 200     | 0.3 | 1606    | 510     | 1793    | 300     |
| 7A04-T6 aluminum alloy    | 2.85                | 69.4    | 0.3 | 568     | 327     | 775     | 294     |
| 45# steel                 | 7.80                | 200     | 0.3 | 506     | 320     | 1790    | 294     |

Table 2(b). Material Johnson-Cook constitutive model parameters.

| Material                  | n       | EPSO   | D\(_1\) | D\(_2\) | D\(_3\) | D\(_4\) | D\(_5\) |
|---------------------------|---------|--------|---------|---------|---------|---------|---------|
| T10A steel                | 0.26    | 0.5E-5 | 0.05    | 3.44    | -2.12   | 0.002   | 0.61    |
| 7A04-T6 aluminum alloy    | 0.378   | 1.15E-3| 0.04    | 0.36    | -1.98   | 0       | 0       |
| 45# steel                 | 0.28    | 0.5E-5 | 0.1     | 0.76    | 1.57    | 0.0005  | -0.84   |

4.2. Finite element analysis

According to the structure of the model and the symmetry of the load, a quarter model is established in order to save calculation time. All entities in the model were used Solid164 solid element, which is a common LS-DYNA element that supports most material algorithms. Solid164 solid element has 8 nodes and each node has 9 degrees of freedom. In ANSYS, select the element type, material type, and mesh type for the impact body model specify the mesh size, and then mesh the model. The meshes are all hexahedral meshes. When solving in the solver, the hexahedral mesh is conducive to the convergence of the simulation calculation [11]. Among them, the bullet head, the gland and the body are meshed by common node method to simulate the thread connection, and the accelerometer and the fixture are meshed by common node method to simulate the thread connection [12]. The model after meshing is shown in Figure 3.

All the nodes on the gasket are selected to create a "DIANPIAN" node assemble in preparation for adding contacts. This paper mainly adopts two types of contact: point-to-surface erosion contact and surface-to-surface contact. The point-surface erosion contact can well simulate the deformation of the object after impact, and this contact is very effective in reducing the hourglass deformation of meshes. Surface-to-surface contact is mostly used when two objects penetrate each other. The algorithm is completely symmetric. There is no requirement when selecting the contact surface and the target surface, and the momentum conservation is accurate.

The contact between the gasket and the bullet head is set as point-surface erosion contact, the contact between the gasket and the anvil is set as point-surface erosion contact, the contact between the accelerometer and the fixture is set as surface-surface erosion contact, and the rest are set as automatic surface-to-surface contact.

We add a downward velocity to the test projectile as a whole, and the speed is set as 21m/s. Fixed constraints is added to the bottom surface of the cutting board, and symmetry constraints on the XY plane and XZ plane is added to the overall simulation model. A pressure load is added to the rear surface of the test projectile to simulate the effect of high-pressure gas. Set the simulation analysis
time of 250us, and set the output time interval of binary result file and time history file to 1us. Finally, the software outputs the K file to be solved. Open the K file, we modify the node constraints on the symmetry plane to restrict the rotation of the nodes on the symmetry plane. After the modification is completed, solve the K file in the LS-DYNA software solver.

5. Test
In this paper, the air gun device is used for the test. The test impact body is the same as the simulation model. In addition, the high-speed photography equipment is used to record the impact process. Figure 4 shows the air gun device of Nanjing University of Science and Technology. The barrel is placed vertically, and the anvil is located below the barrel. After the test projectile is released by the upper control valve, the rear part is subjected to the action of high-pressure gas. The test projectile accelerates in the barrel and hits the gasket above the anvil, thereby generating a high overload signal in the accelerometer. Based on the air gun device, the Phantom series high-speed camera of American VRI company is used to record the impact process, as shown in Figure 5. The Phantom series high-speed camera combined with high-pixel lens to record the impact process. The sampling rate of the high-speed camera is set to 3000, that is, 3000 frames per second, which fully meets the recording needs.

According to the simulation model, the accelerometer and fixture are fixed in the test projectile. The accelerometer adopts the high-overload accelerometer customized and calibrated by the 214th Research Institute of China Weapon Industry. The accelerometer only needs three leads, its working voltage is 3.3V, and its range is 38400g. The test line is led out at the back of the test projectile and connected to the oscilloscope. In this way, we can record high-overload signals generated by synchronization. The test projectile and test line are shown in Figure 6. The test first determines the distance between the muzzle and the gasket, which is 0.07m, as shown in Figure 7. According to the distance and the impact process recorded by the high-speed camera, we can estimate the speed of the test projectile.
6. Analysis of test and simulation results

In the LS-DYNA software, run the LS-PROPOST program and open the solved d3plot file. Select the accelerometer part and draw the acceleration signal of the part, as shown in Figure 8. The overload signal is a "W" shape from high to bottom and then high.

The original signal recorded by the accelerometer in the experiment is shown in Figure 9. The signal sampling frequency is 500MS/s, and the sampling time is 2ms. The effective pulse width is between -160us and 30us. Within the effective pulse width range, the overload signal is a "W" shape with high first, then bottom and then high. In addition, according to the data recorded by the high-speed camera, we calculated that the speed of the test projectile impacting the gasket is about 21m/s, which is the moving speed of the test projectile we set in the simulation.
We select the test result data of the effective pulse width part and import it into the origin software, set the abscissa to time, and the ordinate to overload, and finally draw Figure 10.

![Figure 10. Experimental overload signal after data processing.](image)

According to Figure 8, the simulated overload signal peak value is 28885g and the pulse width is 195us. According to Figure 10, the test overload signal peak value is 29593g and the pulse width is 160us. According to the simulation and test results, it can be seen that under the same impact velocity, the amplitude of the overload curve of the new impact body simulation and test results is roughly the same, both showing a "W" shape, which verifies the reliability of the simulation model and the rationality of theoretical analysis. The shape similarity between the simulation curve and the measured curve is relatively high, and the peak value and pulse width are slightly different, which may be caused by the slight difference between the gasket material parameters in the simulation and the actual one.

7. Conclusion
This paper proposes a new type of impact body model for air cannon device. The impact process of this model is analysed by dynamic impact theory, and the change law of the high overload signal generated by the impact body in this process is obtained through the analysis.

This paper uses ANSYS/LS-DYNA software to establish a finite element model to simulate the impact process, and build a test platform to verify the simulation. The results show that the new impact body can generate a "W" shape high overload signal during the impact process. The test results and simulation results verify the reliability of the simulation model and the rationality of the theoretical analysis.

The methods and conclusions of this paper can be applied to the study of new impact bodies and the high-overload signals generated by them.

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