Simulation of explosion proof capacity of material partition in micro initiation sequence

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Abstract. In order to study the effect of materials gap on detonation capability of micro sequence. The law of the micro sequence initiating ability is simulated using the finite element analysis method in the different material partition. The results show that the capacity of detonation wave pressure attenuated by Ni partition is stronger than the steel. Then the simulation results are tested and verified, indicating that the simulation of initiation sequence can reflect the actual situation accurately.

1. Introduction

MEMS initiating explosive device is becoming the key technology for the development of the new generation of intelligent ammunition[1]. Miniaturized detonation transfer sequence based on MEMS initiating technology is an important technology to realize the safety of MEMS and initiating devices. The baffle interface in the detonation transfer sequence is a typical energy transfer interface. By changing the thickness of the baffle, the detonation transmission or partition between the upper and lower charge can be realized, the reliability and safety of the explosion sequence are improved at the same time. After the small diameter charge is detonated, the detonation wave is absorbed at the interface of the partition, then it spreads inside the partition, and it decreases as the propagation distance increases. In addition, the attenuation coefficient of the shock wave in the separator varies with the material of the separator[2]. At present, the donor explosive used by Hu Xiangyu[3] is 8701 explosive with a diameter of 50 mm. Wang Zuoshan[4] used RDX with a diameter of 5.1 mm, F.X. Jette[5] used nitromethane with a diameter of 50 mm, and they obtained the attenuation law of shock wave in the plexiglass separator respectively. But it is mainly the detonation output of large diameter charge.

The geometry of the micro-initiation sequence studied in this paper is shown in figure 1. CL-20 and JO-9C are used as the first and second stages of the detonation sequence, and the dimensions are 2*2 mm and 4*4 mm respectively. Based on Lee-Tarver ignition growth model, the influence of stainless steel and nickel separator on the detonation capability of micro-sequences are analyzed by finite element simulation method, and are verified by experiments. The research results have important reference value for further research on the structural design of the micro-initiation series.
2. Numerical simulation of initiation of micro sequence

2.1. Establishment of micro sequence initiation model

2.1.1. Finite element model. The initiation of micro sequence is simulated by the finite element method. AutoDyn software is selected for calculation[4]. The model is composed by four parts: a first-stage explosive column, the separator, a second-stage explosive column, and an identification block. The materials are CL-20, steel/nickel sequence, JO-9C and aluminum identification blocks respectively. The micro sequence structure is a rotating body, so its 1/2 model is established due to its axis symmetry, as shown in figure 2.

![Figure 1. Structure of micro sequence.](image1)

In order to simulate effectively, the model is simplified reasonably:
(1) the initial stress of all materials in the micro initiation sequence is 0. The explosive is restrained by the shell, and the rest of the boundary is free surface.
(2) The density of the explosive column is uniform. Micro detonators were not considered in the simulation. The simulation begins with the first stage of the explosive column, and its center is detonated. In order to obtain the pressure-time curve, observation points are established at the symmetry axis position of the model. It is judged whether the two columns are detonated by the pressure curve of the observation point.

2.1.2. State equation and material parameters. The JWL equation describes the explosion process of the first stage explosive cartridge in the following form [6-7]:

\[
P = A(1 - \frac{\rho}{R_1 V})^{\gamma_1} + B(1 - \frac{\rho}{R_2 V})^{\gamma_2} + \frac{\rho E}{V}
\]

Among them, P is pressure. V is relative volume. E is energy density. A, B, R_1 and R_2 are constants. The value of constants are determined by fitting the data of Hugoniot and initial sound velocity.

**Table 1.** The simulation parameters of JWL equation.

![Figure 2. The simulation model.](image2)
The Grunessen equation of state is used for the partition material and the identification block. It is expressed by the compression pressure of the compressed material and the expansion pressure of the expanded material. The compression pressure is defined as:

\[ P = \rho_0 C_s^2 \mu \left[ 1 + \frac{1}{2} \left( \frac{\gamma_0}{2} - \frac{a}{2} \right) \mu - \frac{\mu^2}{\mu + 1} - \frac{\mu^3}{(\mu + 1)^2} \right] + (\gamma_0 + a\mu)E \]  

(2A)

Among them, \( \mu = 1/V - 1 \) \( u_s = C_0 + S \rho_u \). The expansion pressure is defined as:

\[ P = \rho_0 C_s^2 \mu + (\gamma_0 + a\mu)E \]  

(2B)

In the formula, \( C \) is the intercept between the velocity of the shock wave and the particle velocity curve. \( \gamma_0 \) is the Gruneisen coefficient. \( A \) is the first order volume correction of \( \gamma_0 \). \( S_1, S_2 \) and \( S_3 \) are the slopes of the shock velocity and particle velocity curves. It is the degree of compression. \( V \) is the relative volume; \( u_s \) is the speed of shock wave; \( u_p \) is the velocity of protons (particles); \( C_0 \) is the speed of sound.

### Table 2. The simulation parameters of Gruneisen equation.

| Material type | \( \rho_0 \) (g/cm\(^3\)) | \( C \) (s/km) | \( S_1 \) | \( S_2 \) | \( S_3 \) | \( \omega \) | \( a \) |
|--------------|-----------------|----------------|--------|--------|--------|--------|--------|
| steel        | 7.83            | 4.569          | 1.490  | 0      | 0      | 2.17   | 0.46   |
| nkcl         | 8.81            | 4.19           | 1.54   | 0      | 0      | 2.14   | 0.41   |

The second stage explosive column is an explosion caused by shock wave pressure. It is a non-ideal detonation, so its reaction process cannot be ignored. The Lee-Tarver equation is used to describe its action process[8-10].

\[ \frac{dF}{dt} = I(1 - F)^x \left( \frac{\rho}{\rho_0} - 1 - a \right)^x + G_1(1 - F)^c F^d p^x + G_2(1 - F)^e F^f F^z \]  

(3)

\( F \) is the degree of reaction of the explosive. \( T \) is time and \( \rho \) is density. \( \rho_0 \) is the initial density. \( P \) is the pressure. The equation consists of 12 unknown parameters: \( I, B, a, x, G_1, C, D, y, G_2, e, G \) and \( Z \).

### Table 3. The simulation parameters of Lee-Tarver equation.

| \( \rho_0 \) (g/cm\(^3\)) | A(Mbar) | B(Mbar) | R1   | R2   | \( \omega \) | E/V (Gerg/mm\(^2\)) |
|-----------------|--------|--------|------|------|-------------|---------------------|
| 1.84            | 8.524  | 0.108  | 4.6  | 1.3  | 0.38        | 0.102               |
| I(\mu s-1)      | a      | b      | c    | d    | y           |                     |
| 7.43e+1011      | 0.667  | 0      | 3.1  | 0.667| 0.111       | 1                   |
| G2(Mbar-z\(\mu s\)-1) | e    | g      | z    | Figure\( \max \) | F\(G1\max \) | F\(G2\max \) |
| 400             | 0.333  | 1.0    | 2.0  | 0.3  | 0.5         | 0.0                 |

3. Simulation and analysis of micro-sequence flameproof

The fluid-solid coupling method is used to simulate the explosion process of the micro-explosion sequence. When the first stage explosive column is completely exploded, the pressure on the input
surface of the second-stage explosive column is as shown in figure 3, after the shock wave passes through the separator of stainless steel and nickel material of different thicknesses.

![Figure 3. P-T curve of the input surface of the second explosive column through steel and nickel separators of different thicknesses.](image)

As shown in figure 3, when both the stainless steel separator and the nickel separator have a thickness of 0.5 mm, the detonation wave passes through the steel baffle to the input of the second stage explosive column at 0.3 s, and the maximum pressure is 11.85 Gpa. The detonation wave passes through the nickel separator to the input of the second stage explosive column at 0.35 s, and the maximum pressure is 9.8 Gpa. It can be seen that the detonation wave propagates faster in the stainless steel separator than in the nickel separator. And nickel is more resistant to detonation pressure than stainless steel.

3.1. Simulation results of detonation after stainless steel partitions

The detonation process of the second-stage explosive column after the different thickness of the stainless steel separator is simulated. The effect of stainless steel on the propagation of detonation waves was studied. The observation point represents the height in the explosive column. The higher the value of the observation point, the higher the explosive column and the farther from the input end. The pressure-time curves at different observation points represent changes in pressure at different heights of the cylinder over time. The pressure-time curve indicates the detonation results of the second stage explosive column. The result is shown in figure 4.

![Figure 4. P-T curve of the second-stage explosive column when the partition material is steel.](image)

As shown in figure 4(a), when the thickness of the separator is 0.5 mm, the detonation wave propagates to the input of the second stage explosive column at 0.3 s, and the second stage explosive column is detonated. As time goes by, the pressure increases quickly. The pressure is greatest and the pressure reaches a steady value at 0.53 s. The results show that the second stage explosive column can achieve complete detonation. In figure 4(b), when the thickness of the partition is 1.0 mm, when the detonation wave propagates to the input end of the second-stage column, the peak value of the pressure at the observation point gradually increases along the direction of the propagation of the detonation wave. Then the pressure is stable. The second stage explosive column achieves detonation. As shown in figure 4(b), when the separator thickness was 1.3 mm, the second-stage explosive column
was not detonated. When the explosion propagates to the input of the second stage explosive column, the peak of the pressure at the observation point gradually increases to 7 Gpa in the direction of the detonation wave propagation. The pressure value then decreases with time. As the height of the explosive column increases, the peak value of the pressure at the observation point decreases significantly. Over time, the pressure peak is much lower than the detonation pressure.

3.2. Simulation results of detonation after nickel partitions
This part simulates the detonation process of the second stage explosive column after the detonation wave passes through the nickel separator of different thickness. The effect of nickel materials on the propagation of detonation waves is studied. The detonation of the second stage explosive column is obtained from the pressure-time curve. The result is shown in figure 5.

As shown in figure 5, when the thickness of the separator is 0.3 mm and 0.5 mm, the pressure peak at the observation point gradually increases, along the direction of the detonation wave, and then reaches stability. The second stage explosives column detonated. When the thickness of the separator is 0.8 mm, the detonation wave is applied to the input end of the second-stage explosive column at 0.43 s. Along the direction of the detonation wave, the peak of the explosive column pressure rises to 5.6 Gpa, and then the pressure value decreases with time. As the height of the explosive column increases, the peak pressure at the observation point is significantly reduced. And over time, the pressure peak is much lower than the detonation pressure. The second stage explosives column was not detonated.

4. Micro-sequence explosion test verification

4.1. Test structure
In order to verify the simulation results, the ignition test was performed on the micro-initiation sequence. The test assembly structure is consistent with figure 1. Test samples and assembly drawings are shown in figure 6.

(1) When the material is stainless steel, the experimental results are shown in figure 7.
(2) When the material is nickel, the experimental results are shown in figure 8.

As shown in figure 7, when the thickness of the stainless steel separator is 1mm, the cavity containing the second stage explosives was cracked. There is a large indentation on the identification block. The results show that the JO-9C is completely detonated. When the thickness is 1.3mm, the partition is not bad, the second stage explosive column and cavity are intact. It indicates that the JO-9C has not exploded. In figure 8, when the thickness of the nickel separator is 0.5 mm, the cavity containing the second stage explosive column is broken, there is a large indentation on the identification block. It explains that the JO-9C is completely detonated. When the thickness is 0.8 mm, the partition is broken. However, there is no major damage to the second stage explosives column. There is no explosion in the JO-9C. The experimental results show that the simulation results are basically reliable.

5. Conclusions
Through the simulation research and experimental verification of the detonation wave transmission of the micro-initiation sequence of different separator materials, the following conclusions can be drawn:

(1) When stainless steel and nickel materials are used as the separator, the ability of the detonation wave to make the JO-9C explode is: stainless steel > nickel. Because the nickel separator has a strong attenuation effect on the detonation wave, for the above two materials, only from the perspective of achieving micro-sequence explosion-proof, nickel is a preferred material.

(2) The detonation ability of the explosion shock wave after being attenuated by the diaphragm is positively correlated with the pressure value at the input end of the second-stage explosive column. Although the effects of the initial pressure value and the pressure decay rate are only indirect, they are directly related to the residual pressure value. From the point of view of achieving micro-sequence explosion-proof, it is better to select materials with small initial pressure value and faster pressure decay under the same conditions.

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