Study on the Interference of Multi-point Shaped Charge Structure on Jet

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Abstract. In order to improve the defense ability of reactive armor against shaped charge jet, a multi-point shaped charge structure is designed in the first layer of traditional explosive reaction armor, and the active passive combination method is used to interfere with the jet. The specific action process is as follows: after obtaining the signal of series warhead charge impacting explosive reactive armor. Take the initiative to detonate the shaped charge. Multiple damage elements are formed to interfere with the shaped charge jet actively. Based on LS-DYNA, the numerical simulation of multi-point shaped charge structure is carried out, and the charge structure and angle are optimized. The results show that the damage elements in different directions can be focused along the axial direction of the incoming jet by adjusting the charge structure. Changing the focal length of the converging jet can cause interference or fracture at different positions of the jet. The research results of this paper can provide reference for the design of active passive reactive armor.

1. Introduction
Before 1960, tanks used protective armor through the use of different materials and structural design. With the progress of technology, the traditional protective armor has been difficult to meet the needs, people have carried out a lot of research, so the concept of new protective armor was put forward. In 1974, M. held[1] put forward the concept of explosive reactive armor. Two steel plates were added at both ends of the explosive. When the jet penetrated the reactive armor, the reactive armor would be detonated first, and the generated detonation wave would drive the steel plate to move, which would affect the jet and make it slow down and bend or fracture. Tong Zongbao and others[2] studied the problem that the opening of the front stage shaped charge of the tandem warhead is not big, and proposed an M-shaped liner. Li Yongsheng et al.[3] Optimized the design of annular cutter liner. Through numerical simulation, the annular cutting effect of copper, tungsten and iron liner on 100 mm thick homogeneous target was compared. Cao Tao et al.[4] Studied the influence of liner shape on the
performance of lateral annular jet by numerical simulation, and set up four groups of liner with different parameters. The results are as follows: 1. The jet shape formed by conical liner is better than that of elliptical liner; 2. The jet formed by variable wall thickness liner with 60° conical angle has the maximum head velocity. Wu Haijun et al. Simulated the formation and penetration process of annular jet under the condition of multi-point synchronous initiation, and obtained that the penetration ability of annular jet increases with the increase of initiation points. Xue Zhen et al. Studied the jet convergence performance of annular shaped charge with deflection angle, and found that the jet can converge in the axial direction and the head velocity can be improved by using the liner with deflection angle.

Based on the traditional reactive armor, a surface jet converging structure is proposed for armor protection. In this study, the charge in the box detonates at the moment when the front charge impacts the outer shielding plate. Under the action of detonation wave, the deflected liner is used to form a surface jet which can converge to the central axis, so as to cut the main jet of the penetrator. The numerical calculation model is established by LS-DYNA to analyze the influence of the multi-point shaped charge structure on the interference effect of the jet under different structures and angles.

2. Numerical calculation model

2.1. Basic assumptions

In the calculation model of multi-point shaped charge structure studied in this paper, the initiation system is not considered, and an idealized initiation surface is formed at the front end of shaped charge in the form of coordinate points. At the same time, the influence of temperature on the formation, convergence and penetration process of jet is not considered.

2.2. Calculation model

The multi-point shaped charge technology involves the large deformation movement of materials and the fluid solid structure coupling, so the multi-material ALE (arbitrary Lagrangian Eulerian) method and motion grid are used in this study. The structure of multi-point shaped charge used in the calculation is shown in Figure 1. A conical liner with a top cone angle of 40° was used. The deflection angle of the liner was 15° and the wall thickness was 1.6 mm. The outer diameter of the large end of the liner was 48 mm and the inner diameter of the small end of the inner liner was 20 mm. The wall thickness of the inner liner and the outer liner were 1.2 mm and 1 mm respectively, and the charge height was 20 mm.
2.3. Material model and equation of state

Johnson cook material model and Gruneisen equation of state are used in the numerical calculation. The specific parameters are shown in Table 1. Where, \( \rho \) is the density of liner material; \( G \) is the shear modulus; \( A, B, n, c, m \) are material constants; \( T_m \) is the melting temperature of material.

The main material parameters of explosive B are: \( \rho = 1.717 \text{ g/cm}^3 \), \( p_{CJ} = 29.5 \text{ GPa} \), \( D = 7980 \text{ m/s} \). The equation of state is JWL equation, and its parameters are shown in Table 2.

### Table 1. Material parameters of liner.

| \( \rho / \text{(g/cm}^3 \) | \( G / \text{GPa} \) | \( A / \text{GPa} \) | \( B / \text{GPa} \) | \( n \) | \( c \) | \( m \) | \( T_m / \text{K} \) |
|----------------------------------|----------------|----------------|----------------|-----|-----|-----|----------|
| 8.93                            | 47.7           | 0.09           | 0.292          | 0.31| 0.02| 1.09| 1356     |

### Table 2. Parameters of JWL equation for explosive B.

| \( A / \text{GPa} \) | \( B / \text{GPa} \) | \( R_1 \) | \( R_2 \) | \( \omega \) | \( E_0 / \text{GPa} \) |
|---------------------|---------------------|----------|----------|-------------|------------------|
| 524.23              | 7.678               | 4.2      | 1.1      | 0.34        | 8.5              |

3. Numerical simulation results and analysis

3.1. Formation process of converging jet

After initiation, the multi-point shaped charge structure first forms a cone-shaped jet, which moves and stretches along the direction of the cone generatrix, forming a convergence trend in the direction of the axis, so as to form a damage element to interfere with the shaped charge. Figure 2 shows the action process of the multi-point shaped charge structure moving along the axis from the collapse of the liner to the formation of the jet.

It can be seen from Figure 2 that the liner detonates in 0 ~ 12\( \mu \)s, extrudes inward in 13~40\( \mu \)s, forms jet in 41~80\( \mu \)s, and converges to the axis direction. The jet around 80 \( \mu \)s is basically formed and tends to be stable, and then the jet is gradually elongated under the effect of velocity gradient.
3.2. Influence of liner cone angle on convergent jet shape

Based on the numerical simulation of the jet formation process, only changing the size of the cone angle of the liner, the charge structure with the cone angle $\alpha$ of 40° and 50° is simulated respectively. Figure 3 shows the cross section of the jet convergence process at different cone angles.

**Figure 2.** Jet formation process.
It can be seen from Figure 3 that the diameter of the jet increases with the increase of the cone angle of the liner. This is because when the cone angle of the liner is large, the short and thick metal jet will be produced. In addition, the shape and velocity of the jet are affected by the cone angle of the liner. The jet formed by the liner with a cone angle of 50° breaks the jet shape due to expansion, resulting in the instability of the jet. The jet with a cone angle of 40° has better shape and higher armor breaking power.

4. Experimental verification

4.1. Test plan
In order to further verify the influence of multi-point shaped charge structure on jet interference, static armor breaking test was carried out. The liner with deflection angle of 40° and 50° is designed respectively, and the electric detonator of B explosive is used for ring initiation. Figure 4 shows the layout of the test site. The target plate is a 45# steel plate with a diameter of 200 mm and a thickness of 150 mm.
Fig. 5 shows the effect of the jet generated by the multi-point shaped charge structure penetrating the target plate under different cone angles of the liner. Table 3 shows the comparison between the test results and the simulation results.

![Figure 5](image)

**Figure 5.** Effect diagram of jet penetrating target plate under different cone angles

| $\alpha$ (°) | Entrance size / (mm×mm) | Penetration depth / mm |
|--------------|-------------------------|-----------------------|
|              | Test value | Simulation value | Test value | Simulation value |
| 40           | 40.0×45.0  | 44.5×44.5  | 45         | 120             |
| 20           | 60.0×65.0  | 63.0×63.0  | 40         | 98              |

From the target plate after penetration, it can be seen that under the condition of 5 times of charge diameter, the jet formed by small cone angle ($\alpha = 40$ °) converges twice and produces the jet with smaller head diameter and smaller entrance size of penetration hole; while the jet produced by large cone angle ($\alpha = 50$ °) has larger head diameter and larger entrance size of penetration hole, which is basically consistent with the results of numerical simulation.

From the perspective of penetration depth, the jet produced by the charge structure with smaller cone angle ($\alpha = 40$ °) penetrates deeper into the target plate, and the test results under the two cone angles are lower than the simulation results. The main reason is that it is difficult to guarantee the closure delay at the junction between the inner shell and the liner, and the detonation products leak out prematurely from the gap between the inner shell and the liner, This can be seen from the copper coating on the surface of the target.

5. Conclusion

The multi-point shaped charge structure is designed in the first panel of traditional explosive reactive armor. The active passive mode is used to interfere with the jet. The numerical simulation of the action process of the multi-point shaped charge structure is carried out based on LS-DYNA, and the charge structure and angle are optimized.

1. Innovative reactive armor structure, multi-point shaped charge mechanism can form stable and efficient jet, and converge in the axis direction.
2. The cone angle of the liner will affect the shape and velocity of the jet. The top cone angle of 40° and the deflection angle of the liner of 15° can form a stable jet that interferes with the shaped charge jet.

3. The multi-point shaped charge can form a closed jet surface, which can effectively interfere with the shaped jet.

6. Reference

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