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Research on the Characteristic of Projectile Fragments Dispersion Based on Fragment Warhead Design

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Abstract. Dispersion of fragments of projectiles is an important factor affecting the lethal efficiency of projectiles and one of the main objectives of optimal design of fragmented warheads. By using Taylor angle approximation, Shapiro formula and experimental measurement, the fragment dispersion characteristics are analyzed. The results show that if the mass of metal plate (fragments) detonated by explosive is constant, the characteristics of fragments scattering are basically determined; for a certain structure of shell warhead, the direction of fragments scattering is related to the initiation position and the direction of detonation wave propagation; and by marking the size of the dispersing sector, the range of fragments scattering can be determined.

1. Introduction

In the modern battlefield, the main way of warfare is to strike and destroy by fierce fire. Among them, the most important means is to use the fragments of projectiles to kill the personnel and equipment effectively, that is, the metal shell of projectiles is broken down by the explosion of internal explosive charge, resulting in the destruction of personnel, aircraft, vehicles and tank equipment. In order to make full use of the kill efficiency of fragments of projectiles, it is necessary to optimize the design of fragmented warheads in combination with the important parameters such as the number of fragments, the initial velocity of fragments, the mass distribution of fragments and the spatial distribution of fragments. As fragment dispersion is an important phenomenon after explosion of fragment warhead and various artillery shells, its spatial distribution is an important parameter to determine the fragment killing field. Therefore, the optimal spatial distribution (scattering) of the maximum number of effective fragments is the primary objective of the optimal design of fragmented warheads.

2. Fragment dispersion analysis based on Taylor angle approximation

Usually, it is necessary to assume that the moving direction of metal is perpendicular to the surface of the shell when the fragments are scattered by Gurmey equation. But in fact, this is only true when the detonation wave is incident vertically on the inner surface of the shell. When the detonation wave passes through the shell, Taylor angle approximation is needed. As shown in Figure 1, the projection of explosive detonation to metal plates.

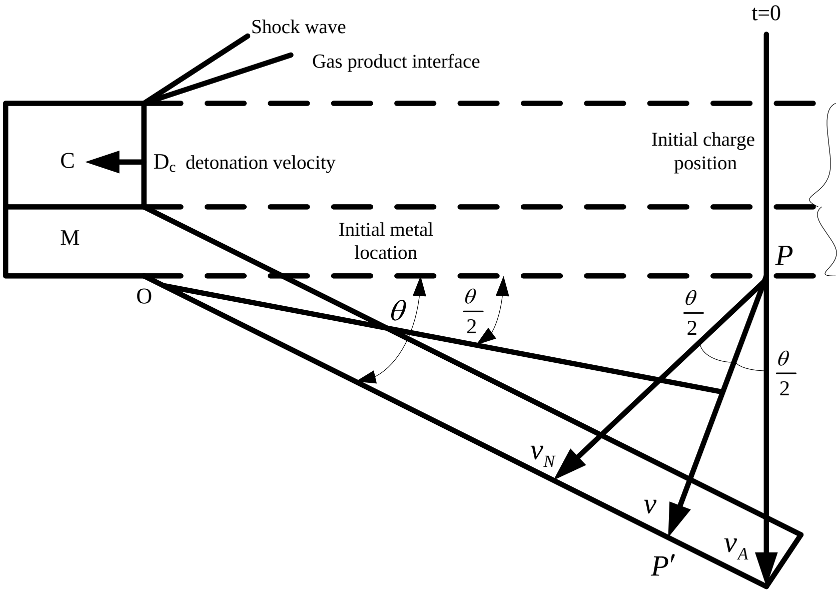

Figure 1 Projection of metal plate by explosive detonation

Analysis of the above figure shows that when the detonation wave passes over the surface of the flat plate, the flat plate deviates from the θ angle. Assuming that under steady-state conditions, the plate accelerates instantaneously from the initial position to the final velocity, and the metal plate undergoes pure rotational motion, and there is no change in length or thickness or shear flow, the original P -point plate element will reach P' -point after projection, and its length is $OP = OP'$. Vertical $\overline{PP'}$ leads from point O, because $\overline{OPP'}$ is an isosceles triangle, so this line is angular bisector, and the bisector θ. If the time of sweeping the detonation wave from point P to point O is t, then there is

$$\sin\frac{\theta}{2} = \frac{\overline{PP'}/2}{OP} = \frac{vt}{2D_e t} = \frac{v}{D_e} \tag{1}$$

The formula is Taylor's angle relation. Among them, v is the scattering velocity of metal plate, which can be obtained by Gurney equation. D_e is the detonation velocity of the explosive. From the analysis of the relationship, it can be seen that the angle $\frac{\theta}{2}$ between the scattering direction of the element and its surface normal can be determined by the formula.

Because the velocity component v_A of the initial position of the vertical plate is

$$v_A = D_e \tan\theta \tag{2}$$

Then there is

$$\frac{v}{v_A} = \frac{2D_e sin(\theta/2)}{D_e \tan\theta} = \frac{\cos\theta}{\cos(\theta/2)} \tag{3}$$

The velocity component perpendicular to the surface of the flying metal plate is

$$v_N = D_e sin\theta \tag{4}$$

It can be obtained as

$$\frac{v}{v_N} = \frac{2D_e sin(\theta/2)}{D_e \tan\theta} = \sec\frac{\theta}{2} \quad (5)$$

From the above analysis, it can be seen that, in practice, only a few percent correlation exists between v, v_A and v_N, that is, the value of $v/2D_e$ is approximately the same for most explosives in projectiles, so the value of θ is almost equal to a constant. If the mass of the driven metal plate is certain (e.g. prefabricated fragments), the velocity of the metal plate will increase with the increase of explosive detonation speed, so $v/2D_e$ is basically equal to a constant. It can be seen that if the metal plate (fragment) detonated by explosive has a certain mass, the characteristics of fragment dispersion of projectile are basically determined.

3. Fragment scattering direction calculation based on Shapiro formula

For the analysis of fragment dispersion, Taylor theory provides a basic idea for predicting the dispersion characteristics of static fragments, while Shapiro applies it to the calculation of the dispersion direction of fragments. According to Shapiro's hypothesis, the warhead is made of many rings arranged continuously, that is to say, the shell or warhead shell is superimposed by rings, and the centers of the rings are all on the symmetrical axis of the projectile body. Although this assumption is not consistent with the actual projectile shell, it still has sufficient accuracy in approximate calculation.

According to Shapiro theory, detonation wave is generated by booster or detonator and propagates outward in the form of spherical wave front. At the same time, the angle ϕ_1 between the normal of the warhead shell and the symmetrical axis of the projectile body, the angle ϕ_2 between the normal of the explosive wave front and the symmetrical axis of the projectile body, and the deviation angle of the fragment velocity vector from the normal of the projectile shell are set as ϕ_s, as shown in Fig. 2.

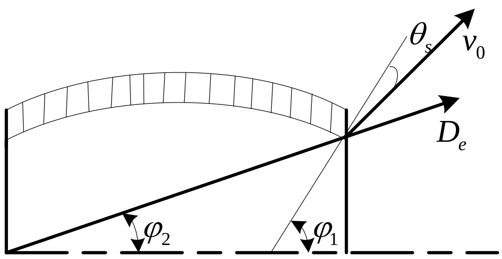

Figure 2 Elements for estimating the dispersion angle of fragment beam

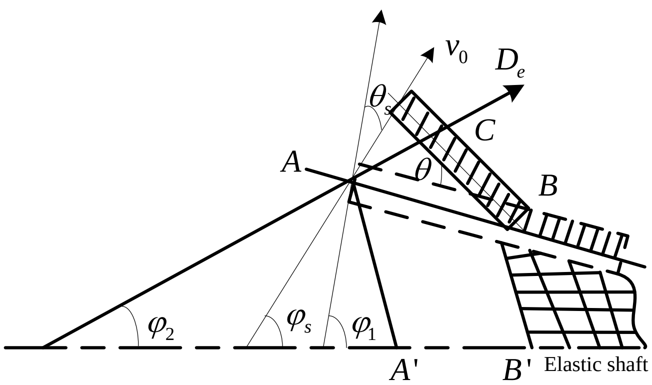

Figure 3 Calculations of Fragment Beam Dispersion Angle

The ring AB of a micro element on a projectile shell is studied, as shown in Fig. 3. The detonation wave moves from the left end of the warhead to the right end. In Δt time, the direction of the

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detonation wave acting on the AB shell remains unchanged. At this time, the detonation wave front moves from $A-A'$ to $B-B'$, and the distance travels is $D_e\Delta t$. The expansion velocity of A-point shell increases from 0 to v_0, and the shell AB turns θ angle. The length and thickness of the shell remain unchanged. In isosceles triangle ABC, according to sine theorem, we can get

$$\frac{\overline{AC}}{\sin\theta}=\frac{\overline{AB}}{\sin(\pi/2-\theta/2)} \tag{6}$$

Using Taylor's hypothesis, it can be seen that the acceleration of AB element to the final velocity is instantaneous. So there are

$$\overline{AC}=v_0\Delta t \tag{7}$$

$$\overline{AB}=\frac{D_e\Delta t}{\cos(\pi/2-\phi_1+\phi_2)} \tag{8}$$

By substituting the above two formulas into Formula (6), we can get the result which is

$$\sin\frac{\theta}{2}=\frac{v_0}{2D_e}\cos(\frac{\pi}{2}-\phi_1+\phi_2) \tag{9}$$

As shown in Figure 3.2, $\theta_s=\theta/2$. And when θ_s is very small, $\tan\theta_s\approx\sin\theta_s$. Therefore, the above formula can be rewritten as

$$\tan\theta_s=\frac{v_0}{2D_e}\cos(\frac{\pi}{2}-\phi_1+\phi_2) \tag{10}$$

This formula is the Shapiro formula. θ_s is the deflection angle of the fragment and v_0 is the initial velocity of the fragment. By analyzing the formula, it can be seen that the direction of fragments scattering is related to the initiation position and the propagation direction of detonation wave for a certain structure of shell warhead shell. At the same time, the scattering direction of fragments can be calculated by this method.

4. Determination of fragment scattering range based on test measurement

For the angle distribution (i.e. the range of dispersion) of fragments of projectiles, not only can the shell of projectiles be divided into a number of micro-elements calculated by theoretical method, but also can be determined by experimental results. That is to say, the target is surrounded by different distances around the warhead. After the warhead explodes, the number of fragments hit on each unit area of the target can be calculated, and the angular distribution density of fragments relative to the projectile axis can be obtained, as shown in Figure 4.

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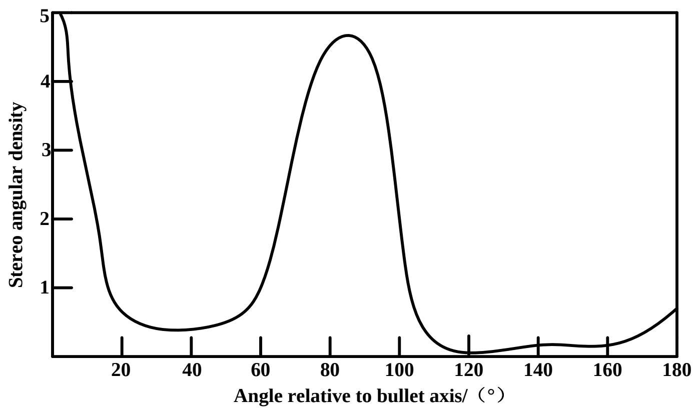

Figure 4 Typical curve of fragment dispersion range of projectile

When measuring the dispersion range of the projectile, the recovery and distribution of the fragments of the projectile are mainly analyzed. In the analysis of distribution, it is assumed that the fragments formed by warhead explosion distribute uniformly around the warhead. Therefore, fragments recovered in one sector can be considered to represent the whole distribution. The warhead is usually placed in the test field in a horizontal state, and then the recovery box, velocity target, speed recovery box and anti-jump baffle are placed in the appropriate position for determining the correlation between speed and quality. The recycling box is used to capture fragment samples intact and nondestructively, and to determine the spatial distribution of fragments accordingly. Therefore, the number of projectile fragments in any area around the warhead can be determined according to the position in the receiving box and plotted as a spatial distribution curve, as shown in Figure 5. Through the curve, the sector size of the effective fragments of the projectile can be marked, and the range of the fragments can be determined.

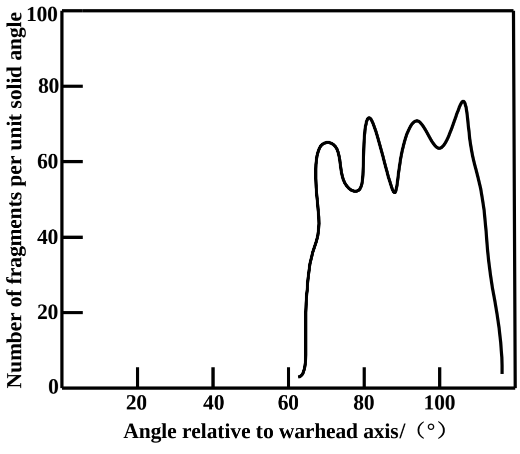

Figure 5 Spatial distribution curve of fragments

5. Conclusion

Projectile fragments are the killer elements directly acting on the target, and their effectiveness directly affects the killing effect of the target. The scattering characteristics of the projectile fragments are one of the important factors determining the killing efficiency of the projectile. When the Taylor angle approximation is used to analyze fragment dispersion, it is not necessary to assume that the moving direction of metal is perpendicular to the surface of the shell. If the mass of the metal plate (i.e. fragment) detonated by explosive is constant, the characteristics of fragment dispersion of projectile are basically determined. When Shapiro formula is used to calculate the direction of fragment dispersion, the direction of fragment dispersion is related to the detonation position and the direction of detonation wave propagation for the shell of a certain structure. Based on the experimental measurement, the range of fragments is determined. The main purpose is to recover the fragments and draw the spatial distribution curve. The range of fragments is determined by indicating the size of the dispersed sector. Through theoretical analysis and numerical calculation of the dispersion characteristics of fragments of projectiles, it can provide theoretical reference for the optimal design of fragmented warheads, make them more in line with the needs of actual combat, and give full play to operational effectiveness.

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