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Research on target damage efficiency calculation algorithm based on finite element analysis method

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ABSTRACT

To study the target damage efficiency of the projectile fragment for the target, a penetration kinetic energy calculation algorithm is put forward to analyze the target damage probability based on projectile spatial coordinate. According to the target features, the finite element analysis method was used to establish the mathematical model of the damage vulnerable area and calculate the kinetic energy of target damage effectiveness evaluation. The ratio of the difference between effective fragments penetration kinetic energy and maximum dynamic deformation work of the target material is utilized to calculate the target damage probability. The target damage level standard was described to evaluate the target damage efficiency. The simulation software ANSYS is adopted to realize the penetration simulation and give out the curves of variational velocity and variational energy on the process.

1. Introduction

Damage efficiency is the most significant indicator on weapon system combat effectiveness assessment. The merits of damage efficiency assessment method determine the effectiveness and the feasibility. It is the key that improving the existed damage efficiency assessment methods continuously and developing new method to enhance the damage ability of ammunition weapon impact the target [1]. At present, many domestic research institutes are exploring and developing assessment method on target damage, which is based on Bayesian network. Generally, domestic studies about target damage mainly focus on damage efficiency assessment based on fixed distance and explosion in certain area and environment [2–4]. It lacks extensive, in-depth and systematic research on dynamic high-speed projectile damage method. Therefore, it has not yet formed that normalized method and auxiliary simulation measure about high altitude dynamic proximity target damage efficiency assessment, which makes user difficult to establish essential data library and method library about target damage efficiency assessment, and the design of weapon ammunition system cannot benefit from it, while most of dynamic simulations are based on certain distance explosion simulation analysis by using finite element analytical method. Though, the dynamic damage research is fully developed in some powerful military countries, we can get limited military resources and documents because of their blockades. Therefore, it is necessary to study the target damage efficiency assessment method on high speed dynamic exploration. An appropriate and universal high altitude dynamic target damage model, calculating methods on target damage kinetic energy and target damage probability are proposed in this paper. In addition, the penetration simulation results are obtained by using the finite element analysis software (ANSYS), which can provide an assessment method on the target damage.

2. Target damage modeling and damage kinetic energy calculation

2.1. Target damage model based on finite element analysis method

Based on the principles of the finite element analysis method, we divide the target vulnerable areas into two-dimensional finite elements and establish a two-dimensional mathematical model of the target damage. At first, the target model will be simplified, and the equivalent target vulnerable cabin will be equivalent to a cylinder. Then in the process of analysis and calculation, the cross-sectional area can be considered as a rectangular target element. Afterwards, the cross-sectional area is divided into M equal size rectangular cabin, and the rectangular cabin area is S_i ($i = 1, 2, \ldots, n$). The target damage model is shown in Fig. 1.

In Fig. 1, the point O is at the center of the target's initial cabin, the X axis lies in the central axis of the target, and the YOZ plane

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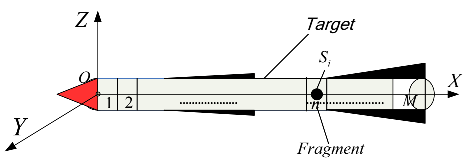

Fig. 1. Target damage finite element model.

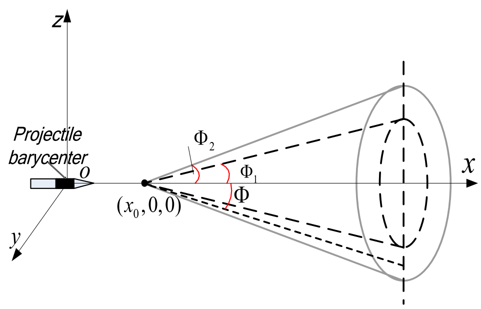

Fig. 2. Uniform distribution angle of fragments.

is created at the cross section of the target center, the Z positive axis is vertical upward and Y axis is perpendicular to the XOZ plane. The target equivalent model is established such that the analysis of target vulnerability mathematical model will become further mathematical and specific.

2.2. Projectile spatial coordinate optical measurement

To gain projectile's fragments to target damage efficiency, we need measure the spatial coordinate. The spatial coordinate measurement method of flying projectile employs six screens test system, its principle and method can see Refs. [5,6], here, we do not introduce specific calculation method.

2.3. Kinetic energy calculation of the fragments

2.3.1. Single fragment kinetic energy calculating

This paper mainly analyzes the target impaction damage which is produced by the projectile fragment. The projectile explodes at a high speed and generates fragment fields, and the fragments disperse uniformity. When the projectile exploded, the projectile fragments obtain a high initial velocity and impact the target at certain angles [7]. Then, it can damage the target with the kinetic energy. Assuming that v_M is the projectile flying velocity, and v_T is the target flying velocity, then the relative velocity of the projectile and the target can be written as: $v_C = v_M + v_T$.

The projectile fragments cloud can be seen as a sphere at the moment of explosion. There are only parts of the fragments cloud will cause damage to the target, therefore, assuming that the effective fragments field is a cone, as shown in Fig. 2. The fragments disperse uniformly in the cone ring which is surrounded by Φ_1 and Φ_2, and the effective fragments field can be described by the fragments average scattering angle Φ, $\Phi = (\Phi_1 + \Phi_2)/2$.

Firstly, we analyze that a single fragment penetrates the target surface element. Supposing that $\overline{m}$ is the quality expectation of the projectile fragments, then the fragment kinetic energy in the impaction is $E_k = (1/2)\overline{m}v^2$ [8–10]. According to the principle of energy conservation, only if the fragment impaction kinetic energy E_k is no less than the average of the target material dynamic deformation work E_0, can it cause perforation. Namely

$$E_k = \frac{1}{2}\overline{m}v^2 \geq E_0 = k_1 b_{A1} \sigma_{A1} S_i \tag{1}$$

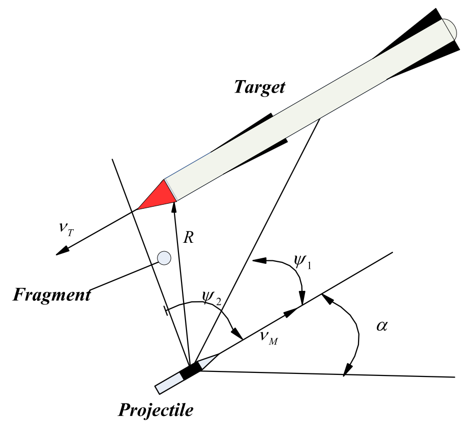

Fig. 3. The projectile-target encounter processing.

Here, k_1 is a proportional coefficient, for duralumin, when the impact speed is not greater than 2500 m/s, then we can write $k_1 = 0.92 + 1.023v^2 \times 10^{-6}$. b_{A1} is the equivalent aluminum target thickness, σ_{A1} is the ultimate strength of duralumin.

E_b is defined as the specific kinetic energy when a single fragment impact on the duralumin target, and we can write: $E_b = E_k / b_{A1} S_i$. Then the target specific kinetic energy of a single fragment is $E_b = \overline{m}v^2 / 2b_{A1}S_i$. Above all, the condition of a single fragment penetrates the target surface can be expressed by the following formula.

$$E_b \geq k_1 \sigma_{A1} \tag{2}$$

2.3.2. Kinetic energy calculating on a single target surface element

Although the scattering of fragments is well-dispersed, the target and the projectile fragments both fly at a high speed, so, the effective fragments number and the fragments mass which impact on the same target surface element are unknown and random. Therefore, in order to calculate the kinetic energy of the effective fragments which impact on the target surface element, the projectile fragment distribution density must be analyzed firstly.

In static experiments, the effective fragments static distribution area can be calculated by the following formula.

$$A_s = 2\pi R^2 (\cos \Phi_1 - \cos \Phi_2) \tag{3}$$

Suppose that R is the distance between the terminal ballistic trajectory and the target, and N is the number of effective fragments in the cone ring surrounded by Φ_1 and Φ_2. Then, the calculation formula of fragments' distribution density ρ is as follows:

$$\rho = \frac{N}{2\pi R^2 (\cos \Phi_1 - \cos \Phi_2)} \tag{4}$$

The target and the projectile fragments both are moving at a high speed, when the projectile encounters the target, the fragment scattering angle will becomes smaller while the speed of fragments will increase. The process of projectile-target encounter is shown in Fig. 3.

The angle between the projectile fragments angle and the projectile flying velocity is φ, it can be calculated by the following formula.

$$\varphi = \frac{360 - 2\Phi_i}{2} \quad (i = 1, 2) \tag{5}$$

And the dynamic scattering angle can be written as:

$$\psi_i = \arcsin\left(\frac{v_C \sin\varphi}{v_\varphi}\right) \tag{6}$$