A Calculation Method of Fragment Initial Velocity of Blast-fragmentation Warhead Based on Neural Network

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Abstract. This paper analyzes the theoretical calculation method of the initial velocity of the static bursting disc and the factors affecting the initial velocity of the static bursting disc. On this basis, a calculation method and device of the initial velocity of the fragmentation warhead based on the neural network is proposed. The strong nonlinear mapping ability of the BP neural network and the associative memory ability of the external stimulation and input information are used to determine the initial velocity of the fragment of the kill warhead and improve the efficiency. The speed of calculation and the accuracy of the results are given.

1. Introduction
The damage effect evaluation of blast-fragmentation warhead is one of the hot issues in the field of damage assessment, and the calculation of initial velocity of natural fragments is a very important part. Under the action of the energy released by the charge explosion of the detonation warhead, the shell expands, breaks and flies away. When the shell is broken, the fragments form and move outward at a certain speed. At this time, the rear detonation products still act on the fragment and make it continue to accelerate. When the force of the detonation product on the fragment is balanced with the air resistance, the fragment velocity reaches the maximum value, which is called the initial velocity of the fragment. The initial velocity of fragment is an important performance parameter of projectile, which directly affects the terminal power of projectile. The initial velocity of fragments can be obtained by theoretical analysis or by experiment.

2. Theoretical calculation of muzzle velocity of static explosive fragment
In order to simplify the analysis, the following assumptions are made:
   - The detonation of explosive is instantaneous;
   - The velocity distribution of detonation products is linear in radial direction without considering the dispersion of detonation products along the charge axis;
   - Ignoring the energy consumed in the process of fragmentation, all the energy of charge is converted into kinetic energy of detonation products and fragments;
   - The fragments formed by shell explosion have the same initial velocity.

   The Gurney formula is used to calculate the initial velocity of the warhead

   \[
   V_0 = \sqrt{2E} \left( \frac{\beta}{1 + 0.5\beta} \right)^{1/2}
   \]

   Where \( \sqrt{2E} \) is Gurney constant related to the type of explosive, m/s.
\[ \beta = \frac{M_\text{e}}{M_\text{s}} \] is the mass ratio of charge and shell (fragment). \( M_\text{e} \) is the mass of explosive charge and \( M_\text{s} \) is the mass of warhead shell (fragment).

3. Factors affecting the initial velocity of static bursting discs

There are many factors affecting the initial velocity of fragments, which can be divided into the following aspects:

1. **Type of explosive**

   The explosive is the energy for shell to obtain velocity. The stronger the explosive power is, the higher the initial velocity of fragment is. The explosive with high work ability is generally selected for killing warhead and shrapnel. From the calculation formula of fragment initial velocity, it can be seen that the initial velocity of fragment is approximately proportional to the detonation velocity of explosive, so the higher the detonation velocity of explosive, the greater the initial velocity of fragment.

2. **Shell material**

   The effect of shell material is mainly reflected in the plasticity. The shell with high plasticity will rupture when it expands to a larger radius under the action of detonation products, and the shell will get a higher speed; the shell with low plasticity will break earlier under the action of detonation products, so the fragment speed is lower. The experimental results show that: for the copper shell, when \( \gamma > 2.6\gamma_0 \), it will break, the fracture radius of 45 steel is \( \gamma = 1.84\gamma_0 \), and that of soft steel is \( \gamma = (1.6 \sim 2.1)\gamma_0 \).

3. **Warhead structure**

   The influence of warhead structure on initial velocity of fragment is mainly manifested in structure type, ratio of shell mass to explosive mass \( \beta \), length diameter ratio \( \frac{L}{D} \), and mass at both ends.

   When the ratio \( \beta \) of explosive mass to shell mass is large, the energy and specific impulse acting on the shell are large, and the initial velocity of fragment is high.

   When the length diameter ratio of the shell is large, the influence area of the axial sparse wave on the velocity of the shell is limited to the end face not far from the initiation point, and the velocity of the fragment in the middle of the shell is greater than that at the end point.

   The mass of the shell or cover at both ends of the explosive is large, the movement of the explosive is slow under the action of detonation products, and the axial rarefaction wave enters later, so the initial velocity of fragment (especially the end micro element) is large. The fragments formed by explosion at both ends (head and tail) have large mass and low velocity. Therefore, the mass at both ends should be as small as possible under the condition of satisfying the strength.

4. **Initiation mode and position**

   In order to simplify the formula of initial velocity of fragments, it is assumed that the velocity of fragments along the axis of projectile is equal. In fact, the length of the projectile, the initiation position and the movement direction of the detonation products all affect the fragment velocity and fragment dispersion direction along the axial direction. The actual measurement results show that the velocity of fragments near the middle of warhead is the highest, and the velocity of fragments is lower at both ends.

   The initial velocity of the fragment at the initiation end is lower than that at the non initiation end when the single end face is detonated;

   The initial velocity of fragment at the middle position of the projectile increases when the dual end initiation occurs, which is 1.2 times of that of the single end initiation. The dual end initiation increases the gradient between the initial velocity of fragment at the middle position and that at the end face.

   When the dual initiation point is moved to the charge center, the velocity gradient between the center and the end face fragment velocity can be reduced.
The dual initiation makes the fragments concentrate in the area near the warhead center of mass and perpendicular to the projectile axis.

For any warhead, the total kinetic energy of fragments is approximately equal regardless of the initiation mode.

The reason for the above results is that the detonation products escape from the end face, which reduces the effect on fragments. The results show that the initial velocity of the fragment near the end face decreases, and the detonation products at the non initiation end also escape, but the initial velocity of the fragment at the non initiation end is higher than that at the initiation end because of the propagation direction of the detonation wave; when dual initiation is adopted, a high-pressure central region is generated due to the collision of detonation waves, which increases the initial velocity of fragments nearby by 20%.

Therefore, it is considered that the decrease of the initial charge velocity makes the initial charge velocity decrease. The function $f(z)$ is introduced to modify the gunny’s formula

\[
V_0 = \sqrt{\frac{2E}{m}} \frac{1 + 0.5F(z)m_s/m}{1 + 0.5F(z)m_s/m} \tag{2}
\]

Where $Z$ is the initial axial position of fragment (m), and $Z = 0$ at the initiation point;

$R$ -- Charge radius, m;

$L$ -- Charge length, m.

4. A calculation method of fragment initial velocity of blast-fragmentation warhead based on neural network

In this paper, based on neural network, a method for calculating the initial velocity of the fragment of blast-fragmentation warhead is proposed.

Step 1. For a certain type of bomb, before the explosion test, measure and record the shell and charge structure material parameters, including: shell material density, yield limit, shell wall thickness, shell mass, shell length diameter ratio, bottom cover mass, end cover mass, charge density, charge radius, charge length, charge speed, charge mass, initiation point position (1 or 2), and axial direction to be tested 14 or 15 parameters such as position.

Step 2: collect the initial velocity of fragments at the axial position to be tested after the explosion test of each projectile;

Step 3: taking the parameters in step 1 as input and step 2 as output, a set of sample data for neural network training and testing can be obtained. In one explosion test, multiple data can be tested due to different axial positions to be tested;

Step 4: repeat the above steps 1 to 3 to obtain several groups of data;

Step 5: build a BP neural network including an input layer, a hidden layer and an output layer, the input layer node is 15, the output layer node is 1, and the hidden layer node is 9; the weight of the BP neural network is a random number between $[-1, 1]$, and the bias is a random number between $[0, 1]$. The weight of the BP neural network is adjusted by adjusting the negative gradient descent principle, and the setting error is described 01.

Step 6, use the data from step 4 to train the neural network constructed in step 5 until the end;

Step 7, the neural network trained in step 8 can be used to predict the same kind of ammunition. The specific process is as follows: the input is the parameter described in step 1, and the output is the parameter described in step 3, that is, the initial velocity of fragment at the specified axial position.

In the above steps, except the input and output in step 3 are fixed, other parameters, including the number of hidden layers, hidden layer nodes, weight, bias and setting error of BP neural network, can be adjusted according to the actual situation. A brief flow chart is shown below.
Before the test, the parameters of shell and charge structure material were measured and recorded

After the explosion test, the initial velocity of fragments in the axial position to be tested is collected

Construction of BP neural network

The BP neural network model is trained and obtained

The trained BP neural network model is used to predict the same kind of bomb

Figure 1. Brief flow chart

5. Conclusions
This paper presents a new method of calculating the initial velocity of fragment in the warhead based on neural network. The principle and the implementation steps of the method are introduced. Based on this method, the initial velocity of fragment in the warhead can be determined and the calculation speed and result accuracy can be improved.

References
[1] NI Qingjie, LI Jia, GUAN Shuai, etc. Technical Approach for Power Improvement of Middle and Large Caliber H.E Projectiles. Transactions of Shenyang Ligong University. 2014, 33(6)
[2] GUO Chao, GONG Xiaoze, LI Xiangdong. Calculation of Fragmentation Distribution and Fragmentation Coefficient of Projectile. Journal of Projectiles, Rockets, Missiles and Guidance. 2017, 37(3)
[3] Yang Qi, Huan Guangzhou, Wang Mengnan. Analysis of Fragment Power of Semi-prepared Fragment Warhead. Aerospace Manufacturing Technology. 2018, (4)
[4] LI Bo, GUO Guangquan, YIN Likui. A New Method for Calculating the Initial Velocity of Cylindrical Charge Shell. Journal of Sichuan Ordnance. 2018, 39(9)
[5] ZHAO Jin, FU Jianping, CHEN Zhigang. Analysis of Forming and Spreading of Pre-Formed Fragment Warhead. Journal of Sichuan Ordnance. 2019, 40(12)
[6] KANG Zhenyu,YUAN Shujiang. Reconstruction and Redevelopment of Prediction Software for Projectile Fragment Quality and Quantity Distribution. Journal of Projectiles, Rockets, Missiles and Guidance. 2019, 39(6)