A Calculation Method of Fragment Number and Mass Distribution of Blast-fragmentation Warhead based on Neural Network

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Abstract. The Mott distribution model is analyzed and deduced in this paper. On this basis, a calculation method of fragment number and mass distribution of blast-fragmentation warhead based on Neural Network is proposed. Based on the Mott distribution model, the empirical parameters in the Mott distribution model are determined by using the strong nonlinear mapping ability of BP neural network and the associative memory ability of external stimuli and input information. Then, the number and mass distribution of fragments are determined, and the calculation speed and result accuracy are improved.

1. Introduction

The damage effect evaluation of the warhead is one of the hot issues in the field of damage assessment, and it is very important to the quantity and quality distribution of natural fragments. Among them, the mass distribution of fragments refers to the number of fragments in different mass ranges. The number and mass distribution of fragments formed after explosion of uncontrolled fragments are related to the structure, shell materials and explosive types of the projectile. In addition, it is also affected by many random factors such as the location, quantity, expansion direction and the inhomogeneity of the material. Therefore, there is no theoretical formula to calculate the number of fragments. Semi empirical formula and experimental method are used to estimate or statistics, among which Mott distribution model is widely used.

2. Mott distribution model

The distribution of the number of natural fragments with mass given by Mott distribution model is considered as a classical model formula. The formula considers that the fragment mass distribution of uncontrolled fragment projectile obeys the following law:

\[ N(m) = \left( \frac{M}{\alpha \mu} \right) e^{-\frac{m}{\mu}} \]

Where \(M\) is the mass of projectile shell; \(m\) is the mass of fragment; \(N(m)\) is the number of fragments with mass greater than or equal to \(m\); \(\lambda\) is the empirical constant, and the explosion process of thin-walled projectile conforms to the two-dimensional crushing result, taking 1/2; for the thick walled projectile, the shell fragmentation conforms to the three-dimensional fragmentation law, and \(\lambda\) is taken as 1/3; \(\alpha\) is the dimensional constant, which is related to the projectile structure, \(\alpha\) is taken as 2.
when $\lambda$ is 1/2, and $\alpha$ is 6 when $\lambda$ is 1/3. $\mu$ is the fragmentation characteristic of projectile, and its size depends on the structure, material and explosive properties of the projectile. There are many empirical formulas to estimate $\mu$.

When $m$ is taken as 0, the total number of fragments $N_0$ formed after shell explosion can be obtained from the above formula

$$N_0 = \frac{M}{\alpha \mu}$$  \hspace{1cm} (2)

$\alpha \mu$ is the average mass of fragments.

3. Derivation process

From the introduction of Mott distribution model mentioned above, it can be seen that $\alpha$, $\mu$ and $\lambda$ are related to projectile structure, material, explosive and other factors. If the test data of a certain type of projectile is known, i.e. $M$ and $N(m)$, the following derivation process will be carried out.

It can be obtained from formula (2)

$$\mu = \frac{M}{\alpha N_0}$$  \hspace{1cm} (3)

The formula (2) (3) is introduced into (1) to obtain

$$N(m) = N_0 e^{-\frac{\alpha \mu m}{M} \lambda}$$

And then get

$$\lambda = \log_{\frac{\alpha \mu m}{M}} \left( \frac{N_0}{N(m)} \right)$$

$$\left( \frac{\ln N_0}{\ln N(m)} \right)^{1/\lambda} = \frac{N_0 m_1}{M} \alpha$$  \hspace{1cm} (4)

Take $m=m_1, m=m_2$ ($m_1, m_2, N(m_1), N(m_2)$ are all known) into the above formula (4)

$$\left( \frac{\ln N_0}{\ln N(m_1)} \right)^{1/\lambda} = \frac{N_0 m_1}{M} \alpha$$

And then get

$$\lambda = \frac{1}{\log_{\frac{\ln N_0}{\ln N(m_1)}} \left( \frac{m_1}{m_2} \right)}$$  \hspace{1cm} (5)

It can be obtained from formula (4)

$$\alpha = \frac{M}{N_0 m} \left( \frac{\ln N_0}{\ln N(m)} \right)^{1/\lambda}$$  \hspace{1cm} (6)
By introducing formula (5) into formula (6), $\alpha$ can be obtained.

The $\mu$ can be obtained by bringing formula (6) into formula (3).

It can be seen from the above derivation process that the test data $M$ and $N(m)$ of a certain type of projectile are known, and $\alpha$, $\mu$ and $\lambda$ have been obtained according to Mott distribution model, and then the fragment number and mass distribution of the projectile are obtained.

In addition, according to the theoretical analysis and experimental summary, the number and mass distribution of fragments depend on the structure, material and properties of explosives. The specific influencing parameters include: shell mass, shell density, shell strength, shell outer diameter, shell inner diameter, explosive mass, explosive density, explosive velocity, etc. Then $\alpha$, $\mu$ and $\lambda$ can be obtained.

4. A calculation method of fragment number and mass distribution of blast-fragmentation warhead based on Neural Network

A method for calculating the number and mass distribution of fragments of blast-fragmentation warhead based on neural network includes the following steps:

![Figure 1. Brief flow chart](attachment:image.png)
Step 1. For a certain type of bomb, before the explosion test, measure and record the structural material and other parameters of the projectile, specifically including: shell mass $M$, shell density $\rho_k$, shell strength $\sigma_k$, shell outer diameter $D_1$, shell inner diameter $D_2$, explosive mass $M_y$, explosive density $\rho_y$, and explosive detonation velocity $V_y$.

Step 2, after the explosion test, collect the fragments produced by each bomb, count and weigh the collected fragments to obtain the total number of fragments $N_0$. Select the typical weights $m_1$ and $m_2$, calculate the number $N(m_1)$ of fragments greater than $m_1$ and the number $N(m_2)$ of fragments greater than $m_2$.

Step 3, at this time, a group of parameters such as $M$, $N_0$, $m_1$, $m_2$, $N(m_1)$, $N(m_2)$ of a group of projectiles are known. According to the above derivation process formula, $\alpha$, $\mu$, $\lambda$ can be calculated, and then the fragment number and mass distribution of the projectile can be obtained from the Mott distribution model.

Step 4, take 8 parameters of step 1 as input and 3 parameters ($\alpha$, $\mu$, $\lambda$) of step 3 as output to obtain a set of sample data for neural network training and testing;

Step 5: repeat the above steps 1 to 4 to obtain several groups of data;

Step 6: build a BP neural network including an input layer, a hidden layer and an output layer, the input layer node is 8, the output layer node is 3, 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 0.01.

Step 7, use the data from step 5 to train the neural network constructed in step 6 until the end;

Step 8, the neural network trained in step 7 can be used to predict the same kind of ammunition. The specific process is as follows: the input is 8 parameters in step 1, and the output is $\alpha$, $\mu$, $\lambda$ and other three parameters. The Mott distribution model is used to calculate the number of fragments and the mass distribution.

This method combines Mott distribution model with BP neural network. In the above steps, except 8 inputs and 3 outputs in step 4 are fixed, other parameters, including hidden layer number, hidden layer node, weight, bias and setting error of BP neural network, can be adjusted according to the actual situation.

5. Conclusion

In this paper, a method of calculating the fragment number and mass distribution of explosive warhead based on neural network is proposed. The Mott distribution model, the derivation process of the model and the specific steps of the method are introduced. Based on this method, the fragment number and mass distribution of explosive warhead can be calculated relatively accurately and quickly.

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 Shuqiang. Reconstruction and Redevelopment of Prediction Software for Projectile Fragment Quality and Quantity Distribution. Journal of Projectiles, Rockets, Missiles and Guidance. 2019, 39(6)