Study on the Influence of Explosive Types on Rod Jet

Bingzhe Wang¹, Liyun Xie¹, Zhounan Guo¹

¹The 713th Research Institute of China Shipbuilding Industry Corporation, Zhengzhou Henan 450015, China

a WANG Bing-zhe: wangbingzheart@163.com

Abstract: In order to study the influence of explosive type on the rod jet formation of energetic composite liner, the process of rod jet formation of this liner is numerically simulated by using finite element analysis and multi-material Euler algorithm. In this paper, the rod jet formation and penetration performance of the liner are studied and analyzed by combining relevant theories and simulation calculation, and the influence law of explosive type on rod jet formation and target penetration thickness is obtained. In this paper, the stability of rod jet formed by this kind of model is verified by numerical simulation, and the influence law of explosive type on rod jet is obtained by simulating the collected data such as effective mass, tip velocity and jet length of rod jet and the equivalent target penetration thickness obtained by the quasi steady incompressible ideal fluid theory of jet penetration; it provides data support and design basis for the application of new explosives in energetic composite liner in the next stage.

1. Introduction

At present, the development trend of modern armor protection means is to increase the flight distance of the penetrator, make the armor breaking warhead lose the favorable explosion height, and even detonate the warhead in advance through the active defense system, to achieve the goal of protecting the key parts. Although, the penetration performance of EFP, is less affected by explosion height, its development potential is limited by aerodynamic stability. Because the aerodynamic shape of the penetrator does not need to be considered under the condition of medium near explosion height, people began to study how to control the velocity distribution and mass distribution of shaped charge penetrator under this condition, so as to achieve the best damage effect according to the needs of target characteristics. The formation mechanism of rod jet is between shaped charge jet and EFP, which can become a bridge for the mutual transformation of the two munitions, so as to give full play to their different advantages.

The factors affecting the rod jet forming involve the cone angle, wall thickness, material, charge type, charge height and so on. A lot of research has also been carried out on the rod jet forming of multi-layer charge liner. By studying the influence of wall thickness of single-layer liner on rod jet forming, Liu Jianfeng analyzed the jet forming mechanism of double-layer liner [1]; According to the typical structure of the liner, Yi Jianya analyzed the influence of liner material on the forming of rod jet [2]; He Haimin simulated and analyzed the process of rod jet formation from the perspectives of explosive performance, initiation mode and liner wall thickness [3]; Long yuan, Yang Dazhao and Dou Chengbiao studied the rod jet forming and damage mechanism of multilayer liner from multiple influencing factors [4-6].

In this paper, the Euler algorithm is used to simulate the rod jet, and the numerical simulation method is used to study the influence of explosive type on the damage indexes such as effective mass, tip velocity...
and penetration thickness of rod jet, to obtain the influence law of explosive type on rod jet, and provide data support for the later simulation analysis of multilayer liner.

2. Principle Analysis

2.1 Formation principle of rod jet

After the initiation click is fired, the shaped charge is ignited, the generated detonation wave acts on the metal liner, the extruded liner converges to the center at a great speed, and finally converges into a continuous high-speed metal jet under the action of collision high pressure.

Dependent on the different end-point effects, the formed metal jet can be divided into three damage forms: rod jet, metal jet and explosively formed projectile. Among them, rod jet has been studied a lot because it combines the advantages of the other two damage forms. Rod jet has the highest damage efficiency, but its shape maintenance is also the most difficult. It is necessary to comprehensively consider the factors such as liner structure, charge and explosion height. In this paper, the theoretical calculation is based on the quasi steady incompressible ideal fluid theory formed by metal jet, and the scheme design and simulation research are carried out by comprehensively considering the rod jet forming simulation of traditional liner.

2.2 Theoretical calculation of jet penetration

At first, the target plate is in a static state, and the impact stress caused by jet impact on the target plate is also the largest. Considering the unloading effect on the positive surface of the target plate, the material fluidity of the target plate at the initial stage is very large, and the process is unsteady, but the penetration depth of the initial target plate accounts for the smallest proportion in the whole penetration process. The purpose of this simulation study is to compare the effects of different explosive types on the penetration depth of rod jet, so the whole penetration process is regarded as the dynamic flow of quasi steady ideal fluid for solution and analysis.

Based on the quasi steady incompressible ideal fluid theory of jet penetration, the calculation formula of the maximum armor breaking depth of the model is obtained

$$L = (H - b)[(\frac{\rho_i}{\rho_j})^\frac{n}{2} - 1]$$  \hspace{1cm} (1)

Where $L$—armor breaking depth, mm;
$H$—blasting height of liner, mm;
$b$—quasi steady coefficient of material, mm;
$\nu_j$—jet tip velocity, m/s;
$\nu_{jc}$—critical penetration velocity, m/s;
$\rho_j$—jet density, g/cm$^3$;
$\rho_i$—target plate density, g/cm$^3$.

3. Model Establishment

3.1 Geometric model

In this paper, the liner structure model shown in Figure 1 is adopted, in which the liner cone angle is 100 °, the liner wall thickness is 2 mm and the charge height is 120 mm.
3.2 Material model
In the numerical simulation of the rod jet with spherical sub spherical liner, three material models of charge, liner and air are involved. The liner material is copper and the charge type is explosive 8701 and explosive B respectively.

The liner material is copper, and the selected material model is STEINBERG. This material model takes the thermodynamic factors into account, such as melting energy, melting temperature and cold pressing energy of metal substances at ultra-high temperature, and the equation of state is GRUNEISEN. The equation describes the dynamic response of the liner under the action of detonation wave.

The material model selected for air is blank, and the equation of state is EOS\_GRUNEISEN.

4. Simulation Analysis

4.1 Scheme design
The explosive type is changed without changing the shape and structural parameters of the liner. The parameter values of each scheme are shown in Table 1, and the simulation analysis is carried out according to the scheme design.

| Parameter/factor       | Program | Program |
|------------------------|---------|---------|
|                        | 1       | 2       |
| Charge height H/mm     | 120     | 120     |
| Charge type            | 8701 explosive | B explosive |
| Cone angle α/°         | 100     | 100     |
| Wall thickness B/mm     | 2       | 2       |

4.2 Process simulation
When the charge quantity and other shape parameters of the liner are the same, the different charge types lead to great differences in the performance of rod jet. In order to study the influence of charge type on rod jet forming, two charge types of 8701 explosive and B explosive are selected for numerical simulation. Fig. 2 shows the penetration state of rod jet at initial state, 0 ms, 27 ms, 43 ms, 52 ms and 61 ms under different charge types.
Through the process simulation, it can be found that on the premise of ensuring the shape and structure of the liner, adjusting the charge type can ensure the formation of the rod jet, and the necking and fracture of the jet will not occur prematurely. The simulation data can effectively analyze the influence law of the charge type on the rod jet.

4.3 Data analysis

The thickness and length of jet penetrating target are important indexes of rod jet damage ability. It is necessary to analyze the effective mass, tip velocity and jet length of jet from the simulation results. Figure 3 shows the effective mass of rod jet formed by sub spherical liner with different spherical defect height.
In this paper, No.45 steel target is used as the jet penetration target, the target material density is 7.806g/cm³, and the critical penetration velocity is 2090m/s; The liner material is red copper, the material density is 8.906 g/cm³, the blasting height of liner is 164 mm, and the material quasi steady coefficient is -6 mm. Based on the above numerical simulation, the equivalent target thickness that can be penetrated by rod jet generated by different charge types under the same liner shape structure can be obtained from the quasi steady incompressible ideal fluid theory of jet penetration.

According to the analysis of Formula (1) and simulation data, the power indexes of rod jet armor breaking produced by different charge types are shown in Table 2.

| Power index                        | Program | 1  | 2  |
|------------------------------------|---------|----|----|
| Effective mass m/10³mg             | 22.3    | 21.2|
| Total mass M/10⁵mg                 | 2       |    |    |
| Effective mass percentage p/%      | 11.15   | 12.5|
| Tip velocity v/10²m·s⁻¹            | 4.4142  | 4.3533|
| Jet length l/mm                    | 168.5   | 206 |
| Penetration thickness d/mm         | 179.4   | 219 |

It can be found from Table 2 that the effective mass percentage and penetration depth of explosive B are significantly higher than those of explosive 8701; However, the rod jet velocity is low when filling explosive B. Overall, the armor breaking power is better when explosive B is loaded.

5. Conclusion
In this paper, the research on the type of charge provides a lot of data support for the formation of rod jet in the liner, and accumulates the research foundation for the application of this kind of model to multi-layer liner. Although the rod jet velocity when filling 8701 explosive is slightly higher than that of explosive group B, the effective mass percentage and penetration depth when filling B explosive are significantly higher than those when filling 8701 explosive. When filling B explosive, the armor breaking power is better, and the rod jet necking fracture problem did not often occur. It is suggested to add more charge types in the later stage in order to study the charge liner formed rod jet formation systematically.

Reference
[1] Liu Jianfeng; Longyuan; Ji Chong; Zhou Hui; Jiang Zhenhua. Study on the forming law of coaxial EFP affected by different liner wall thickness combinations [J]. Engineering blasting, 2012, v.18; No.70,13-17.
[2] Ijaya; Wang Zhijun; Yin Jianping; Xu Yongjie. Numerical simulation study on the effect of different...
liner materials on the property energy of K charge [J]. Weapon material science and engineering, 2016, v.39; No.278,38-42.

[3] He Haimin, Wang Lixia, Sun Jian, Gu Hongping, Liu Fengwang. Numerical simulation and experimental study on the formation of rod jet in molybdenum liner [J]. Explosion and impact, 2013, s1:28-33

[4] Longyuan; Liu Jianfeng; Ji Chong; Zhong mingshou; Liu Ying; Zhou Hui. Numerical simulation of multi-point initiation on the forming and penetration characteristics of explosive formed projectile with double liner [J]. Journal of ordnance industry, 2016, v.37; No.237,52-60.

[5] Yang Dazhao; Chen Zhigang; Fu Jianping; Fan Xiaojie. Simulation study on composite jet formed by variable wall thickness double-layer liner [J]. Science, technology and engineering, 2016, v.16; No.396,208-212.

[6] Dou Chengbiao; Yin Jianping; Xu Quanzhen; Sun Jiaxiao; Tang Qi. Numerical simulation of EFP in series formed by sub caliber three-layer spherical powder lack liner [J]. Journal of Ordnance Equipment Engineering, 2017, v.38; No.225,69-73.

[7] Ijaya; Yin Jianping; Wang Zhijun; Ma Likang. Study on the characteristics of rod jet formed by eccentric sub hemispherical molybdenum liner [J]. Weapon material science and engineering, 2015, v.38; No.269,59-63.

[8] Liu Runzi. Technical research on energetic composite liner [C]. Zhongbei University, 2016

[9] Zhang Guowei. Endpoint effect and its application technology. Beijing: National Defense Industry Press, 2005

[10] Sui Shuyuan, Wang Shushan. Endpoint effect. Beijing: National Defense Industry Press, 2000