The Penetration Performance Research of Arrow Shaft Warhead Damage Element

Yachao Guo[1, a], Guanglin He[1, b] and Jiashuo Zhang[1, c]

[1]School of Mechatronical Engineering, Beijing Institute of Technology, Beijing 100081, China.

[a]xingchenchao110@163.com, [b]heguanglin@bit.edu.cn, [c]644699667@qq.com

Abstract: To deal with soldiers who are wearing the bulletproof helmet and bulletproof clothe on the modern battlefield, the design idea of the individual small caliber projectile using arrow shaft warhead damage element is put forward, and three different structures of arrow shaft type damage element are designed. The penetration performance of arrow shaft warhead damage element is calculated and analyzed through using DeMar penetration theory and the limiting penetration velocity theory of spherical fragment penetrating target plate. The results show that the arrow shaft warhead damage element penetration ability is far greater than the spherical fragment. When the diameter of the arrow shaft type damage element of homogeneous steel material is 2.5mm, the initial target velocity not be less than 336m/s. When the diameter of arrow shaft type damage element of combination of steel and aluminum materials is 2.8mm, the initial target velocity not be less than 410m/s.

Keywords: Individual small caliber projectile, Arrow shaft warhead, Limiting penetration velocity, The penetration performance.

1. Introduction

Shotgun weapons of cluster submunition technology as the core play an important role in assault encounters,jungle warfare and other melee in CIWS [1,2,3]. Every shot can throw many submunitions, so this weapon can effectively increase the probability of hitting the target in per unit area. Commonly used submunition types are spherical and arrow shaft shaped. For example, in the United States Olin CIWS [4,5], shotgun weapon can be equipped with 8 pieces of tungsten alloy spherical submunition or 20 pieces of small flechette of tail stable. China has developed cluster flechette with 7 pieces of tungsten steel composite flechette of tail stable [2]. For soldiers wear the bulletproof helmet and bulletproof clothe on the modern battlefield, how to realize the individual small caliber projectile effectively intensive killing such personnel is the key in a limited battlefield environment. In view of this, this paper designed three kinds of different structure of arrow shaft type damage element. The study found that arrow shaft type damage element has better penetration performance than spherical submunition, and the killing and penetrating effect is more outstanding.

2. The structure scheme of arrow shaft warhead damage element

Many arrow shaft warheads are arranged in the sabot of projectile. When the ammunition is fired, arrow shaft warheads fly with the projectile in the air. After the projectile flies in the air for a distance, it opens by precise timing and throwing out cluster arrow shaft to obtain accurate and efficient damage. Three different structure schemes of arrow shaft type damage element are designed with the basis of arrow shaft size and exterior ballistic characteristic as shown in figure 1.

Fig. 1 The structure scheme of arrow shaft warhead

The design of scheme 1 and scheme 3 are arrow shaft type damage element of combination of steel and aluminum materials. The arrow shaft diameter of this two schemes are 2.8mm; however, tails of this two scheme are different. Though the tails of scheme 2 and scheme 3 are same, the arrow shaft diameter of scheme 2 of homogeneous steel material is 2.5mm. The joint of the tail and arrow shaft of scheme 3 is connected by approximate smooth arc.

3. The penetration model of arrow shaft warhead damage element

With the basis of operational requirements and the structure scheme of arrow shaft warhead, the penetration performance of arrow shaft warhead damage element is calculated and analyzed by using DeMar penetration theory. In addition, the penetration performance of spherical fragment is calculated and analyzed through using the limiting penetration velocity theory of spherical fragment penetrating target plate.

3.1 DeMar penetration theory

DeMar formula [6] as follows :

$$b = \frac{V_c^{1.43} m^{0.715} \cos\alpha}{K^{1.43} d^{1.07}} \quad (1)$$

where V_c is the initial target velocity(m/s); m is the quality of arrow shaft (Kg); d is the diameter of arrow shaft (dm); α is angle of arrow penetration(rad/s); b is the penetrate thickness(dm)and K is penetrate composite coefficient.

3.2 The limiting penetration velocity theory of spherical fragment penetrating target plate

In this theory [7], all thermal effects are ignored during penetration. Spherical fragment is made of steel material without influence of deformation. The physical equation of the penetration process is obtained by dimensional analysis as follows:

$$\frac{\rho_p^{\ 0.5} \bullet V_j}{\sigma_t^{\ 0.6}} = a \bullet \left(\frac{h}{d}\right)^b \bullet \left(\frac{\rho_t}{\rho_p}\right)^c \qquad (2)$$

Where a, b and c are undetermined constant coefficients.

$$\lambda_1 = \frac{\rho_p^{\ 0.5} \bullet V_j}{\sigma_t^{\ 0.5}}, \lambda_2 = \frac{h}{d}, \lambda_3 = \frac{\rho_t}{\rho_p} \qquad (3)$$

Both sides of the formula (2) are processed with the logarithm as follows:

$$\ln \lambda_1 = \ln a + b \ln \lambda_2 + c \ln \lambda_3 \qquad (4)$$

$$Y = \ln \lambda_1, A = \ln a, X_1 = \ln \lambda_2, X_2 = \ln \lambda_3 \qquad (5)$$

The formula (4) is replaced with formula (5) as follows:

$$Y = A + bX_1 + cX_2 \qquad (6)$$

With the basis of the test datas and the penetration parameters, the limiting penetration velocity formula of spherical fragment penetrating target plate is obtained by making use of theory of multiple linear regression as follows:

$$V_j = a \bullet \left(\frac{h}{d_1}\right)^b \bullet \frac{\rho_t^{\ 0.3}}{\rho_p^{\ 0.8}} \bullet \sigma_t^{\ 0.5} \qquad (7)$$

where d_1 is the diameter of the spherical fragment (m); ρ_p is the density of fragment material (Kg/m^3); V_j is the fragment velocity; h is the thickness of the target plate (m); ρ_t is the density of the target plate; σ_t is the limiting strength of the target plate; a is 4.62 and b is 0.71.

4. Comparative analysis of penetration performance between arrow shaft warheads and spherical submunition

With the basis of the DeMar penetration theory and The limiting penetration velocity theory of spherical fragment penetrating target plate, the parameters of penetration calculation are based on the parameters of the structure and the parameters of exterior ballistic. The spherical submunition choose the 00 deer submunition, and the penetrate target plate choose the plate of low carbon steel. The penetration performance of the arrow shaft warheads and the 00 deer submunition are calculated and Comparative analysis.

Many submunitions are arranged in the projectile. Every submunition has different penetration performance because every submunition has a different distance from the projectile axis. The limiting penetration thickness of the plate of low carbon steel is calculated at the distance r=6mm and r=12mm. The limit penetration thickness of the low carbon steel plate at different initial target velocity velocity and angle is calculated as shown in table 1. $V_0 = V_c = V_j$, $\alpha_0 = \alpha$.

Table 1 The limiting penetration thickness of the plate of low carbon steelt at different initial target velocity and angle(mm)

Scheme \ Radial distance \ Initial target velocity			221m/s (α_0=4.6°)	213m/s (α_0=4.7°)	191m/s (α_0=5.3°)
The arrow shaft warhead	Scheme 1	r=12mm	2.4874	2.3514	2.0200
		r=6mm	2.4935	2.3574	2.0263
	Scheme 2	r=12mm	3.3620	3.1781	2.7308
		r=6mm	3.3686	3.1848	2.7381
	Scheme 3	r=12mm	2.4874	2.3514	2.0206
		r=6mm	2.4934	2.3573	2.0266
The 00 deer submuni-tion	Scheme 1	r=12mm	1.2210	1.1651	1.0265
		r=6mm	1.2239	1.1680	1.0297
	Scheme 2	r=12mm	1.2213	1.1654	1.0270
		r=6mm	1.2237	1.1679	1.0298
	Scheme 3	r=12mm	1.2209	1.1651	1.0268
		r=6mm	1.2239	1.1680	1.0299

The data in Table 1 are summarized as follows:

1)When the scheme and radial distance have same value, the limiting penetration thickness of the arrow shaft warheads and the 00 deer submunition is decreasing trend with decreasing the initial target velocity or increasing the angle. The limiting penetration thickness of the two kinds of damage element increases slightly with the decrease of the radial distance at the same scheme and the initial target velocity.

2)The limiting penetration thickness of scheme 2 is significantly higher than that of scheme 1 and scheme 3 at the same initial target velocity in schemes of the arrow shaft warhead. That is to say, the damage ability of the arrow shaft warhead of homogeneous steel material is better than that of combination of steel and aluminum materials. The penetration ability of scheme 1 and scheme 3 is almost the same when the penetration parameters are the same.

3)The damage effect of the arrow shaft warhead obviously better than that of the 00 deer submunition at the same scheme and the initial target velocity. The penetration ability of the 00 deer submunition is almost the same when the penetration parameters are the same.

5. Analysis of penetration performance of the arrow shaft warhead to the bulletproof helmet and bulletproof clothe

The designs **of** bulletproof equipment almost use the American NIJ standard [8,9]. It includes grade 6, grade I,grade II_A,grade II,grade III_A,grade IIIand grade IV. The level of PASGT [10] and IBA [11] are grade III_A in the U.S. military equipment. The variation range of the limiting penetration thickness is calculated at different initial target velocity and angle through using DeMar penetration theory as shown in figure 2. The angles have 0°,2°,4°,6°,8°,10°,and the initial target velocity is from 200m/s～500m/s(Interval is 50m/s).

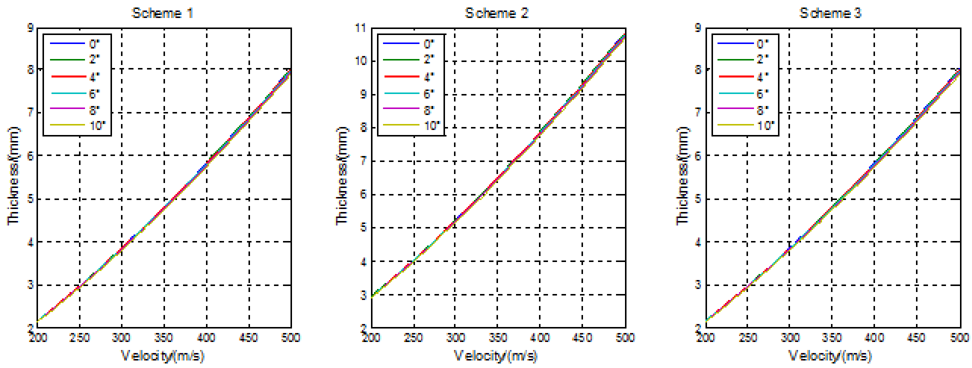

Fig. 2 The variation of the limiting penetration thickness at different initial target velocity and angle

The equivalent thickness of limiting penetrating the plate of low carbon steel is calculated in the three different structures of arrow shaft type damage element under the condition of parabellum 9mm pistol cartridge as shown in table 2.

Table 2 The Equivalent thickness requirement for limiting penetrating the plate of low carbon steel and minimum initial target velocity requirement

Category / Level	The equivalent thickness(mm)	The minimum velocity of scheme 2 (m/s)	The minimum velocity of scheme 1 or scheme 3 (m/s)
IIIA	6	336	410
II	4.7	281	345
II A	4.2	259	321

It is observed in figure 2 and table 2 that the limiting penetration thickness of this three schemes of arrow shaft warhead are the linear proportion increases with the increase of the initial target velocity. However, the maximum penetration thickness of the three schemes have little change with the change of angle. When the level is grade $III_{A,}$ grade II and grade II_{A}, the equivalent thickness of limiting penetrating the plate of low carbon steel is 6mm, 4.7mm and 4.2mm. The minimum initial target velocity requirement of the scheme 2 is about 336m/s, 281m/s and 259m/s.The minimum initial target velocity requirement of the scheme 1 and scheme 3 is about 410m/s, 345m/s and 321m/s because this two schemes almost have the same damage effect.

6. Conclusions

The design of the arrow shaft warhead is aimed at the soldiers who are wearing the bulletproof helmet and bulletproof clothe. The structure scheme of the individual small caliber projectile is put forward and designed on the basis of the design idea of modern cluster munitions.

1)The three kinds of structure schemes of the arrow shaft warhead and the spherical 00 deer submunition are designed and analyzed with the DeMar penetration theory and the limiting penetration velocity theory of spherical fragment penetrating target plate. The results show that the penetration ability of the arrow shaft warhead was significantly greater than that of spherical 00 deer submunition at the same initial conditions. The damage ability of the arrow shaft warhead of homogeneous steel material (scheme 2) is better than that of combination of steel and aluminum materials (scheme 1 or scheme 3). Although the diameter of arrow shaft of scheme 1 and scheme 3 is different, its damage ability is almost the same.

2)The limiting penetration thickness of the arrow shaft warhead is calculated at different initial target velocity by using DeMar penetration theory. The results show that the limiting penetration thickness increases with the increase of the initial target velocity, but it changes little with the change of angle. Most of the bulletproof helmest and bulletproof clothes are grade $III_{A.}$ When the level of bulletproof standard is grade III_A, the equivalent thickness of limiting penetrating the plate of low carbon steel is 6mm, The minimum initial target velocity requirement of the arrow shaft warhead of homogeneous steel material(scheme 2) is 336m/s. The minimum initial target velocity requirement of the arrow shaft warhead of combination of steel and aluminum materials(scheme 1 or scheme 3) is 410m/s.

References

[1]Chen Peiqi. Development status and future outlook of the infantry "iron broom" domestic shotgun [J]. Modern Weaponry, 2010, (06): 16-19.
[2]Lin Maoxiang. Cluster arrows projectile and shotguns [J]. Small Arms, 1995, (05): 11-12.
[3]Chen Shengzheng, Gao Hongchao, He Qinghua, Bai Fengke, Wang Keqin. Research on the probability of combat damage of the cluster arrows projectile against the helicopter [J]. Journal of Projectiles, Rockets, Missiles and Guidance, 2014, (03): 99-101 +105.
[4]King of Jungle War: "Olin" shotgun [N]. World Newspaper, 2006-05-10 (014).
[5]Chen Siquan. The study on key techniques of a sub caliber shotgun[D]. Nanjing University of Science and Technology.
[6]Wang Fengying. Damage theory and technology [M]. Beijing Institute of Technology Press, 2009.
[7]Huang Changqiang,ZHU Hesong. Ballistic limit velocity expressions for sphe rical fragment penetrated through target plates [J]. Journal of Projectiles, Rocke ts, Missiles and Guidance, 1993, (02): 58-61.
[8]National Institute of Justice.Ballistic resistance of body Armor NIJ Standard-0101.06 [S].US: National Institute of Standards Technology, 2008.
[9]Li Changsheng, Huang Xiancong, Li Yan, Wang Lei, Li Maohui, Zhou Hon g. Analysis of penetration probability of soft body bulletproof clothe [J]. Act a Armamentarii, 2013, (01): 20-24.
[10]Zhou Hong, Chen Xiao. Helmet-shaped design research of the modern military bulletproof helmet [J]. China Personal Protective Equipment, 2009, (05): 10-13.
[11]Chen Lei, invulnerable "IBA" bulletproof clothe [J]. Modern Weaponry, 2000, (07): 24.