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The Initiation Parameter of Detonation Wave Aiming Warhead

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Abstract: To optimize the performance of the detonation wave aiming warhead, the different forms of asymmetrical initiations were studied. The fluid dynamic simulation model verified by experiment was used to research the effects of asymmetrical one initiation line with different initiation points, asymmetrical two initiation lines with different central angles, and the asymmetrical three initiation lines with different central angles of the adjacent lines on warhead fragment velocity and scattering. The results show that for the researched object, 4 initiation points are adequate in one initiation line; in the asymmetrical two lines initiation, the central angle of 60° may produce the highest velocity enhancement 38.37% in the aiming direction side, so do the asymmetrical three initiation lines with central angle of 45°, with an enhancement of 39.36%. The velocity enhancement of the fragments in the aiming direction is the interacting results of detonation transfer length (time) and the detonation pressure.

Key words: aiming warhead; multi-point initiation; asymmetrical initiation

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1 Introduction

Asymmetrical initiation is an important way to enhance the warhead lethality, and it makes sense to study the layout parameters of the initiation. Resnyansky A. et al[1] conducted simulation and experiment study about the influences of the detonation travel length and initiator number on the fragments velocity. Influence of different initiation ways on the enhancements of fragment density, velocity and kinetic energy were numerically modeled by QU Ming et al[2], and the involved initiation types include asymmetrical one initiation point, asymmetrical one initiation line, asymmetrical two initiation lines with central angle of 45° and 90°, and asymmetrical three initiation lines with each central angle of 45°. ZHANG Xin-wei et al[3] tested the rod velocity and density enhancement in the aiming direction under asymmetrical two lines initiation, and the different central angles between the two initiation points were studied. ZHU Xu-qiang et al[4] introduced a practical formula for calculation of the fragment velocity under asymmetrical initiation. Before a widely acceptable formula for calculating fragment velocity is appeared, the above mentioned studies are necessary. But these studies are not thorough enough and the rules behand the fragment velocity enhancements are not toughed. Limited by the experiment condition, there are rare reports on the systematical research of initiation layouts and initiation parameters of the detonation wave aiming warhead. Therefore in this paper, a systematical study regarding the different asymmetrical initiation types, different initiator number and different central angles between initiation lines were carried out using the numerical modeling method.

The numerical model was first verified by the experiment data and then used to study the different initiation types and parameters affecting the fragment's damage capability. The fragments velocities under different initiation types were obtained, the velocity enhancements in the aiming direction were compared and the optimal initiation types were selected. The rules underlying the enhancement results were also investigated. The study results could be a good reference to the initiation style selection of the detonation aiming warhead.

2 Warhead Experiment

The warhead structure and test data are referred to Ref.[5]. The warhead structure is cylindrical, as shown in Fig.1. It is composed of HMX main charge, 1020 steel cubic fragment, 6061-T4 aluminum shell, and 2024-T3 end plate. The charge diameter is 126 mm, ratio of length to diameter of the charge is 2, and the cubic fragment size is 8 mm.

As shown in the Fig.1, the warhead is one point initiated at the end face centre in the experiment. During the experiment, shown in Fig. 2, the warhead is placed behind the

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shield panel which has an aperture, which allows only one column fragments passing throught. Two X flash cameras are arranged on the other side of the shield panel to record the fragments position at distinct time. Then the fragments velocity and ejecting angle could be determined by the processing of X films.

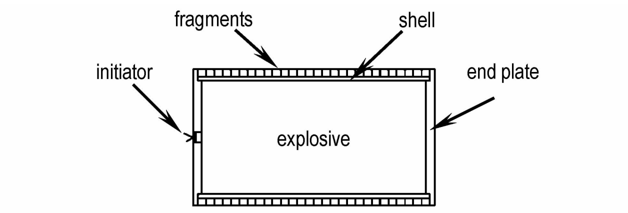


Fig. 1 Warhead structure

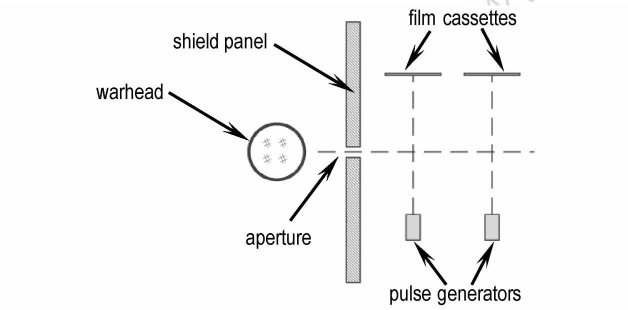


Fig. 2 Experiment layout

3 Numerical Modeling

The numerical modeling of fragmentation warhead has been researched a lot, involving different warhead styles like focusing fragmentation warhead, multi-layer fragmentation warhead, rod warhead etc. Because the physical detonation process includes the detonation product's extreme expansion and its complicated interacting with the fragments, ALE multi-material Lagrange Euler coupling algorithm is usually selected in the numerical modeling[6-8].

3.1 Model Setup

TrueGrid software[9] is chosen to set up the element model of the warhead, as shown in Fig. 3. For the convenience of the later research of different asymmetrical initiations, the whole element model is used. The explosive and the air domain are meshed as Euler grid, and the shell, fragment, and endplates are meshed as Lagrange grid. In order to guarantee the right interaction of Lagrange and Euler mesh and seek a balance between the computer time and simulating accuracy, different element sizes are tested and the eventually Euler and Lagrange element size is selected to be 0.25 mm. The whole model contains 1842216 elements.

The keyword CONSTRAIND_LAGRANGE_IN_SOLID is used to define the interaction between the Euler and Lagrange mesh. The non-reflection boundary condition is attached to the air boundary, and the bulk viscosity control and hourglass control are used. The explosive is modeled by MAT_HIGH_EXPLOSIVE_BURN and JWL equation of state. The air is described by MAT_NULL and LINEAR equation of state. The shell and end plates are modeled by MAT_PLASTIC_KINEMATIC[10]. Study shows that the fragment shape changes not relatively during the detonation propellant, especially in the case of existing inner shell[11], therefore, for the sake of saving computing time and convenience of post-processing, the fragments are modeled by rigid material model.

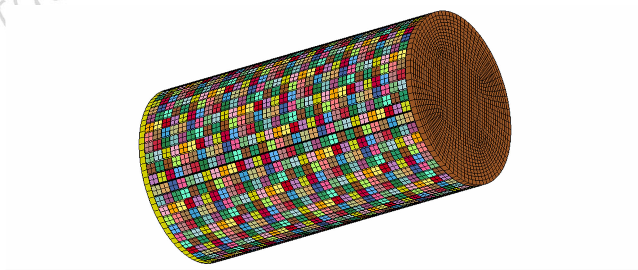
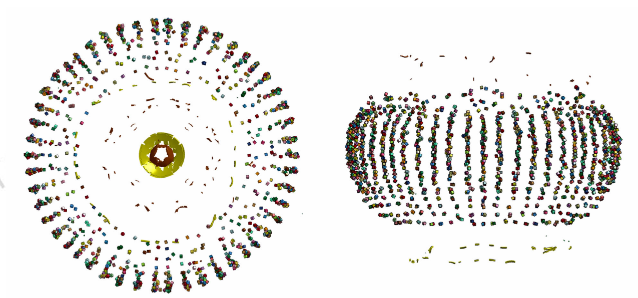


Fig. 3 Element model

3.2 Modeling Results and Verification

Fig. 4 is fragments dispersion pattern at 200 μs after initiated at the end face center. It can be seen that, under the initiation of end face center, the fragments fly uniformly around the warhead axis, and the pattern shaped like a barrel. Therefore, to study the dispersion and damage parameters of the warhead fragments, only one column fragments are actually needed to consider.



a. top view **b.** right view

Fig. 4 Fragments dispersion

The results ASCII files MATSUM and RBDOUTA are outputted. From the output files, a code is developed by C program language to extract the message of every fragment, including fragments velocity and dispersion angle. The fragment message at 100 μs is obtained by the code, and drawn in Fig. 5 and Fig. 6. There are also the corresponding test data from the experiment[4].

It can be seen from Fig. 5 and Fig. 6 that there is a good agreement between the numerical model and the experiment result. For the fragments velocity, near the initiation point, the modeling result is slightly lower than the test result, but slightly larger than the test result opposite the initiation point. The average value of the relative error of the fragments velocity is about 3.89%. The coincidence of the simulation result of the fragments dispersion angle with the test data is better than the fragments velocity.

The error of 3.89% may come from material model parameters errors, computing model error or the experimental test errors and so on. These errors can be reduced by refining the element size or using better material model, but taking all these errors into account, the error of 3.89% is very acceptable for engineering application. As a result, the numerical modeling algorithm, material models and parameters used in this simulation are regarded to be rational, and can be used as a basis for the following study.

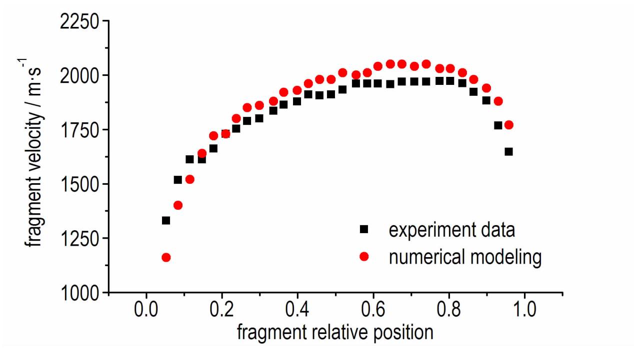


Fig. 5 Fragments velocity

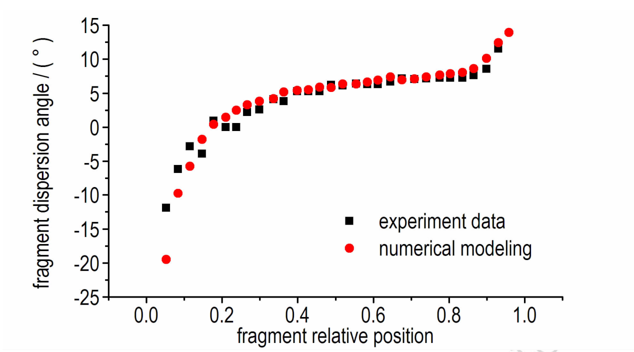


Fig. 6 Fragments dispersion angle

4 Asymmetrical One Line Initiations

With other parameters of the warhead kept the same, the initiation way is changed. As shown in Fig. 7, asymmetrical one line initiation is used. In order to study the effect of initiator number on the warhead, the 2 initiation points, 4 initiation points and 8 initiation points are adopted.

The typical fragments dispersion of asymmetrical one line initiation at 200 μs is shown in Fig. 8. The fragments distribute no longer circumferentially uniform, but look like an ellipsoid. The fragments velocity in the aiming direction (the direction opposite the initiation points) is obviously enhanced.

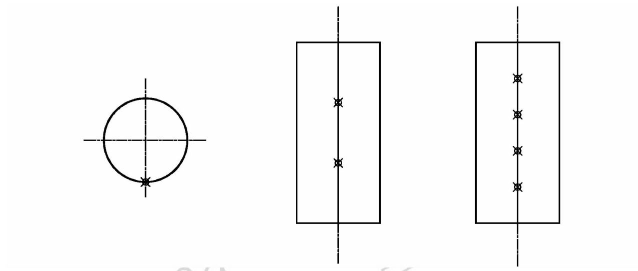
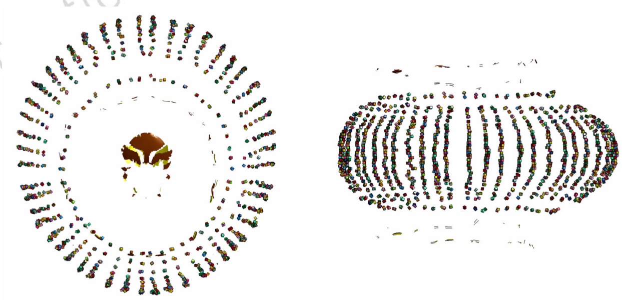


Fig. 7 Initiator layout of asymmetrical one line initiation



a. top view **b.** right view

Fig. 8 Typical fragments dispersion of asymmetrical one line initiation

As pictured in Fig. 9, the fragments round at the midpoint of the warhead length are considered. They are portion that affected least by the end rarefaction wave. Because they are plane symmetrical, only half of the fragments' velocities are extracted and plotted in Fig. 10.

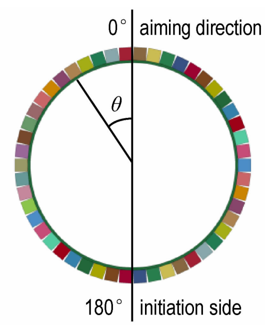


Fig. 9 Fragments round

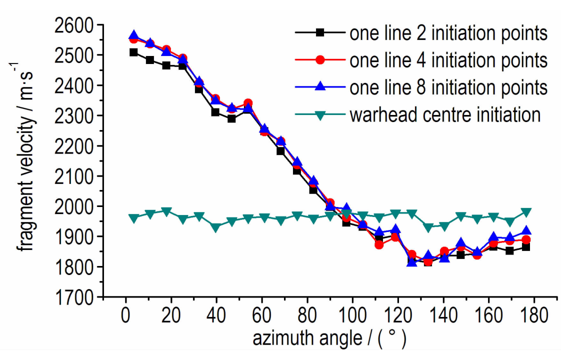


Fig. 10 Fragments velocity

In the Fig. 10, the fragment velocities versus azimuth angles under different initiation points are drawn. When the warhead is center initiated, the fragments velocity is almost equal and its average value is 1963.42 m · s^{-1}. When asymmetrical one line initiated, the fragments velocity is biggest in the aiming direction (azimuth angle is 0 degree). As the azimuth angle getting bigger, the fragments velocity decreases and equals to the velocity of the center initiation at 90° angle, then continues decreasing until the azimuth angle reaches about 120°. Finally the fragments velocity bounced back a little in the azimuth angle of 120° to 180°. The asymmetrical one line initiation increases the fragments velocity of the aiming direction, and lowers the fragments velocity of the initiation site.

The velocity enhancements in the aiming direction under the asymmetrical one line initiation of 2 points, 4 points and 8 points, relative to the warhead centre initiation, are 27.71%, 29.98% and 30.51% respectively. Compared to the asymmetrical one line 2 points initiation, the 4 points initiation increases the fragments velocity, obviously in the aiming direction. The influences of the asymmetrical one line 4 points and 8 points on the fragments velocity are almost equal. Taking together the velocity enhancement and the initiator cost, the asymmetrical 4 points initiation may be a better choice.

According to Resnyansky's research[1], why the asymmetrical one line initiation could increase the fragment velocity in the aiming direction is mainly because that the asymmetrical initiation elongates the distance between the initiation points and the fragments, and thus imposes more momentum on the fragments in the aiming direction.

5 Asymmetrical Two Lines Initiation

As a step further study of influence of the detonation wave collision on the fragments velocity, the warhead detonation initiated by asymmetrical two lines is numerical simulated. The initiation layout is shown in Fig. 11, and each initiation line contains 4 initiation points.

The central angle between the two initiation lines is β, which is assigned different value, as 30°, 45°, 60° and 90°. These angles correspond to aiming warheads with different aim sections, namely with different aiming resolutions.

The fragments dispersions of asymmetrical two lines initiations at 200 μs are shown in Fig. 12. Relative to the asymmetrical one line initiation, the fragment velocity in the aiming direction of the asymmetrical two lines initiation is much higher, leading to the fragment cloud becoming more flat.

The velocities of the mid-plane fragments are similarly extracted and plotted in Fig. 13. For the sake of comparison, the fragment velocity distribution of asymmetrical one line 4 points initiation is also drawn in Fig. 13.

From Fig. 13, the fragment velocity in the aiming direction under asymmetrical two lines initiation is higher than the asymmetrical one line initiation, which is caused by the detonation wave collision. And there are two key points need to pay attention to: in the azimuth angles of about 30° to 70°, fragment velocity decreases as the central angle of the two initiation lines getting bigger; in the azimuth angles of about 90° to 160°, fragment velocity increases as the central angle increases. The fragment velocity enhancement in the aiming direction relative to the warhead center initiation is calculated and listed in Table 1.

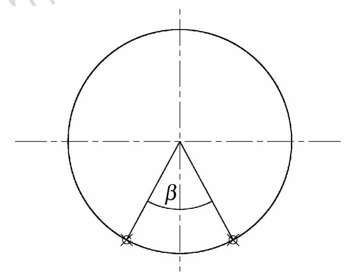


Fig. 11 Layout of two lines initiation

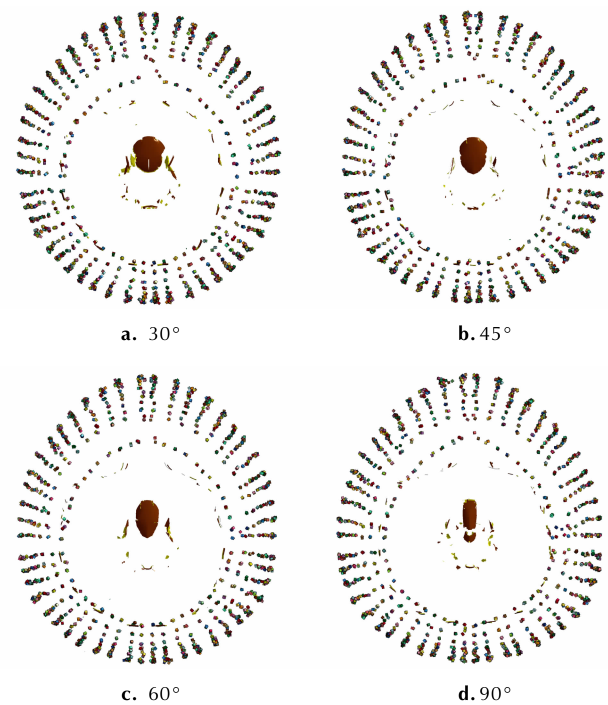


Fig. 12 Fragments dispersion of asymmetrical two lines initiation with different central angles (β)

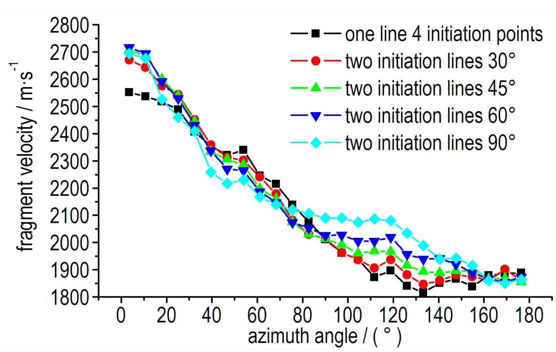


Fig. 13 Fragment velocity distribution along the azimuth angle

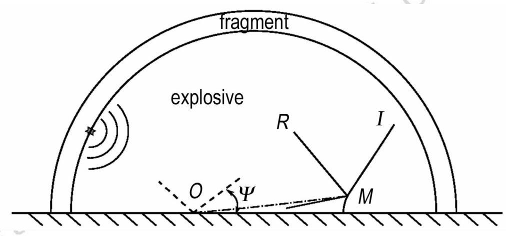
Table 1 Aiming fragment velocity enhancement of different initiation ways

asymmetrical initiation ways	one line	two lines			
		$\beta=30°$	$\beta=45°$	$\beta=60°$	$\beta=90°$
velocity enhancement/%	29.98	36.01	37.85	38.37	37.22

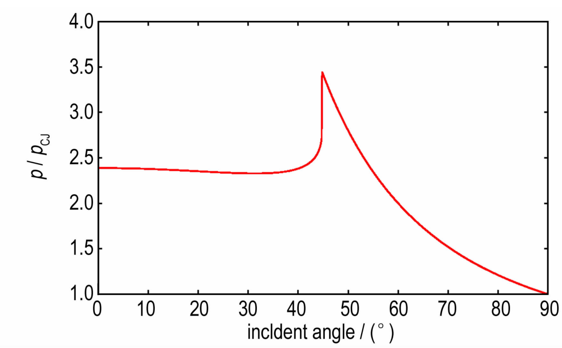
It can be seen from Table 1, in the central angle range of 30° to 60°, as the central angle increases the aiming fragment velocity enhancement increases. However, as the central angle reaches 90°, the fragment velocity enhancement falls down. Thus, the central angle of 60° will be a better choice if the asymmetrical two lines initiation is adopted.

Asymmetrical two lines initiation can produce much higher fragment velocity in aiming direction. In addition to the effects of the longer detonation transfer length, it is more important that the collision of the detonation waves from the two initiation lines generates higher detonation pressure, making the fragment velocity higher. As shown in Fig.14a, the problem of two detonation wave colliding can be considered as one detonation wave strikes the rigid surface. Along with the detonation wave propagating, the incident angle ψ of detonation wave against the rigid surface gets bigger and bigger. When ψ is below certain critical value, the reflection is regular reflection, otherwise Mach reflection is occurred. The starting point of Mach reflection is shown as the point O in Fig. 14a. The pressure ratio against the C—J detonation pressure of the reflecting point under regular reflection and Mach reflection is shown in Fig. 14b. When the adiabatic exponent of the charge is 3, the critical incident angle is about 44.8°.

As we can see from Fig. 14b, when the incident angle is under 44.8° (regular reflection), the shock pressure is about 2.37 times the p_{CJ}; while the incident angle is just above the 44.8 ° (Mach reflection), the pressure is about 3.45 times the p_{CJ}, and then decreases as the incident angle ψ increases. Therefore, the Mach stem pressure reduces with the distance from the starting point of the Mach waves. Increasing of the central angle between the two asymmetrical initiation lines will decrease the distance from the starting point of Mach reflection to the fragment, so the pressure on the fragment will be increased, and the fragment velocity will get bigger. However, as the increasing of the central angle, the distance from the initiation points to the fragments is reduced, that is the detonation propagating time is reduced, then the fragment velocity is going to decrease. Therefore, this is a problem of interaction of two aspects: pressure and time, also a problem of who dominates during the changing of the central angle. From the research, it can be seen that during the changing from 30° to 60°, the Mach wave pressure dominates, so the fragment velocity increases with the central angle; but at the central angle of about 90°, the detonation transfer length (time) dominates the contribution to the fragment velocity, hence the velocity enhancement decreases.



a. mach reflection of detonation wave



b. pressure ratio under Mach reflection

Fig. 14 Detonation wave reflection

6 Asymmetrical Three Lines Initiation

The configuration of asymmetrical three lines initiation is sketched in Fig. 15, with the central angle of adjacent initiation lines to be α. The α is taken different values of 30°, 45°, 60° and 90°. Typical fragment cloud under asymmetrical three lines initiation is like Fig. 16. It can be seen that except the section of aiming, the fragments distribute almost uniform along the circumferential direction.

Fig. 17 depicts the velocity of the mid-plane fragments. It shows that when the azimuth angle is small than 48°, the fragment velocity decreases as the central angle α gets bigger; when the azimuth angle is beyond 48°, the fragment velocity increases as the central angle increases. As the central angle getting bigger, the fragment velocity distribution tends to be uniform. There is almost no enhancement in the fragment velocity when the central angle becomes 90°.

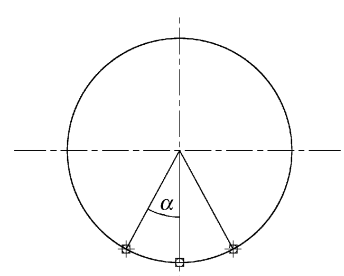


Fig. 15 Configuration of three initiation lines

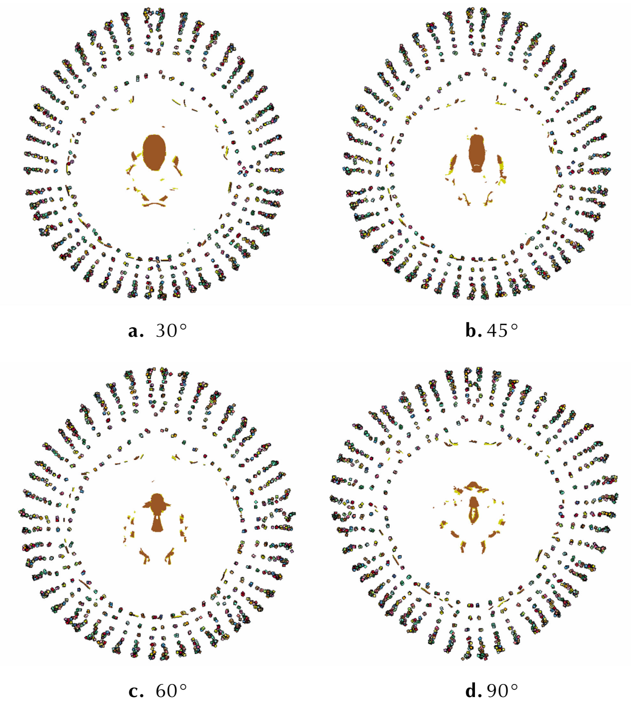


Fig.16 Fragments dispersion of asymmetrical three lines initiation with different central angle (α)

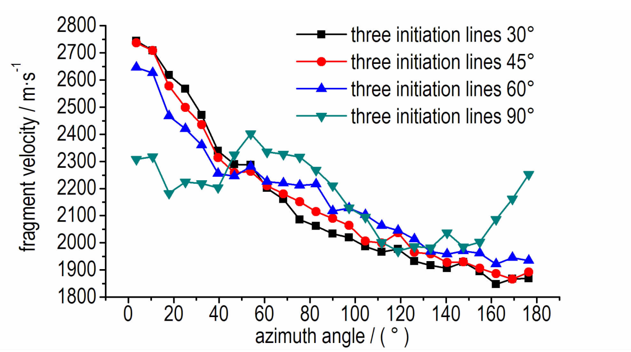


Fig.17 Fragment velocity distribution

The fragment velocity enhancements in the aiming direction relative to the warhead centre initiation under different asymmetrical three lines initiations are counted and listed in Table 2.

For the asymmetrical three lines initiation, the aiming fragment velocity decreases, from 39.73% to 17.54%, as the central angle α increasing. Compared to the asymmetrical two lines initiation of the same central angle, the 30° and 45° three lines initiations increase the aiming fragment velocity enhancements, while the 60° and 90° three lines initiations reduce the velocity enhancements. The aiming fragment velocity enhancement 17.54% of 90° three lines initiation is even lower than the velocity enhancement 29.98% of the asymmetrical one line initiation.

The detonation wave collision of the asymmetrical three lines initiation is more complicated, and the detonation pressure is much higher, thus the fragment velocities of three initiation lines are higher than the two initiation lines at central angle of 30° and 45°. But because of the same reason of the detonation transfer length, the continuing growth of the central angle will reduce the function time of the detonation wave, thus lower the momentum and velocity of the fragments. Anyway, the velocity enhancement in the aiming direction is the interacting result of the detonation pressure and the detonation transfer length (time).

Table 2 Aiming fragment velocity enhancement versus central angle

asymmetrical initiation ways	three lines $\alpha=30°$	$\alpha=45°$	$\alpha=60°$	$\alpha=90°$
velocity enhancement/%	39.73	39.36	34.74	17.54

7 Conclusions

(1) Asymmetrical one line initiation can obviously enhance the fragment velocity in the aiming direction, and the velocity enhancement increases with the initiation point number. When the initiation point number is more than 4, the fragment velocity enhancement increases slowly. Taking account of the cost, the proper initiation point number of an initiation line can be set to 4, and then the fragment velocity enhancement is 29.98%.

(2) When initiated by asymmetrical two lines, the fragment velocity enhancement increases from 36.01% to 38.37% as the central angle ranges from 30° to 60°. When the central angle is 90°, the velocity enhancement falls down to 37.22%.

(3) While initiated by asymmetrical three lines, the fragment velocity in the aiming direction falls from 39.73% to 17.54% with increasing the central angle. Compared to the same central angle but asymmetrical two initiation lines, the velocity enhancement is increased at angle of 30° and 45°, but reduces as the central angle continues to increase, even lower than the enhancement of the asymmetrical one initiation line.

(4) The velocity enhancement of the fragments in the aiming direction caused by asymmetrical initiation is the interacting results of function time increase caused by detonation transfer length and the pressure increase caused by detonation wave collision. Only when the two factors are both constructive, the velocity enhancement of the fragments can reach the most.

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爆轰波定向战斗部起爆参数研究

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摘　要: 为了优化爆轰波定向战斗部的性能,研究了不同的偏心起爆形式。利用试验验证过的流体动力学仿真模型研究了偏心一线起爆不同起爆点数、偏心两线不同夹角和偏心三线不同夹角等对战斗部破片速度、飞散的影响。结果表明: 对于本研究对象,在一条起爆线上布置 4 个起爆点是足够的; 对于偏心两线起爆,两线之间夹角 60°可在定向侧产生最高的速度增益,达 38.37%; 同样对于偏心三线起爆,夹角 45°时的破片速度增益最大,达 39.36%。定向方向的破片速度增益是爆轰到破片的传播距离(时间)和爆轰压力共同作用的结果。

关键词: 定向战斗部; 多点起爆; 偏心起爆

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