STUDY ON TANDEM SHAPED CHARGES TECHNIQUE

Huang zhengxiang[1], Zhang xianfeng[1]

[1]School of Mechanical Engineering, Najing University of Science & Technology, Nanjing 210094, P.R.China

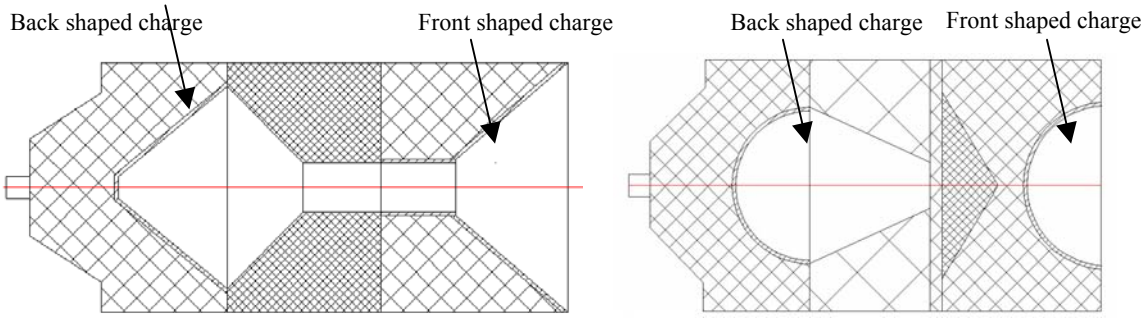
The two stage shaped charge is investigated through the design of the detonation interrupter and detonation propagation parameters. The reasonable design of the detonation interrupter and detonation propagation parameters can attain the best coupling of the two-stage shaped charge during formation and relay penetration. The results of experiments showed that two stage shaped charge can increase the penetration ability effectively, the depth of penetration increases about 10%~15%, and the radial crater by shaped charge jet penetration is growth obviously.

INTRODUCTION

With the development of the advanced technique and its application in the tank armor protection, the protection ability of tank main armor has been increased greatly. The compound armor and spaced armor appeared in the 1980's, and it reduced penetration depth of HEAA effectively, and the protective capability is increased greatly with ERA (Explosive reactive armor) was appeared. At present, the protective capability of the ERA along with compound armor is about from 900mm to 1000mm thickness of homogeneous armor. It can forecast that the protective capability of armor will reached 1200-1300 mm thickness of homogeneous armor in the future, but the penetration ability of single stage shaped charge can not reach that level. It's necessary to study the multi-stage shaped charge. Therefore, the multi-stage shaped charge was studied around the world today. For example, Russia has been worked out three stage shaped charges of the 125mm empennage stabilizing HEAA, it can penetrate the main armor along with ERA about 350mm / 60^{o}. The structures of tandem shaped charges is adopted retarded detonation mode and synchronous detonation mode mostly today is shown in Figure 1.

Tandem structure retarded detonation is the back shaped charge detonated first, and then front shaped charge is retarded detonated through the multi-point or annular detonated. The back shaped charge jet passes through the central hole in the front charge, and penetrates the armor target first, then the front shaped charge jet continues to penetrate increasing the penetration depth. Tandem structure synchronous detonated that the two charges are detonated synchronously through the initiating device, forming

tandem jets which then penetrate the target armor one by one, it needs the two jet's velocities match reasonably in this tandem structure. In order that the two jets penetrate coaxially and continuously, the fore jet's tail velocity must be high, and it should reach 2000m/s at least; the after jet's head velocity should be controlled 3000m/s below; the detonation interrupting distance should be short. How to solve the interference between the two tandem charges is the key problem, including following aspects:



tandem structure retarded detonation tandem structure synchronous detonated

Figure 1. Structural diagram of tandem shaped charges

a) The detonation interruption and detonation propagation technique. Namely, the front shaped charges structure and its blast effect can not be affected the second charge. And the second charge should be detonated reliably after delay definite time.

b) The delay time. It is necessary to choose reasonable delay time, ensuring that the head of the first jet reaches the bottom of the penetration hole synchronously with the tail of the second jet. If the delay time is short, the first and the second jets will be interrupted; while long delay time, the HEAA's stance will become skew, which decreasing the penetration ability of the HEAA.

c) The tandem structure technique. Namely, it needs to design the reasonable structures of charges and hole, which makes for achieving relay penetration and increasing the penetration ability.

In this paper, the structure retarded detonation is mainly studied. Through the reasonable design of the detonation interrupter and detonation propagation parameters attained the best coupling of the two-stage shaped charge during formation and relay penetration.

TECHNIQUE OF DELAY TIME, DETONATION INTERRUPTION AND DETONATION PROPAGATION

Delay Time

The delay time is affected by the structures of the two charges, including the quantity and the performance of the explosive, the structure and the material

performance of the liners, the detonation interrupting distance ΔH between the two charges. And the detonation interrupting distance lies on the explosion-proof material. Geometry relation sketch of calculating delay time see Figure 2.

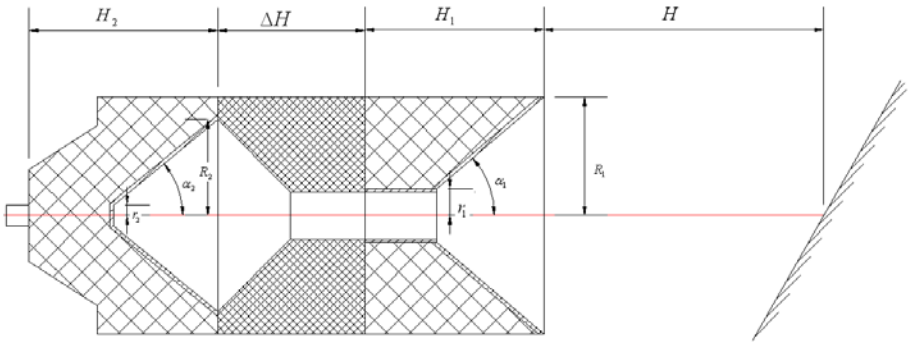


Figure.2 Schematic diagram of calculating delay time

The bottom radius of first and second liner, the top radius of them, the height of the charges and the half cone apex angle of the liner are respectively R_1、R_2; r_1、r_2; H_1、H_2; α_1、α_2. H is stand-off distance[1]. When the second jet's tail reaches the bottom of the penetration hole synchronously with the first jet's head, according to geometry relation of Figure 2.We obtained:

$$t_2 = (\frac{H_2}{D_2} + \frac{R_2}{\cos\alpha_2 V_{2k}}) + \frac{\Delta H - R_2 \mathrm{tg}\alpha_2 + H_1 + H + P_2}{V_{j2k}} \tag{1}$$

$$t_1 = (\frac{h_1}{D_0} + \frac{r_1}{\cos\alpha_1 V_{10}}) + \frac{H_1 - h_1 - r_1 \mathrm{tg}\alpha_1 + H + P_2}{V_{j10}} \tag{2}$$

There, P_2 is depth of penetration by back shaped charge jet;

D_1, V_{10}, V_{j10} are respectively the detonation wave velocity of first charge, the collapsing velocity of first liner apex and the head velocity of the first jet;

h_1 is thickness of charge at liner apex of first stage;

t_2 represents the time from the second charge detonating to the second jet's tail reaching the bottom of the penetration hole;

t_1 represents the time from the first charge detonating to the first jet's head reaching the bottom of the penetration hole.

So the delay time should be:

$$\Delta t = t_2 - t_1 \tag{3}$$

The second jet's tail velocity V_{j2k} and the first jet's head velocity V_{j10} mainly factors that influence the delay time Δt. According the above formula, increase V_{j2k} and decrease V_{j10} can shorten delay time Δt. Calculation indicate that the delay time must be 150μs at least for the high velocity HEAA.

Technique of Detonation Interruption and Detonation Propagation

The explosion-proof material is used to $45^{\#}$ steel, Bakelite, Glass fiber reinforced plastics and Reinforced polyurethane plastics, etc. Experiment indicates that each material of proper thickness can satisfy the detonation interruption need, and the better are Glass fiber reinforced plastics and reinforced polyurethane plastics.

The detonation propagation device between the two charges involves multi- point detonation through small jet, DDT delay multi- point detonation and multi-point detonation through detonating cord (shown as Figure 3). As the restricting of warhead's size, the thickness of explosion-proof material can not too thick. So the detonation propagation through small jet or DDT can not satisfy the design need. Experiment results indicate that multi- point through detonating cord (shown in Table 1 and Figure 4) is reliable, and its error of delay time is satisfied.

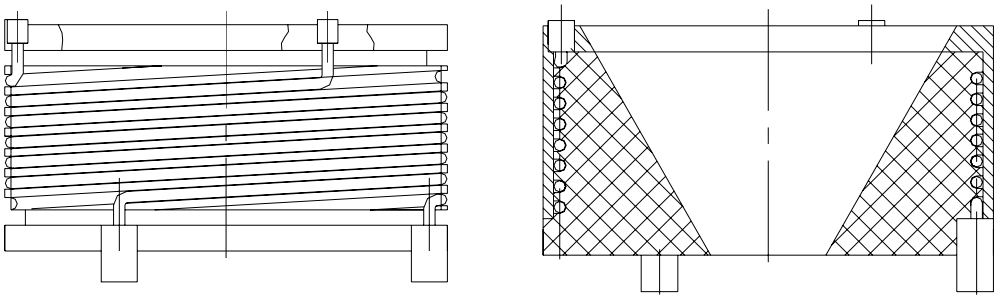


Figure 3. Schematic diagram of three-point detonation

Figure 4. Experiment of three-point detonation t

Table 1. Test results of delay time in three-point detonation

Serial number	Length of detonating cord	Test results	Calculation time	error
1	945mm	167.3μs	168.73μs	3.96%
	945mm	181.1μs		3.96%
	Not input			
2	899mm	148.1μs	160.53μs	1.44%
	899mm	152.4μs		1.42%
	899mm	150.6μs		0.23%

DESIGN OF TANDEM STRUCTURE

Besides the two charges structure being designed reasonably, the central hole design of the front charge is vital. Wile the hole is too small, the second jet will not pass through successfully, which will decrease the penetration ability; while the hole is too big, it will influence the penetration ability of the first jet. Experiments indicate that central hole is smaller, the depth of penetration will decline, results of experiments as shown in Table 2 and Figure 5. The first charge's diameter isØ86.6mm, same favorable stand-off distance, the depth of penetration is decline 25% when the central hole diameter is Ø14mm, while its decline is about 10% when the central hole diameter is Ø18mm.

Figure 5. Experiment of the central hole diameter 18mm

Table 2. Results of experiments

Serial number	Hole diameter/mm	DOP/mm	Experiment results	
			Fist steel	Second steel
1	Φ14	303	EntranceΦ49×Φ45	EntranceΦ8×Φ13
2	Φ14	302	EntranceΦ55×Φ55	EntranceΦ11×Φ11
3	Φ16	302	EntranceΦ60×Φ65	EntranceΦ9×Φ9
4	Φ16	334	EntranceΦ58×Φ50	EntranceΦ11×Φ10
5	Φ18	339	EntranceΦ60×Φ52	EntranceΦ12×Φ12
6	Φ18	364	EntranceΦ50×Φ55	EntranceΦ12×Φ12

EXPERIMENTS VALIDATION

The explosion-proof material is chosen the 45# steel. And the detonation propagation device is chosen three-point detonation through detonating cord. And the delay time was 160 μ s. The first charge's diameter is Ø 86.6mm, and the apex angle of liner was 60^{o}, and the central hole diameter and stand-off distance is respectively 18mm and 300mm. Three warheads were tested total. Experiments indicate that three-point detonation acted reliably, and that the performance of explosion-proof material was satisfied with the explosion-proof part unabridged. There are small rounded pits which was stroke by the second jet beside the entrance of the second steel ingot, which indicates the tandem shaped charge acted in anticipation. The diameter of penetration entrance is Ø 70mm, bigger than the one the single stage shaped charge, the depth of penetration increases about 10%~15%, shown as Figure 6.

Figure 6. Experiment photograph of tandem shaped charge

CONCLUSION

The tandem shaped charge can be used to attack not only the homogeneous armor but also the compound armor along with the ERA. In order to achieve continuous penetration, the tandem jets should not be interrupted each other, and the second jet's head should link up with the first jet's tail. Experiments indicate that, through designing reasonably delay time, detonation interrupter and detonation propagation structures, we can achieve the goal of increasing the radial crater and depth of penetration by shaped charge jet penetration.

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