Electromagnetic Interactional Experiment Equipment Designation and Effect Rule Analysis of Shrapnel Fuze

Jiu-Liang XIONG

Luoyang Hydraulic Engineering Institute, Xishan Rood of Luolong District in the City of Luoyang, Henan Province, China
email:xiongjiuliang@163.com

Keywords: Shrapnel fuze; Electromagnetic interactional; Effect rule; Threshold interactional distance (TID).

Abstract. To solve the problem of the high early-destruction rate of a certain shrapnel fuze in fusillade station, interactional effect experiment method of the fuze in the laboratory was proposed. Experiment equipment for two fuzes was developed. Then, two fuzes’ interactional effect experiments were done, and the effect rules were analyzed. The experiment results show that: (1) The equipment can achieve two fuze’s experiment in several factors. The relative pose range is about 0~180 degree, with 5 degree adjusting precision. The relative height range is about 0~5 metres, with 1 centimeter adjusting precision. The relative velocity range is about 0~8 meter per second, with 0.1 meter per second adjusting precision and the fire angle range is about 15~90 degree, with 5 degree adjusting precision. (2) Relative pose, relative height, relative velocity, irradiation energy, irradiation frequency and power supply style can affect the threshold interactional distance.

Introduction

With the complexity of the battlefield electromagnetic environment, radio fuze is increasingly vulnerable to interference [1]. At present, the researches, including effect rule [2], failure mechanism [3] and protection method [4, 5], on electromagnetic compatibility of fuze are mostly based on external interference source. The main source of interference involves information interference and strong electromagnetic pulse interference, lacking of interactional effect study of fuzes. Reference [6] points out that electromagnetic compatibility of the autodyne transceiver may exist when the fuzes in fusillade station. However, lacking of firing verification, the interactional problems did not cause too much concern. Especially, how to simulate the interactional process of fuzes in the laboratory is a new problem, no reporting in the public references at present.

Recently, it is found that interactional interference of a certain shrapnel fuze is existed in fusillade station. The early-destruction rate is several times as the design rate. In order to understand the interactional rule, the experiment method in the laboratory is advanced. Experiment equipment for two fuzes interactional effect is developed, and two fuzes’ interactional effect experiments are done. Also, the effect rules are analyzed. The conclusions of the study not only have important significance for the battlefield application of the shrapnel fuze, but also a good guidance for other fuze.

Experiment Methods

From the practical situation, the interactional effect is related to the relative state of the fuzes not the absolute state of each fuze. Therefore, the interactional effect system of two fuzes is shown as Fig.1. The control system is used to adjust the parameters, send control command and display the parameters of the test fuzes. State adjusting device is used to receive the control command, and then adjusts the relative state of the two fuze. Signal monitoring system is used for real-time testing and recording the fuze’s parameters and changes of the response signal. In order to ensure the safety and reliability, the test fuzes are modified in accordance with the method of reference [1], and the firing
signal are educed to estimate whether the fuze occurs interactional effect. In order to ensure the accuracy of the experiment, the experiment system is placed in a shield room.

For the quantitative evaluation of fuze’s interference effect, threshold interactional distance (TID) is definition as the maximum distance of firing between two fuzes. The specific experiment methods are as follows: (1) Test and record the parameters of fuzes such as irradiation energy and frequency before experiment; (2) one fuze fixed, and another one moves toward the fixed one with the strongest energy coupling attitude [1]. The two fuzes are power supplied by DC source. Adjusting the relative states of two fuzes to study the effect of different factors on TID. (3) The irradiation parameters and fire signal are real-time tested in the experiment, and the experiment results are recorded.

Development of the Experiment Equipment

Analysis of the requirement. According to the firing conditions, assuming that the projectile as a point target and launched at the same time. Schematic diagram of two fuzes interaction is shown in Fig. 2. \( P_1 \) and \( P_2 \) are the position of the two artilleries, \( O_1, O_2 \) are the early-destruction position. \( M \) is the position of the target. From the triangle relationship we can get:

\[
\frac{O_1O_2}{PP_1} = \frac{O_1M}{PM}
\]  

(1)
Assuming the distance of the two artilleries is 15m, the firing distance is 1500m, and the early-destruction distance of the fuzes is about 800m. So \( |\overrightarrow{PE}| = 15 \text{m}, |\overrightarrow{OP}| = 800 \text{m}, |\overrightarrow{PM}| = 1500 \text{m} \), then \( |\overrightarrow{OO}| = 7 \text{m} \). According to the encountering conditions [6], we can get the Doppler frequency \( f_d \) :

\[
f_d = \frac{2}{\lambda} \sqrt{v_1^2 + v_2^2 - 2v_1v_2 \cos \beta} \sqrt{1 - \left(\frac{P_2}{R}\right)^2}
\]

(2)

where \( f_d \) is Doppler frequency; \( \lambda \) is the irradiation wavelength; \( v_1 \) is the velocity of fuze 1; \( v_2 \) is the velocity of fuze 2; \( \beta \) is the contact angle; \( \rho \) is the miss distance; \( R \) is the distance between the target and the fuze.

Ignoring the spread position of the fuze, if the initial velocity is 1000m/s, then \( \beta = 0.6^\circ \). In the actual, \( \rho = 5 \text{m} \), then \( f_d = 0.0489 \text{Hz} \). According to the working characteristics of the fuze’s circuit, this value of \( f_d \) is far less than the fire condition. As a result, the early-destruction of the fuzes is not caused by Doppler signal. In addition, in the firing conditions, the relative velocity of the two fuzes in the early-destruction position \( v = 2 \times 1000 \times \cos((180 - 0.6)/2) = 10 \text{m/s} \). Obviously, the relative velocity of the fuzes in the simulation does not need to design too high.

From the firing scene, to simulate the interactional effect of the fuze successfully in the laboratory, different relative state should be adjusted. For two fuzes, different states include relative velocity, relative pose, relative height and different firing angle. According to the firing condition of the fuze, there is 15 degrees firing forbidden angle.

Considering two fuze’s interactional process, the equipment needs to achieve different condition. Based on the above analysis, the design index of the equipment needs to meet the relative pose 0–180 degrees adjustable and the adjustment precision is less than 10 degrees; the relative height 0–3m adjustable and the adjustment precision less than 5cm; the relative velocity 0–5m/s adjustable and the adjustment of the precision is less than 0.5m/s; firing angle 15–90 degrees adjustable and the adjustment precision is less than 10 degrees. Also, the equipment should not affects the normal work state of the fuzes and convenience to observe and control.

**Overall design.** The overall design scheme of the experiment platform is shown in Fig.3. The platform includes console, control subsystem 1, control subsystem 2, state adjusting device, signal testing device, driving mechanism, shield cables and so on. The console is used to input command and display state parameters, including control interface and display interface. Control interface is used to achieve various control functions, such as power supply and parameter settings. Display interface is used to display and record the running state of the fuze and data parameters. The system includes two control subsystem symmetry, which are used to control the running state of the fuzes. By receiving the control command, control subsystem drive the auxiliary device by motor. The auxiliary device comprises with traction line, brake, line storage slot and shielding module. Traction line is used to tow the pulley. Brake mainly accepts stop instruction and controls the system operation state. Line storage slot is used to storage the traction line, which is calculated to confirm the fuze’s running distance. The fuze’s trajectory is controlled by a rail with one end fixed on the top of a adjustable stanchion, and another end fixed on auxiliary device.
Performance test of the experiment equipment. Actual object of the fuze interactional effect experiment system is shown in Fig.4. After testing, the performance indicators of the equipment are as follows: (1) The relative pose range is about 0~180 degree, with 5 degree adjusting precision; (2) The relative height range is about 0~5 metres, with 1 centimeter adjusting precision; (3) The relative velocity range is about 0~8 meter per second, with 0.1 meter per second adjusting precision; (4) The fire angle range is about 15~90 degree, with 5 degree adjusting precision; (5) Control mode: shield cable; (6) Attitude adjustment mode: manual and automatic; (7) Other indicators: shielding treatment in order to avoid affecting the normal work state of the fuzes; meet the bearing requirements; support data input and acquisition. It can be seen from above indicators that the fuze interactional effect experiment system can fully meet the requirements of two fuzes interactional experiment.

Analysis of the Interactional Effect Rule

Effect of relative velocity. Three groups of test fuze, which are denoted as A, B and C, are carried out in the experiment. During the experiment, a fuze is fixed in a place, while another one moves toward the fixed one with the strongest energy coupling attitude, different relative velocity and the same height. The two fuzes are power supplied at the same time by DC source, and TID is observed.
and recorded when the fuze firing. The experiment results are shown in Fig. 5. We can see from figure 5, no matter in relative static state (i.e., the relative speed is 0) or in the state of relative movement, the fuzes will be fire under the experimental conditions. TID in the state of relative movement is greater than that in relative static state. With the increase of the relative velocity, TID exists increase trend, but the absoluteness value is small. From the experiment results it can be seen that TID is related to the relative velocity. But when the relative velocity is high enough, TID can be seen as a constant. We also can see that in the same relative velocity 0.8m/s, TID of group A, B and C are about 134cm, 75cm, 50cm, respectively. It can conclud that different fuze group has different TID.

Effect of relative height. Using fuzes group B, C and D to do the experiment. One fuze fixed vertically, and another fuze moves towards to the fixed fuze with different height and the same velocity. The two fuzes are also power supplied at the same time by DC source, and TID is recorded in Fig. 6. We can see from figure 6, TID is related to the relative heligh. TID decreases with the relative height increasing. TID of group B, C and D are 50cm, 40cm and 35cm, respectively.

Effect of relative pose. Selecting fuzes group A, B and C to do the experiment. The tested fuzes are fixed in energy coupling direction and relative height, and tested in different relative pose and the same relative velocity. The two fuzes are power supplied at the same time by DC source, and the TID is recorded in Fig. 7. We can see from figure 7, TID is related to the relative pose. In vertical pose (the angle is 0 degrees), TID is the most. TID in this condition of group A, B and C are about 135cm, 75cm
and 50cm, respectively. When the fuzeheads toward each other (the angle is 180 degrees), TID is the least. TID in this condition of group A, B and C are about 46cm, 20cm and 9cm, respectively.

**Effect of irradiation frequency.** In the experiment, the fuzes with same irradiation energy and different frequency difference are choose to compare in the condition of the strongest energy coupling direction, relative height, relative pose and relative velocity. Also, the two fuzes are power supplied at the same time by DC source, and the TID is recorded in Fig.8. As can be seen from figure 8, TID increases when the irradiation frequency decreases. It can concludes that in order to produce interaction effect, the irradiation frequency difference should be limited in a certain frequency range. From the results, in 0.5MHz frequency difference, TID of fuzes with 0.21dBm, 0.12dBm and 0.38dBm are 75cm, 55cm and 150cm, respectively.

![Figure 9. TID in different radiation energy.](image)

**Effect of irradiation energy.** In the experiment, the fuzes with same irradiation frequency difference and different energy difference are choose to compare in the condition of the strongest energy coupling direction, relative height, relative pose and relative velocity. Also, the two fuzes are power supplied at the same time by DC source, and the TID is recorded in Fig.9. As can be seen from figure 9, TID increases when the irradiation energy difference increases. From the results, in 0.5MHz frequency difference, TID of fuzes with 0.17dBm, 0.12dBm and 0.43dBm are 55cm, 75cm and 150cm, respectively.

![Figure 10. TID in different power supply style.](image)

**Effect of power supply style.** In the experiment, four groups of fuzes are choose to compare in the condition of the strongest energy coupling direction, relative height, relative pose and relative velocity. One fuze is power supplied firstly, and the other one power supplied instantly. Then, the two fuzes are power supplied at the same time by DC source in order to compare. TID in different power supply style is recorded in Fig.10. As can be seen from figure 10, To group one, TID is about 50cm in the condition of the same time power supply. While in instant power supply, TID is about 227cm, far greater than the result in other condition. The same rule can be concluded in group three, in which the fuze cannot be interaction (TID is about 0cm) in the condition of the same time power supply, while in instant power supply, TID is about 115cm. From the results we can get that the power supply style has a great effect on TID, and TID in the conditions of instant power supply is much larger than at the same time.

**Summary**

According to the interactional effect problem of shrapnel fuze in fusillade station, interactional effects experiment method of the fuze is advanced, and experiment equipment for two fuzes interactional effect is developed. The interactional effect rules of fuze are analyzed. We can concluded that the equipment can achieve two fuze’s experiment in several factors. Relative pose, relative height,
relative velocity, irradiation energy, irradiation frequency and power supply style can affect the TID. The researches conclusions have important guide significance for studying other fuze’s interactional effect.

References

[1] Xiong Jiuliang, Wu Zhancheng, Sun Yongwei, LEMP irradiation effects on continuous wave Doppler fuze, High Power Laser And Particle Beams, 27(2015):0432031-0432036.

[2] Xiong Jiuliang, Wu Zhancheng, Effect of ultra-wide band on security of typical frequency modulation fuze, High Voltage Engineering, 42(2016):1997-2002.

[3] Feng Ying, Zhang He, Zhang Xiangjin, Electromagnetic Interference Technique of Transmitter and Receiver Modules for Pulsed Laser Fuze, High Power Laser and Particle Beams, 23(2011):249-254.

[4] Cheng Erwei, Chen Yazhou, Tian Qingmin, Effect of dual sources irradiation on a radio fuze, High Power Laser and Particle Beams, 26(2014):0732191-0732195.

[5] Qin Dongze, Fan Ningjun, Weight Distribution of Sub-munitions Fuze Design, Journal of Beijing institute of technology, 22(2013):153-157.

[6] Bai Yupeng, Shi Jusheng, Hao Xinhong, The analysis of electromagnetic compatibility of the autodyne transceiver, Journal of Detection & Control, 24(2002):33-36.