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Recent Advancements in Proximity Fuzes Technology

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***Abstract*— Proximity fuzes are the most common fuzes used in artillery munitions. This is because of their advantage of inflicting maximum damage of the target they deal with. The advancements of proximity fuzes technology have been occurred rapidly. In this paper, all types of artillery fuzes in conjunction with a detailed discussion of proximity fuzes, which have not been exploited in any other literature before, are presented. A thorough review of proximity fuzes regarding their classifications, technologies, and operation is introduced.**

Keywords—artillery fuzes; proximity fuzes; fuzes technology;

I. INTRODUCTION

An artillery fuze is the type of munition fuze used with artillery munitions such as projectiles fired by guns (field, anti-aircraft, coast and naval), howitzers and mortars. A fuze is a device that initiates an explosive function in a munition, most commonly causing it to detonate or release its contents [1].

Since the second half of the 19th century, most artillery fuzes are fitted to the nose of the projectile. The base of the fuze is screwed into a recess, and its nose is designed to conform to the shape of the shell's curve. The depth of recess can vary with the type of the shell and fuze [2].

The fuze action is initiated by impact, elapsed time after firing or proximity to a target. In most cases, the fuze action causes detonation of the main high explosive charge in a shell or a small charge to eject a carrier shell's contents. These contents may be lethal, such as the now-obsolete shrapnel shell or modern sub-munitions, or non-lethal such as canisters containing a smoke compound or a parachute flare [1].

Fuzes normally have two explosive components in their explosive train: a very small detonator (or primer) which is struck by a firing pin, and a booster charge at the base of the fuze (sometimes called the 'magazine'). This booster is powerful enough to detonate the main charge in a high explosive shell or the ejecting charge in a carrier shell. An ideal fuze would detonate the projectile at the most favourable position to inflict maximum damage to the target [1].

After the introduction, the rest of this paper is organized as follows; section II introduces the major types of artillery fuzes. A detailed discussion of proximity fuzes as common artillery fuze covering their classification, technologies and principle of operation is introduced in section III. Finally, conclusion comes in section IV.

II. TYPES OF ARTILLERY FUZES

There are four major types of artillery fuzes: impact (percussion) fuzes, airburst fuzes, multifunction fuzes and sensor & course correcting fuzes.

A. *Impact Fuzes*

They are the type of fuzes which detonate the explosive charge when the munition hit the target. The detonation action could be happened directly by hitting the target or delayed after hitting the target. There are two major types of impact fuzes, direct action fuzes and delay fuzes [3].

1) Direct action fuzes

The scenario describing the use of direct action impact fuze in an artillery projectile is shown in Fig. 1. Direct action fuze starts its function when the fuze nose hits something reasonably solid, such as the ground. This action pushes a firing pin into a detonator which detonates a booster charge that is strong enough to detonate the explosive charge.

Fig. 1 Artillery projectile using direct action fuze

2) Delay fuzes

Direct action fuzes can have a delay function, selected at the gun as an alternative to direct action. Delay function may be achieved using different delay mechanisms. One of these mechanisms is the deceleration resulted from hitting a ground, as shown in Fig. 2. This deceleration causes the firing pin to move forward, or the detonator to move backward, sharply and strike each other. This is called graze fuze. The graze fuze also is called base fuze in naval use.

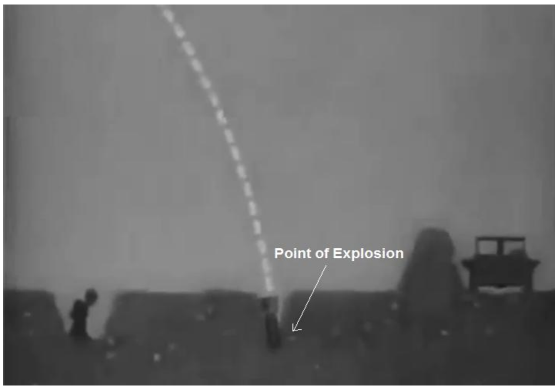

Fig. 2 Artillery projectile using delay fuze

B. *Airburst Fuzes*

Unlike impact fuzes, airburst fuzes are the type of fuzes which detonates the explosive charge at a distance from the target. They are particularly important and were widely used. There are four major types of airburst fuzes; time fuzes, proximity fuzes, distance measuring fuzes and electronic time fuzes.

1) *Time fuzes*

Artillery time fuzes detonate after a predetermined period of time. Early fuzes were igniferous or combustible using a powder train.

The time length of a time fuze is usually calculated as part of the technical fire control calculations.

The problem with these fuzes was that they were not very precise and somewhat erratic, but good enough for flat trajectory fragments or high bursting carrier shells [3].

2) *Proximity fuzes*

The benefits of a proximity fuze that functioning when it detects a target in proximity are obvious, particularly for use against aircraft [4, 5]. For the first 18 months of manufacturing the proximity fuzes, they were restricted to anti-aircraft use to ensure that none were retrieved by the enemy and copied. They were also called ‘Variable Time’ or VT to obscure their nature. They were finally released for field artillery use in December 1944 in Europe. While they were not perfect and bursts could still be erratic due to rain, there were a vast improvement on mechanical time in delivering a very high proportion of bursts at the required height [1]. Proximity fuzes are the most common fuzes used in artillery projectiles because they can measure the range accurately especially after the recent developments achieved in them.

3) *Distance measuring fuzes*

The distance measuring fuzes or mechanical distance fuzes have been used a little, Thompson’s pattern was trialled by the British but did not enter service. The fuzes operated by counting revolutions. It has the advantage of inherent safety and not requiring any internal driving forces but dependeds only on muzzle velocity and rifling pitch [3].

4) *Electronic time fuzes*

In the late 1970s / early 1980s, electronic time fuzes started replacing earlier types. They were based on the use of oscillating crystals that had been adopted for digital watches. Like watches, advances in electronics made them much cheaper to be produced than mechanical devices. This type of fuzes was introduced at the same time when some North Atlantic Treaty Organization (NATO) countries start using cluster munitions [3].

C. *Multifunction Fuzes*

A multifunction fuze assembly may include more than one fuze function. A typical combination would be a T & P ("Time & Percussion") fuze with the fuze set to detonate on impact or expiration of a preset time. Initially, they were little more than enhanced versions of proximity fuzes, typically offering a choice proximity heights or impact options. They were much more widely issued. In some countries, all their war stock of high explosives (HE) were fitted with them, instead of only 5 to 10% with proximity fuzes [1, 6].

D. *Sensor and Course Correcting Fuzes*

Sensor fuzes can be considered smart proximity fuzes. Initial developments were the United States ‘Seek and Destroy Armour’ (SADARM) in the 1980s. These sensor fuzes typically use millimetric wave radar to recognize a tank.

The main fuze development activities in the early 21st century are course correcting fuzes. These fuzes add guidance and control functions to the standard multi-option nose fuze package [1, 6].

III. PROXIMITY FUZES

Impact fuze detonates and losses more than 50% of its energy compared to the case if explosion takes place at certain high. Proximity fuze is used to enhance the performance of warhead explosion and increase the effective distance of fragmentation warhead. Optimum burst point varies according to the nature of the target and the properties of the shell itself. For example, optimum burst point against an aerial target could be closest point of approach to the aircraft or an optimum point according to some preset criteria by the signal processing algorithm [6]. Against ground, the optimum burst height varies from 2 m to 20 m for fragmentation and blast bombs, 100 m for a chemical warfare bomb, 3 m for 81 mm mortar and 12 m for a 155 mm field artillery shell [1].

Fig. 3, Fig. 4 and Fig. 5 show the effectiveness of the proximity fuzes over that of the impact fuzes (direct fuzes and delay fuzes).

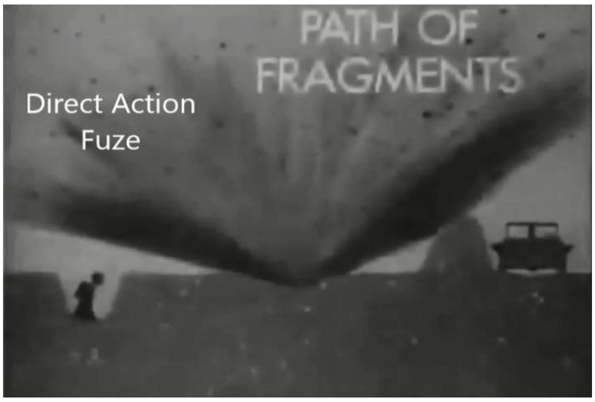

Fig. 3 Path of fragments in direct action fuze

Fig. 4 Path of fragments in delay fuze

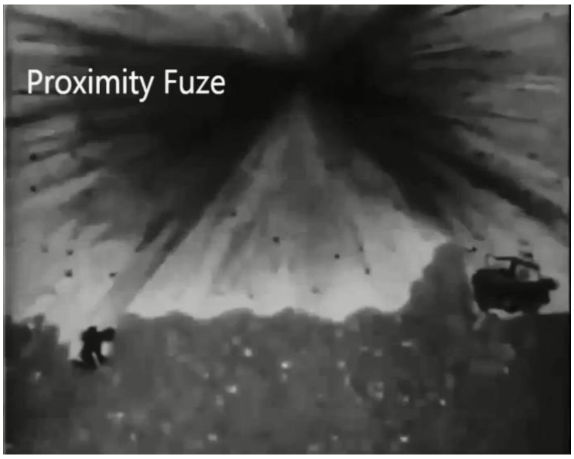

Fig. 5 Path of fragments in proximity fuze

A. Classifications of Proximity Fuzes

Proximity fuzes can be classified according to ammunition, targets, fuzing techniques and antenna configuration [1].

1) According to ammunition

a) Field artillery shells

This type of fuzes requires high 'g' shocks at the time of firing and high Revolution per Minute (RPM). As an example, a 155 mm field artillery shell requires 15000 'g' at the time of firing and the RPM is of the order of tens of thousands.

b) Anti-aircraft shells

In this type of fuzes, the 'g' problem is more severe than that of field artillery shells. For example; A 40 mm anti-aircraft fuze is subjected to about 100,000 'g'. They require much higher sensitivity and must solve the microphonic problem (when the proximity sensor is acoustic) under these conditions. In the naval role, sea clutter problem is dominant, the fuze receiver must meet its function under severe clutter environment.

c) Mortars

Mortars require a burst height between 2 m to 4 m from the ground, the height of burst therefore has to be precise. The mortar fuzes need to employ much wider transmitter bandwidth to achieve the high accuracy at the low height of burst.

d) Rockets

In this type of fuzes, there is no ‘g’ problem, but they are particularly susceptible to vibrations. The microphonic problem is therefore more severe.

e) Missiles

The fuzes for missiles are the most sophisticated and complex amongst all the fuze applications. They must have very high reliability, they must function in the presence of severe airborne Electronic Countermeasure (ECM) environment and they have to use complex algorithms in their signal processor to optimize the burst position.

f) Submunitions

Submunitions consists of clusters in which fuzes interfere with each other within the cluster. So, clusters demand complex modulation waveform and special techniques.

2) According to targets

a) Ground targets

The ground target is characterized by high radar cross-section. That is why the fuzes are designed with moderate sensitivity. For the fuzes that work against tanks, they must discriminate between ground surface and tanks.

b) Aircraft targets

Aircraft targets are characterized by low radar cross-section and multiple scattering centers. The airborne targets employ sophisticated ECM. So, fuzes have to function in the presence of ECM and also in the presence of strong sea clutter from the sea surface against low-level naval targets.

c) Ship targets

Ship targets are the most difficult targets to deal with. Fuzes have to function under strong sea clutter conditions. Also the problem compounded because of very low speed of ships making the Doppler discrimination rather difficult.

3) According to fuzing techniques

a) Pulsed Doppler [7]

Pulsed Doppler fuzes have limited application which require functioning at high altitude between 1000 to 5000 ft, it is required also in dispensing submunitions.

b) Continous Wave (CW) fuze

CW fuzes primarily measure the target echo Doppler shift. Range cannot be measured directly (there is no time reference) but it is measured indirectly from the strength of received signal. Proximity fuzes of the World War II and till early 1980's, used CW fuzes. This type of fuzes has the disadvantages that it can be easily jammed and the range measurement is not accurate.

c) Frequency Modulated Contious Wave (FMCW) fuze

FMCW fuzes using sinusoidal and linear triangular modulation have the capability of measuring target range. Fuzes of most ammunition use the linear FMCW technique owing to their excellent features. Wide band FM modulations achieve very high target range accuracies. The FMCW systems are also resistant to ECM. Their deterministic waveforms also allow the signal processing using Fast Fourier Transform (FFT) techniques.

d) Pseudo-random binary-coded and noise-modulated

The pseudo-random binary-coded and noise-modulated fuzes use time-variant modulations on the CW and are capable of measuring the target range. These waveforms are more complex than the FMCW waveforms and need correlators in the signal processors to extract range information. They cannot be jammed easily because of the complexity of their waveforms.

e) Pulsed laser fuzes

The pulsed laser fuzes is characterized by having very high precision in ranging and very high resistance to countermeasures. On the other hand, the laser source used in artillery projectiles is very expensive.

4) According to antenna configuration [8]

Proximity fuzes are classified also according to transmitter and receiver antennas hardware setup as follows:

a) Common receive-transmit antenna fuzes

As shown in Fig. 6, these fuzes use a common transmit/receive antenna, owing to the space limitations. But these antennas have to solve the problem of leakage between the transmitter and receiver through the circulator, mismatch of the antenna, and reflections from the radome.

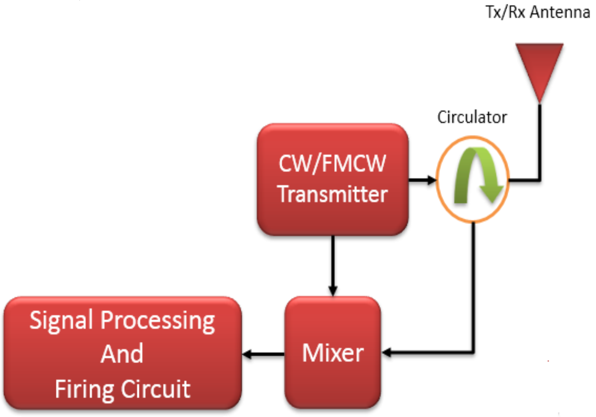

Fig. 6 Strucure of common Tx. and Rx. antenna fuze

b) Separate transmit and receive antenna fuzes

As shown in Fig. 7, these fuzes use separate transmit and received antenna, positioned to achieve physical isolation. These fuzes are capable of achieving much higher sensitivities than the fuzes using common transmitter and receiver antenna.

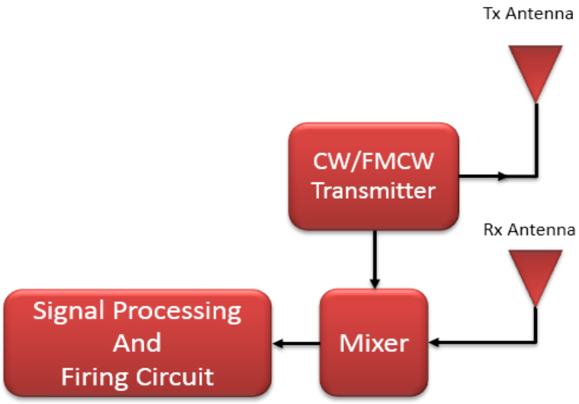

Fig. 7 Strucure of separate Tx. and Rx. antenna fuze

B. Development of Proximity Fuze Technology

In the last three decades, the proximity fuze technology has become more advanced and evolved considerably. The advancements in proximity fuzes have taken place in the following areas [1]:

- Accurate height of burst in ground fuzes.
- Optimum point of burst against airborne.
- Resistant to severe electronic countermeasures [9].
- Ultra wide band fuzes [10].
- Advanced signal processing techniques.
- Application of Monolithic Microwave Integrated Circuit (MMIC) techniques. MMIC are devices that operate at microwave frequencies, (300 MHz to 300 GHz), in the front-end/RF system in the fuzes.

There are different generations for the proximity fuzes. Each generation is characterized by certain features related to the achieved development in technology. These generations are classified into four groups.

1) First-generation fuzes

- These fuzes use CW/pulsed Doppler.
- They operate with a fixed frequency.
- These fuzes become active 2 to 3 sec after firing.

2) Second-generation fuzes

- These fuzes use FMCW/pulsed Doppler.
- They operate with repetitive signals.
- These fuzes are inactive until 2 to 4 sec before the ground target.
- The power levels of these fuzes are from 1 mW to tens of mW in FMCW fuzes.

3) Third-generation fuzes

- These fuzes use FMCW with advanced Digital Signal Processing (DSP) techniques.
- They operate with non-repetitive signals, using frequency agility and Pulse Repetition Frequency (PRF) agility.
- They use also random binary phase coding.
- They use noise modulation waveforms.
- They apply time gating.

- The power levels of these fuzes are from 1 mW to tens of mW.
- They use surface-mount devices and MMIC techniques.

4) *Current fuzes*

- The same as third-generation fuzes with further advancement.
- They may use pulsed high power laser diodes and high energy short-pulsed lasers based on laser diode pumped solid state microlasers.

C. *Basic Proximity Fuze Block Diagram*

The basic block diagram of a common proximity fuze is shown in Fig. 8 [1]. The function of each module in this block diagram is discussed in the following points.

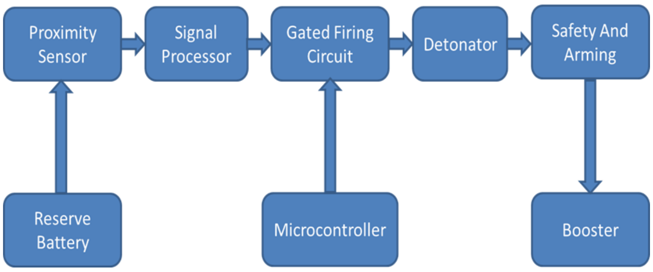

Fig. 8 Basic block diagram of a common proximity fuze

1) *Proximity sensor*

The function of the proximity sensor is to generate the transmitted signal, detect the target from the received signal and generate a signal which carries the range information. The proximity sensor is composed of modulated/encoded oscillator (which is modulated by a waveform generator), Power Amplifier (PA), an antenna, Low Noise Amplifier (LNA), circulator, receiver mixer and Intermediate Frequency (IF) filter.

The proximity sensor may be classified according to the used fuzing techniques into radio, optical, acoustic, magnetic and pressure sensor.

- Radio sensor:

  Radio frequency sensing is the main sensing principle for artillery shells. Radio sensor is the most common used proximity sensor because it can function well in bad weather conditions, easy to implement and can be used in several applications.

- Optical sensor:

  It is used with anti-aircraft missiles fired from the ground. It uses a toroidal lens that concentrates all light out of a plane perpendicular to the missile's main axis onto a photo cell. When the cell current changed a certain amount in a certain time interval, the detonation is triggered. In bad weather conditions, optical proximity sensor cannot do its function well.

- Acoustic sensor:

  Acoustic sensing uses a microphone in a missile. The characteristic frequency of an aircraft engine is filtered and triggers the detonation. Acoustic proximity sensor has a little use because it suffers from the projectile's vibrations.

- Magnetic sensor:

  Magnetic sensing can only be applied to detect huge masses of iron such as ships.

- Pressure sensor:

  Pressure sensing is used in some naval mines that are able to detect the pressure wave of a ship passing overhead.

2) *Signal processor*

The basic function of a signal processor is to extract the range information from the output of the proximity sensor. Then it compares this range with a pre-stored range value. Depending upon this comparison, it generates an activation signal to fire a detonator to activate the payload/explosive. Signal processing circuit can be quite complex in order to overcome different noise, interference and jamming environments. The signal processor may use FFT based techniques to extract the desired range information.

3) *Gated firing circuit*

Gated firing circuit fires the detonator on receiving a command signal from the signal processor. Firing circuit is gated and blocks the signal until the gate is opened, either after a preset time or by a command from a microcontroller.

4) *Detonator*

The detonator is fired by the gated firing circuit. Then it detonates a booster charge.

5) *Booster*

The booster charge is detonated by the detonator. It is powerful enough to detonate the whole explosive charge.

6) *Reserve battery*

The fuze is powered by a reserve battery which is activated only at the time of firing the ammunition.

7) *Safety and arming device*

Safety and Arming (SAM) device interrupts the path between the detonator and the booster pellet/explosive train using a shutter until the safety and arming device is armed.

8) *Microcontroller*

The control functions in the earlier fuzes were hardware-controlled, now they are being controlled by a microcontroller. Microcontroller carries out a number of functions such as reading the safety switches to arm the firing circuits at the appropriate time, blocking the firing circuit for a time set by the fuze setter, activates the firing circuit on receiving a command from the signal processor and also carries out the fuze self-check. In complex microcontrollers, some of the signal processing functions are also carried out.

IV. CONCLUSION

There are many types of artillery fuzes, each type has its own advantage over other types according to the required application. In this paper, a survey of the major types of artillery fuzes has been introduced. Proximity fuzes are the most common type of artillery fuzes. Their classifications, technologies, developments, and operation have been discussed in details.

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