Analysis of initial velocity measurement methods of projectile muzzle

ZHANG Bin-zhen(张斌珍)[1], HAO Yi-long(郝一龙)[1], LI Jie(李　杰)[2], FAN Jian-ying(范建英)[2], LIU Jun(刘　俊)[2]

(*1. National Key Laboratory of Science & Technology on Micro/Nano Fabrication, Institute of Microelectronics, Peking University, Beijing 100871, China;*
2. Science and Technology on Electronic Test & Measurement Laboratory, North University of China, Taiyuan 030051, China)

Abstract: Because of the influence of conventional ammunition working in high rotation, high overloading, high temperature, high pressure and other harsh environments during the launch, it is difficult to measure the initial velocity of projectile muzzle. This paper analyzes and compares each sort of characteristics of several typical initial velocity measurement methods of projectile muzzle both at home and abroad, and proposes the development trend based on current research and practical aplication.

Key words: muzzle; initial velocity; magnetism

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0 Introduction

With the increasing development of modern precision weapons, the conventional ammunition guided transformation becomes the main development trend of accurate weapons. Accurate measurement of the initial parameters of the projectile muzzle is directly related to the external ballistics calculation precision, and then affects the hit rate of the projectile. The initial parameters of the muzzle means the projectile gets rid of the role that gas is on it when the projectile is launched from the muzzle, and still maintains the effect of inertia of the measured parameters. Muzzle's initial speed is one of the main parameters of the conventional ammunition muzzle. Because the projectile works in a high rotation, high overloading accompanied with high temperature, high pressure of propellant gas, it is difficult to measure the initial velocity of the projectile muzzle.

So far, domestic and foreign researchers have proposed external measurement methods and internal measurement methods to get the initial velocity of the muzzle. The external measurement methods need to use the launch platform or projectile external equipment, such as laser velocimetry, Doppler speed radar, and so on[1-3]; The internal measurement methods are interiorly equipped with measuring unit or system inside of the projectile to measure the projectile information and conduct ballistic calculation in real time, including optical velocimetry and magnetic velocimetry[4-8]. This paper analyzes and compares several typical measurement methods. Accompaning with the research and practical application, the prospects about this field are proposed, which lays the foundation for engineering application.

1 Measurement principle of initial velocity of muzzle

1.1 External measurement methods

Early researchers used the external measurement methods to measure the initial velocity of the muzzle, by installing measuring device outside the muzzle and conducting ballistic calculation, which used the launch platform and depended on the external environments. The typical methods involve laser velocimetry and Doppler radar velocity measurement.

1.1.1 Laser velocimetry

Laser velocimetry measurement needs to place a laser source in the muzzle, the principle is shown in

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Corresponding author: ZHANG Bin-zhen(zhangbinzhen@nuc.edu.cn)

Fig. 1. In Fig. 1, when the projectile tail flies from the starting position point A to B, the laser source light, in turn, from point i of the projectile head to point j. According to the principle of the optical reflector, the tested point moves from point C to point D after being reflected to the plane mirror 2 of points i' and j'. Accordingly, the moving distance is $d_{i'j'}$, and distance-time (d-t) curve can be drawn by the logger. Furthermore velocity-time (v-t) curve of the muzzle is drawn, so that the initial velocity of the muzzle is obtained.

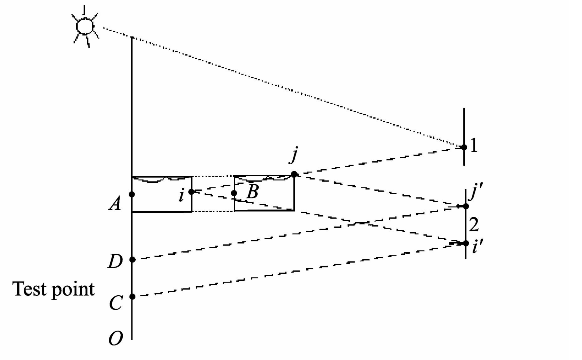

Fig. 1 Laser velocimetry measurement

1.1.2 Doppler radar velocity measurement

With the development of national defense science and technology, various countries proposed new requirements of precision attack weapons. Foreign researchers first manufactured Doppler radar velocity measuring device. It consists of a tuner, an infrared starter, a pretreatment system and a terminal system. Schematic diagram of Doppler radar velocity measurement is shown in Fig. 2.

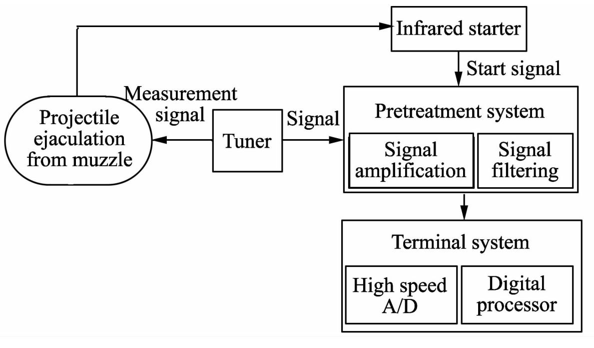

Fig. 2 Schematic diagram of Doppler radar velocity measurement

As shown in Fig. 2, the infrared starter produces an electric signal as a starting signal of the radar timing. This electric signal is produced by transient light when the projectile flying out of the muzzle. When projectile flying in the range of electromagnetic field radiation of radar, the tuner measures signals of the projectile out of the muzzle, and sends them into the pretreatment device for signal amplification and filtering. Finally, the measured signals enter into the terminal device. After A/D convter, d-v and v-t curves are calculated by digital processor.

1.2 Internal measurement methods

Internal measurement methods mainly use optics principle, magnetic induction principle, and so on. Compared with the traditional external measurement methods, the internal measurement methods have strong independence and high precision. They do not rely on the launch platform to transmit measuring information timely, and can complete calculation of ballistic missile in real time, so they are the main development direction of the conventional measurement methods of muzzle's initial velocity.

1.2.1 Photoelectric target velocimetry

Photoelectric target velocimetry uses photoelectric conversion principle. It needs two equal-size and equal-shape devices in the muzzle whose position can be measured accurately. Every device consists of a number of photodiodes and light emitting diodes. The projectile is interiorly equipped with a signal processing circuit and a control circuit. Powered on, photosensitive diodes control the circuit when they are sensitive to the light emitting diodes' shine. The projectile flies through the apparatus 1, which shades part or all of the light and makes photosensitive diodes be sensitive to the light intensity's change, and then this change is converted into the electrical signal counted by the counting unit of the processing circuit. Similarly, passing through the apparatus 2, photosensitive diodes sense the light intensity's change, which is converted into an electrical signal to stop counting. Thereby, the time passing the two apparatus can be calculated. Compared with the projectile's velocity, it is very short for the distance of the two devices. Assuming that the projectile passing through the two devices is of uniform motion, the initial velocity of the muzzle can be got as

$$v = \frac{d}{t}, \tag{1}$$

where d is the distance of the two devices, t is the time of the projectile passing through the two devices.

1.2.2 Magnetic induction velocity measurement

Magnetic induction velocity measurement methods include coil target measurement method and magnetoresistive sensor velocity measurement method. Coil targets consist of single-coil target and dual-coil target. Dual-coil target includes transmitting coil and receiving coil.

1) Principle of dual-coil target

Dual-coil target and photoelectric target belong to blockade screens' velocity measurement. The difference from the coil target is that it has transmitting coil and receiving coil, which are made of a certain number of turns and layers of the coil as shown in Fig.3.

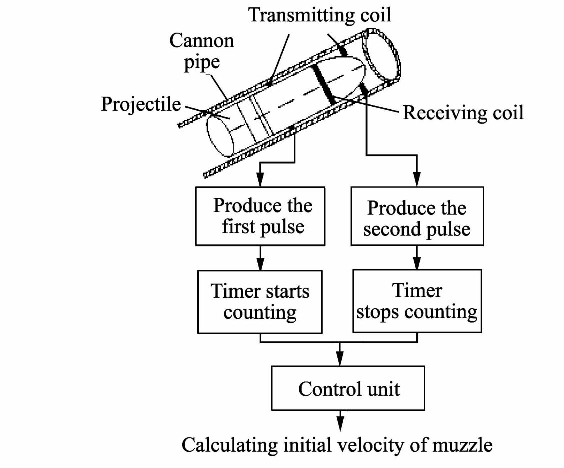

Fig.3 Principle of coil target

The projectile successively flies through the two coils, and the magnetic flux of the receiving coil changes aod generates two different voltage pulse signal, start timing signal and stop timing signal, to calculate the time of the projectile passing through the two coils. Then initial velocity of the muzzle is calculated by Eq.(1).

2) Principle of single-coil target

The work of the magneto-resistive sensor mainly uses Wheatstone bridge with four resistances of permalloy, as shown in Fig.4.

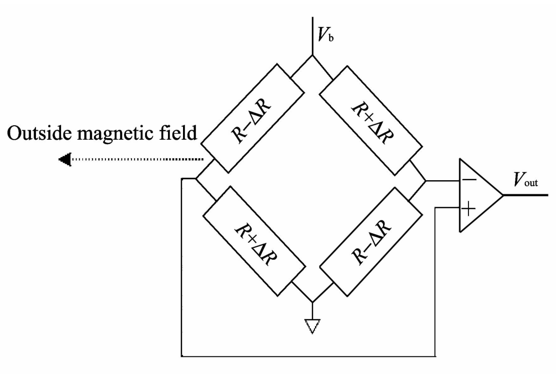

Fig.4 Principle of magneto-resistive sensor

When the current goes through the longitudinal direction of permalloy, the increase of magnetic field in width direction will cause the inner magnetization direction of two diagonal resistors to rotate toward the direction of the current, while the other two resistors move in the opposite direction. In this way, change of resistance will lead to the conversion of the external magnetic field's strength into differential voltage output. It can be described as $\Delta V_{out} = \left(\frac{\Delta R}{R}\right)V_b$, where R is the thin film resistor, ΔR is the change amount of the resistance and V_b is the sensor output voltage.

The magneto-resistive sensor velocity measurement is interiorly equipped with magnetoresistive sensor, signal processing circuit and control circuit. The magneto-resistive sensor can be measure rotating frequency relating to magnetic field when the projectile flies out of the muzzle. When the initial velocity of the muzzie is measured by signle-coil target method, magneto-resistive sensor can used to measure rotating frequency. According to rotating frequency, the initial velocity of projectile muzzle can be calculated, namely, $v = fD\eta$. where f represents rotating frequency of the projectile; D, bore diameter; η , the bore rifling twining angle[10].

2 Comparison of measurement methods of initial velocity of muzzle

2.1 Similarities of measurement methods of initial velocity of muzzle

1) Vulnerable to the impact of the surrounding environment, poor adaptability;

2) Only applied to the shells of a single model, not universal;

3) Low measurement precision;

4) Principle is relatively simple, but it needs to consider a variety of factors in actual operation and is not easy to be operated.

2.2 Difference of four kinds of measurement methods of initial velocity of muzzle

The external measurement methods need the launch platform, which can lighten the weight of the projectile, while it depends on the outside circumstances. When the projectile flying out the muzzle with gunpowder gas and thick smoke, the laser velocimetry would affect the optic reflection, and gunpowder particle would produce optic effect. Doppler radar velocity measurement has higher precision. But it only measures initial velocity of the projectile flying out of the muzzle some distance, the initial velocity of the projectile is amended by using the Westjace law. Using this method, the device is expensive and prone to expose itself to significant electromagnetic radiation, which is not fit to actual combat.

Compared with the external measurement methods, to some extent, internal measurement methods have improved and have more independence, which can accomplish the real-time calculation of trajectory and improve the measuring precision. However, there are still some drawbacks, such as vulnerable to the effects of ambient light, difficult to extract signal using zero-crossing detection. Dual-coil target has good reliability and can avoid the communication between fire control system and the fuse of the projectile when launching and flying. Since the coil is relatively fragile, it is not fit to the spin ammunition. The magneto-resistive sensor for measuring is installed in the projectile, thus it does not damage the barrel structure and has less influences on varieties of physical reaction when the projectile flying out of the muzzle. So this method has high precision and is fit to the spin rate.

Comprehensive comparison of various methods is as follows. The optical tachometer is vulnerable to the impact of weather and varieties of physical reactions when projectile flying out of the muzzle, so it has poor operability and measuring precision. The magnetic tachometer is less affected by these factors, and the problems of respective measurement methods can be solved by other methods as follow. For duak-coil target with magneto-resistive sensor tachometer, in the structure, the receiving coil is replaced by magnetoresistive sensor; For the muzzle, muzzle brake is installed to avoid the impact of high temperature of the barrel. The improved method is the main development direction of the conventional ammunition because it is cheap, less destroys the barrel structure and has strong applicability.

3 Conclusion

The initial velocity of the muzzle is one of the main parameters of the conventional ammunition guided transformation, which directly relates to calculation precision of the external ballistics.

In the early days, the device was installed outside the transmitting device, using the optics principle and high speed photography to record the moving trajectory of the projectile. These methods are influenced by the surrounding environment so that they produce large errors; Researchers study Doppler radar velocity measurement, but it can not accomplish the calculation of the projectile ballistics.

Subsequently, researchers proposed that the projectile was interiorly equipped with microcontroller and the control unit, which can help accomplish the calculation of the projectile ballistics. Comparing each method, taking account of complex flight environment and operability of the projectile in practical application, magneto-resistive sensor measurement is proposed for high sensitivity, small size, low power consumption, long working time and accumulated errors over time; coil target velocity measurement has two coils installed in the muzzle's brake, which does not destroy the barrel structure and coils. Combining two methods effectively, measuring precision is improved, which points out the research direction of measuring initial velocity of the projectile muzzle and has the significance of practical application.

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