Sensors & Transducers, Vol. 183, Issue 12, December 2014, pp. 142-146

Sensors & Transducers

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An Accurate Method to Determine the Muzzle Leaving Time of Guns

[1] H. X. Chao, [1] M. Guo, [1] H. S. Huang, [2] X. Y. Gao, [1] S. L. Li, [1] W. B. Du
[1] Northwest Institute of Mechanical and Electrical Engineering,
712099, Xianyang, Shanxi, P. R. China
[2] Information Center of China North Industries Group Corporation, 100089, Beijing, China
E-mail: gqpianpian202@163.com

Received: 18 August 2014 /Accepted: 20 October 2014 /Published: 31 December 2014

Abstract: This paper states the importance of determining the muzzle leaving time of guns with a high degree of accuracy. Two commonly used methods are introduced, which are the high speed photography method and photoelectric transducer method, and the advantage and disadvantage of these two methods are analyzed. Furthermore, a new method to determine the muzzle leaving time of guns based on the combination of high speed photography and synchronized trigger technology is present in this paper, and its principle and uncertainty of measurement are evaluated. The firing experiments shows that the present method has distinguish advantage in accuracy and reliability from other methods. *Copyright © 2014 IFSA Publishing, S. L.*

Keywords: Muzzle leaving time, High speed photography, Photoelectric, Synchronous trigger.

1. Introduction

The conception of muzzle leaving time is defined as the time when the projectile leaves muzzle of a firing gun. This parameter plays an important role in many research fields, such as gun's firing accuracy analysis, gun's dynamics analysis and gun's test and measurements. When studying the factors that influence the gun's firing accuracy, such as the initial disturbance of the muzzle and the projectile's in bore movement rule, the muzzle leaving time is needed. When analyzing the structure response of guns, dynamics, the muzzle leaving time has essential effect on gun's vibrate dynamic module [1-4]. Besides, in gun's firing test, many parameters, such as the shock wave of the blast, the displacement and the velocity of gun's organ, need the unified benchmark to record the time process. Therefore, acquiring the precise value of muzzle leaving time has important guiding significance and great engineering application value.

2. The Commonly Used Methods of Muzzle Leaving Time

Several methods are commonly used in the gun's research field all over the world, such as the muzzle cord on-off method, photoelectric transducer method, and the high speed photography method [5]. The muzzle cord on-off method is universal and primeval, in which a cord of copper line is bound at the center of end muzzle surface of a gun, and DC current flows through the cord. When the gun fires, the cord is broken by the projectile's head, the DC current is cut to zero and a sudden voltage altar may occur in the circuit, thus voltage altar indicating the muzzle leaving time. The trait of this method lies in its simplicity and convenience, but it is vulnerable to the leakage gas of the muzzle, and t in many cases, the cord is broken by the gas before the projectile reaches the muzzle, so the use rate of this method is decreasing. Another adopted method in abroad is muzzle pressure method. In this method, by clamping a pressure probe to the gun tube approximately 50 mm from the first muzzle brake exit vent [6], the pressure signal is provided to determine the muzzle leaving time. This method requires excellent shock wave protection which is hard to be fully meet. Currently, the photoelectric method and high speed photography method are two mainly used methods.

2.1. Photoelectric Transducer Method

The principle of photoelectric transducer method is based on photoelectric transformation. The photoelectric transducer is composed of lens, photosensitive unit, and signal processing circuit. Its principle diagram is shown in Fig. 1. When measuring, the transducer is located apart from the gun and directly facing the muzzle, the image of the muzzle is clearly focused on the photosensitive unit by adjusting the focal of lens. When the gun fires and the projectile leaves the muzzle, the fire light or the heavy smoke may cause the changes in the number of the photoelectron on the photosensitive unit, hence producing a voltage signal to indicate the muzzle leaving time.

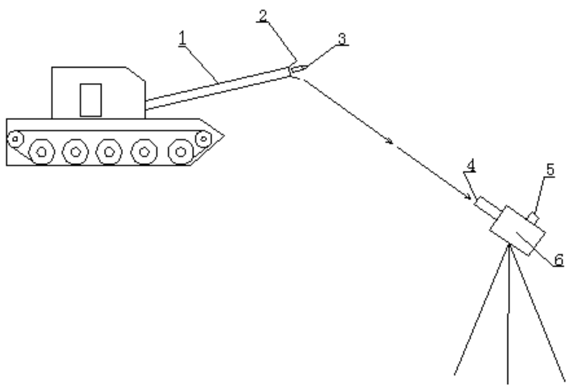

Fig. 1. The principle sketch of electric transducer method. 1 - gun tube, 2 - fire or smoke, 3 – projectile, 4 – lens, 5 - observation window, 6 - photosensitive unit.

The trait of this method lies in its simplicity in operation. Since either firing flame or muzzle smoke can cause obvious signal, the sudden change of the signal caused by the firing flame is used to determine the muzzle leaving time. The muzzle photoelectric signal obtained by the photoelectric transducer is shown in Fig. 2, in which the point A indicates the muzzle leaving time.

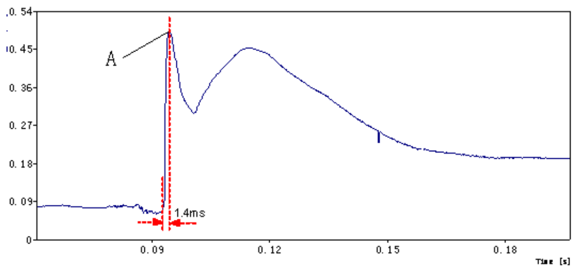

Fig. 2. The muzzle photoelectric signal obtained by the photoelectric transducer.

However, the method also has its inherent fault. Since the occurring time of muzzle firing flame is different depend on the type of gun, the feature point of muzzle leaving time is different. For example, some 120 mm gun's firing flame occurs after the projectile flies apart from the muzzle, as shown in Fig. 3, and some 155 mm gun's firing flame occurs when half of the projectile is still in bore, as shown in Fig. 4.

(a) The muzzle smoke

(b) The end of the projectile leaving the muzzle

(c) The muzzle firing flame

Fig. 3. The process of projectile passes through a 120 mm gun muzzle.

(a) The projectile goes out the muzzle

(b) The muzzle firing flame

Fig. 4. The process of projectile passes through a 155 mm gun muzzle.

Besides, the rising edge of the signal of the transducer is about 1.5 ms, as shown in Fig. 2, thus the specific location of muzzle leaving time on the curve is hard to accurately determine. In this method, the resolution of muzzle leaving time is in ms magnitude and it makes little sense.

2.2. High Speed Photography Method

As the sampling rate of the high speed photography increases, a method based on high speed photography it is widely used to determine muzzle leaving time in recent years. The principle of this method is shown in Fig. 5.

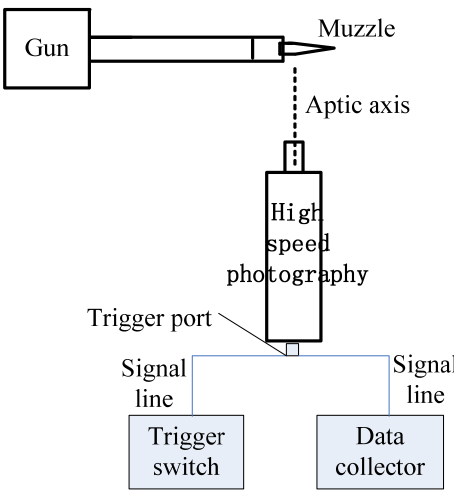

Fig. 5. The sketch of high speed photography method.

In the test, the high-speed photography is placed in the right place on the side of the gun, and its lens focus on the muzzle. A switch for the trigger of the high speed photography is connected to the data recording machine. During the firing, the switch triggers the high speed photography and the switch signal is transferred to the data recording machine at the same time. By subsequent image processing, the passing frame number between the trigger time and the muzzle leaving time is numbered as s, suppose the frame sample rate is f, thus the interval between the switch time and the muzzle leaving time is determined as $t_1 = (s-1)/f$. The sketch is shown in Fig. 6.

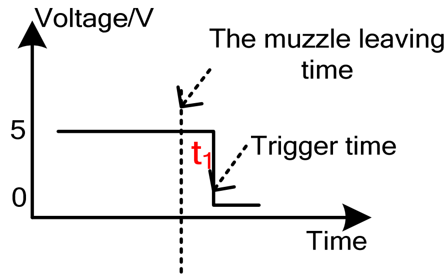

Fig. 6. The sketch of the relationship between the muzzle leaving time and the trigger time.

The precision of the high speed photography method are subject to two main factors. One is the frame sample rate; another is the time resolution of the trigger switch. Under the field condition, the maxim frame sample rate can be set at 10 thousand frames per second, that is, the time resolution can be controlled within 0.01 ms, which can meet the need of measurement accuracy. However, the precision of trigger switch is difficult to be conveniently controlled. Since the usual trigger switch is designed to switch between on and off state by a mechanism device, the corresponding signal is not a clean step signal, which usually has intermittent up and down edges. As shown in Fig. 7, the twitters can last more than 10 ms, thus the muzzle leaving time is hard to determine.

Even though some newly developed high speed photography can send its regulated trigger pulse when being triggered, this trigger pulse also has some twitters under the field condition, so further efforts is needed to improve the time precision.

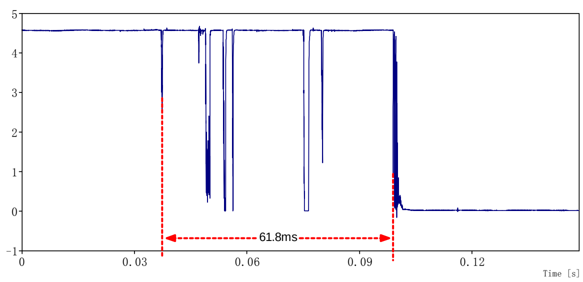

Fig. 7. The trigger signal of on-off switch.

3. A New Method to Determine the Muzzle Leaving Time of Guns

Based on the photoelectric transducer and high speed photography, and with the application of synchronized trigger technology, an accurate method to determine the muzzle leaving time of guns is present in the paper. The prime instruments for the new method include the photoelectric transducer, the high speed photography, and a synchronous device. The synchronous device is developed by the project group in which the author of this paper is involved.

3.1. The Synchronous Device

In order to precisely acquire the muzzle leaving time of guns, a synchronous device is designed to receive the photoelectric signal which is transformed by photoelectric transducer. In the gun test, a photoelectric transducer is located apart from the gun and directly facing the muzzle and its output signal is transferred into the synchronous device. Before the firing, the light level of background is turned into corresponding voltage level by the photoelectric transducer, and is sent to the synchronous device. According to this signal level, the synchronous device adjusts its trigger voltage level to keep out signal stable. When the gun fires, the voltage level of the photoelectric transducer surpass the trigger level of the synchronous device, and the comparator circuit in the synchronous device executes voltage reversal, thus triggering the high speed photography and sending a step signal to the data recording machine to realize the synchronizing.

3.2. The Principle and the Implement of This New Method

The principle of the present method is shown in Fig. 8. In the test, the photoelectric transducer and the high speed photography are placed on each side of the gun, and both being aimed at the muzzle. When the gun fires, the photoelectric transducer executes the muzzle flame light-to-electricity conversion. Meanwhile, the video movement of the muzzle is recorded by the high speed photography. The synchronous device is put in the nearby test room and is pre-adjusted by testers. When preparation is ready, and the all parameters are set, the high speed photography starts to circulate recording. When the gun fires, the synchronous device receives the signal sent by the electric transducer, it automatically trigger the high speed photography and simultaneously sent the step signal to the data acquisition machine. The step signal is as the time benchmark for the other electrical measuring signal. In the end, the muzzle leaving time is accurately determined by the process which is shown in Fig. 6.

Fig. 9 shows a real step signal and a photoelectric signal in a field test.

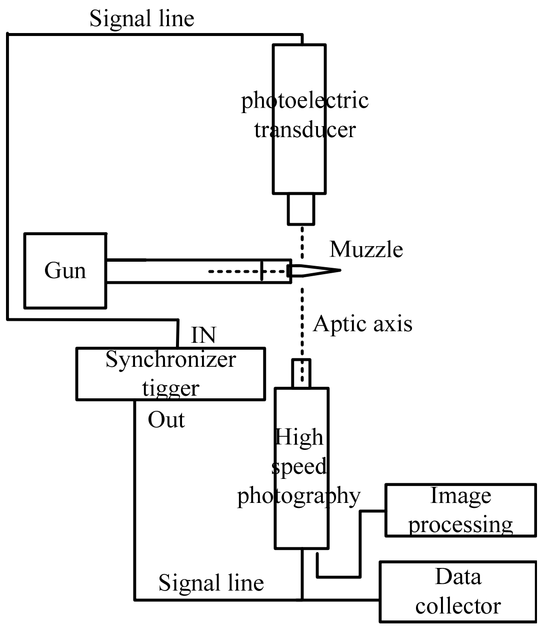

Fig. 8. The sketch of the new method.

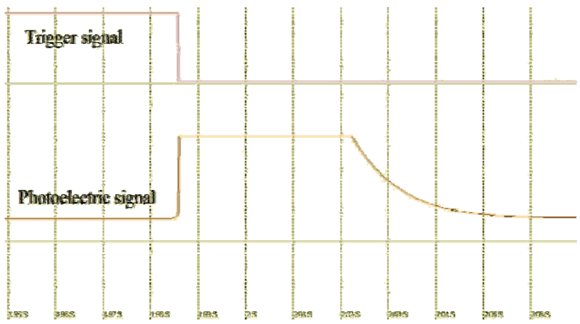

Fig. 9. The trigger signal and the photoelectric signal of a real gun fire test.

The application of the new method avoids the reading error, which is caused by the twittering of the on-off switch, and ensures the precision of the time base. As the muzzle leaving time is close to the automatically trigger time, the number of the intercept frames can be directly set and fixed, thus the workload for artificial interpretation is alleviated and the working efficiency is increased. Owing to the precise location and good consistence, the low-end high speed photography, which has small storage capacity, may woks at a rather high speed sample rate.

3.3. Analysis on the Uncertainty of Muzzle Leaving Time

The formula for the muzzle leaving time t_0 is:

$$t_0 = t_2 - t_1, \tag{1}$$

where t_2 is the trigger time, t_1 is the interval between the switch time and the muzzle leaving time. These two parameters are weekly related, it can be considered that the correlation coefficient is zero, so the variance equation is

$$u_c^2(t_0) = u^2(t_2) + u^2(t_1) \quad (2)$$

The component of uncertainty and evaluation is shown in Table 1.

Table 1. Component of uncertainty and evaluation.

Para-me-ters	Compo-nent	The sources of uncertainty	Dis-tribu-tion	K	Uncer-tainty (μs)
$u(t_1)$	u_1	trigger time of synchronous device	uni-form	$\sqrt{3}$	0.58
$u(t_2)$	u_2	trigger response time of high speed photography	uni-form	$\sqrt{3}$	2.3
	u_3	resolution of frame rate of photography	normal	2	2.5

As the components in table1 are independent, the combined standard uncertainty is

$$u_c(t_0) = \sqrt{\sum_{i=1}^{3}(u_i)^2} = 3.45 \text{ (μs)}, \quad (4)$$

choosing the confidence level as 95 percent, the coverage factor k=2, then the expended uncertainty of muzzle leaving time t_0 is:

$$U_P(t_0) = k \times u_c(t_0) = 7 \text{ (μs)} \quad (5)$$

4. Conclusions

Up to now, the new method which uses a photoelectric transducer as trigger source to automatically trigger high speed photography is the highest accurate measurement to determine the muzzle leaving time of guns. It is applicable to various types of muzzle radius. Based on the recent experiment conducted by the projectile group, the method is reliable and convenient. Meanwhile, the synchronous device can trigger several high speed photography simultaneously, and with specifically designed photoelectric circuit, it can sent step signal to gun's servo control system, thus a unified time base is constructed for all the signals in the gun's test field.

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