

Calibration Method of Bullet Speed Measuring Devices

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Abstract –The bullet speed measuring device is an instrument for measuring the speed of bullets, which is widely used in public security systems, judicial identification departments, gun performance research institutions, etc. For bullet speed measuring devices, speed is the most important parameter. This article provides a method for measuring the speed of a bullet speed measuring device and an analysis of the uncertainty in measurement. There are two methods to calibrate the speed: simulation method and live ammunition method. The simulation method selects a signal generator with a time base relative frequency deviation better than 5×10^{-8} for calibration, and the speed calibration range is (10~1000) m/s. The live ammunition shooting method uses a time interval measuring instrument with a time base relative frequency deviation better than 5×10^{-8} , and the speed calibration range is (40~250) m/s.

Keywords –Bullet speed, calibration method, live ammunition shooting, measurement, simulation shooting, time interval, analysis of the uncertainty

I. INTRODUCTION

Bullet speed measuring device is an instrument or equipment that measures the firing speed, specific kinetic energy and other parameters of metal or other material projectiles fired by various barrel shooting weapons (using tubular equipment to launch projectiles, usually less than 20mm in diameter)[1]. Pass through the two layers of photoelectric screens to generate photoelectric signals. The time interval measuring unit measures the time interval of the front and back screens triggering the photoelectric signals, and performs data processing through the distance between the two screens to obtain the bullet speed. The bullet speed measuring device is generally composed of a photoelectric screen, a speed measurement and display unit, and an output printing part[2]. It is widely used in public security departments, judicial authentication institutions, gun performance research institutions, etc. In recent years, users have become more and more aware of the importance of accurate measurement of bullet speed measuring devices. Its accuracy directly affects the fairness and justice of the public security and judicial departments[3]. Currently, various departments have an increasing demand for the

calibration of bullet speed measuring devices, and the number of calibrations is increasing. The national metrology department is formulating unified calibration specifications. This article provides a calibrating method for bullet speed measuring device[4-10].

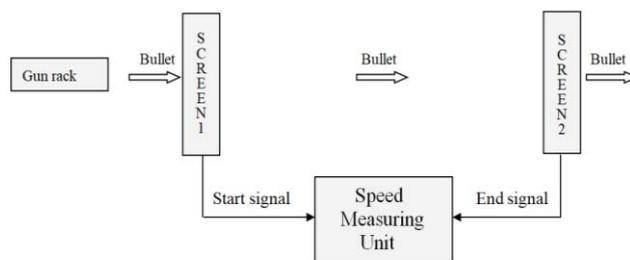


Fig. 1. Working diagram of bullet speed measuring device.

II. DESCRIPTION OF THE METHOD

The velocity range of bullet speed measuring device is (10~1000) m/s, and the maximum permissible error of velocity measurement is $\pm (0.1\% \sim 2\%)$. In this paper, it is calibrated according to these metrological characteristics. There are two methods to calibrate the speed: simulation method and live ammunition method. The simulation method selects a signal generator with a time base relative frequency deviation better than 5×10^{-8} for calibration, and the speed calibration range is (10~1000) m/s. The live ammunition shooting method uses a time interval measuring instrument with a time base relative frequency deviation better than 5×10^{-8} , and the speed calibration range is (40~250) m/s.

A. the Simulation Shooting Method

For the speed calibration of the simulation method, the signal generator with time base relative frequency deviation better than $\pm 5 \times 10^{-8}$ is selected to output the time interval signal, and the signal generated by the simulation bullet shooting is connected to the speed measurement unit for calibration. The common trigger

signal of the bullet speed measuring device is two rising edge pulses with amplitude of 5V, so we set the signal generator channel A to send the first rising edge signal to the first screen of the bullet speed measuring device. After the standard time interval, channel B Send the second rising edge signal to connect to the second screen of the bullet speed measuring device. This speed calibration of the simulation method does not need live ammunition shooting, and the speed calibration range is (10~1000)m / s.



Fig. 2. Connectivity graph of simulation shooting method

As shown in Fig. 2, connect the output A of the signal generator to the start signal terminal of the calibrated bullet speed measuring device, and the output B to the end signal terminal. According to the received level signal mode and value of the calibrated bullet speed measuring device, set the corresponding output mode and output level of the signal generator and the speed measuring unit receives the signal and displays the speed.

According to the speed measurement range, select at least 5 speed calibration points evenly for calibration. Calculate the output value of standard time interval according to equation (1).

$$t_s = l/v_s \quad (1)$$

where v_s represent the speed calibration points and t_s represent the standard time interval and l represent speed measuring distance.

Set the signal generator for output, record the speed display value of the speed measuring unit, measure three times, and take the average value as the speed measurement result of this point. According to equation (2), the relative error between the speed measurement value and the speed setting value at a speed calibration point is calculated and recorded.

$$\delta_s = \left(\overline{v_x} - v_s \right) / v_s \times 100\% \quad (2)$$

where δ_s represent the relative error of speed measurement and $\overline{v_x}$ represent the average value of three times of speed measurement . It shows the commonly used time interval and speed comparison like Table 1.

Table 1. Comparison table of standard time and speed.

Standard time interval (s)	Standard speed value (m/s)		
	$l=0.402m$	$l=1m$	$l=2m$
0.0005	804.00	/	/
0.001	402.00	1000.00	/
0.002	201.00	500.00	1000.00
0.004	100.50	250.00	500.00
0.005	80.40	200.00	400.00
0.01	40.20	100.00	200.00
0.02	20.10	50.00	100.00
0.04	10.05	25.00	50.00
0.05	/	20.00	40.00
0.1	/	10.00	20.00
0.2	/	/	10.00

0.0005	804.00	/	/
0.001	402.00	1000.00	/
0.002	201.00	500.00	1000.00
0.004	100.50	250.00	500.00
0.005	80.40	200.00	400.00
0.01	40.20	100.00	200.00
0.02	20.10	50.00	100.00
0.04	10.05	25.00	50.00
0.05	/	20.00	40.00
0.1	/	10.00	20.00
0.2	/	/	10.00

B. the Live ammunition shooting Method

In this method, it is necessary to select a time interval measuring instrument with time base relative frequency deviation better than $\pm 5 \times 10^{-8}$ and a bullet speed measuring device to measure the bullet firing speed at the same time.

Place the gun on the gun shooting rack, adjust the angle of the gun shooting rack, make the firing direction of the bullet perpendicular to the photoelectric conversion screen, launch a certain speed of the bullet, the bullet passes through the front and rear photoelectric screens, generate the time interval signal, and use the bullet speed measuring device and the time interval meter to measure at the same time. The speed calibration of live ammunition shooting method requires live ammunition shooting, and the speed calibration range is (40~250) m/s.



Fig. 3. Connectivity graph of live ammunition shooting method

As shown in Fig. 3, connect the channel A of the time interval measuring instrument to the start signal terminal of the calibrated bullet speed measuring device, and the channel B to the end signal terminal. Set the time interval meter to the "time interval measurement" mode, adjust the trigger edge, trigger level and trigger slope of channel A and channel B, and match the output signal of the calibrated bullet speed measuring device.

The live ammunition shooting bullet with the corresponding speed passes through the two-layer photoelectric screen, generating the start signal and the end signal. After the signal processing, the speed value is displayed by the calibrated bullet speed measuring device, and the time interval of the two signals is measured by

the time interval meter. Calculate the actual value of bullet speed according to equation (3).

$$v_0 = l/t_0 \quad (3)$$

where v_0 represent the actual value of bullet speed and t_0 represent the time interval measurement.

Calculate the relative measurement error of the speed indication according to equation (4).

$$\delta_0 = (v_y - v_0)/v_0 \times 100\% \quad (4)$$

where δ_0 represent the relative error of speed measurement and v_y represent the speed display value on the speed display unit of the calibrated bullet speed measuring device.

III. EVALUATION OF UNCERTAINTY IN MEASUREMENT

A. Evaluation of Uncertainty of Speed Measurement by Simulation Method (Take 100m/s as an example)

A.1 Measurement model and sensitivity coefficient

$$\Delta v_x = v_x - v_s = v_x - \frac{l}{t_s} \quad (5)$$

where Δv_x represent the error of speed measurement.

The sensitivity coefficient:

$$c_1 = \frac{\partial \Delta v_x}{\partial v_x} = 1 \quad (6)$$

$$c_2 = \frac{\partial \Delta v_x}{\partial t_s} = \frac{l}{t_s^2} \quad (7)$$

$$c_3 = \frac{\partial \Delta v_x}{\partial l} = -\frac{1}{t_s} \quad (8)$$

A.2 Standard Uncertainty Induced by the Repeatability of Readings of Bullet speed measuring device $u(v_{x1})$

Set the output standard time interval of the time synthesizer to 0.02s, the corresponding speed value is 100m/s, and the bullet speedometer is used to repeat the measurement 10 times. The data obtained is shown in Table 2.

Table 2. Simulation method speed measurement data.

Serial number	Measured value
1	100.0 m/s
2	100.0 m/s
3	100.0 m/s

4	100.0 m/s
5	100.0 m/s
6	100.0 m/s
7	100.0 m/s
8	100.0 m/s
9	100.0 m/s
10	100.0 m/s

Then the average of the measurements:

$$\bar{v}_x = \frac{1}{n} \sum_{i=1}^n v_i = 100.00 \text{m/s} \quad (9)$$

Experimental standard deviation:

$$s = \sqrt{\frac{1}{n-1} \sum_{i=1}^n (v_i - \bar{v}_x)^2} = 0.0 \text{m/s} \quad (10)$$

Standard uncertainty introduced by the repeatability of readings:

$$u(v_{x1}) = \frac{s}{\sqrt{n}} = 0.0 \text{m/s} \quad (11)$$

A.3 Standard Uncertainty Induced by the Reading Resolution of the Bullet speed measuring device $u(v_{x2})$

Assuming that the uncertainty caused by the resolution is uniformly distributed, the confidence factor $k = \sqrt{3}$, when the speed is 100m/s, the resolution is 0.1m/s, and the standard uncertainty brought by it is

$$u(v_{x2}) = \frac{0.1}{2\sqrt{3}} \text{ m/s} \approx 2.9 \times 10^{-3} \quad (12)$$

A.4 Standard uncertainty introduced by time interval output error of time synthesizer $u(t_s)$

Assuming a uniform distribution, the confidence factor $k = \sqrt{3}$, the maximum allowable error of the time synthesizer is $\pm(T \times 1 \times 10^{-7} + 5 \text{ns})$, and the output 0.02s brings standard uncertainty

$$u(t_s) = \frac{(0.02 \times 1 \times 10^{-7} + 5 \times 10^{-9}) \text{ s}}{\sqrt{3}} = 4.04 \times 10^{-9} \text{ s} \quad (13)$$

A.5 Standard uncertainty introduced by the uncertainty of velocity measurement interval $u(l)$

Assuming a uniform distribution, the confidence factor $k = \sqrt{3}$, the known uncertainty of the velocity measurement interval is 0.5mm, then the standard uncertainty caused by the uncertainty of the velocity measurement interval during speed measurement is

$$u(l) = \frac{0.5 \text{mm}}{\sqrt{3}} = 2.9 \times 10^{-4} \text{ m} \quad (14)$$

A.6 Summary of measurement uncertainty

The uncertainty of each standard is not related, summarized in the following table.

Table 3. Summary of simulation method speed measurement standard uncertainty at 100 m/s.

Serial number	source	Standard uncertain
$u(v_{x1})$	repeatability of readings	0.0m/s
$u(v_{x2})$	reading resolution	2.9×10^{-2} m/s
$u(t_s)$	time interval output error	4.04×10^{-9} s
$u(l)$	uncertainty of velocity measurement interval	2.9×10^{-4} m

It can be seen from the above table that the standard uncertainty of resolution is greater than the standard uncertainty of repeatability, so the uncertainty component of repeatability can be ignored.

A.7 Synthetic standard uncertainty

Known sensitivity factor, then

The uncertainty component introduced by the reading resolution of the bullet speedometer measurement result:

$$u_2 = |c_1| u(v_{x2}) = 1 \times 2.9 \times 10^{-2} \text{ m/s} = 2.9 \times 10^{-2} \text{ m/s} \quad (15)$$

The uncertainty component introduced by time synthesizer output error:

$$u_3 = |c_2| u(t_s) = \frac{1.9997}{(0.02)^2} \times 4.04 \times 10^{-9} \text{ m/s} = 2.02 \times 10^{-5} \text{ m/s} \quad (16)$$

The uncertainty component introduced by uncertainty of velocity measurement interval:

$$u_4 = |c_3| u(l) = \frac{1}{0.02} \times 2.9 \times 10^{-4} \text{ m/s} = 1.45 \times 10^{-2} \text{ m/s} \quad (17)$$

Each standard uncertainty component is irrelevant, and the combined standard uncertainty is the square root of each uncertainty component of the output:

$$u_C = \sqrt{\sum_{i=1}^n u_i^2} \quad (18)$$

Then Synthetic standard uncertainty:

$$u_C = \sqrt{u_2^2 + u_3^2 + u_4^2} = 0.032 \text{ m/s} \quad (19)$$

A.8 Extended uncertainty

Take the inclusion factor $k=2$, then expand the uncertainty Synthetic standard uncertainty:

$$U = k u_C = 2 \times 0.032 \text{ m/s} = 0.064 \text{ m/s} \approx 0.1 \text{ m/s} \quad (20)$$

Which is $\bar{v}_x = 100.0 \text{ m/s}$, $U = 0.1 \text{ m/s}$, $k=2$.

B. Evaluation of Uncertainty in Velocity Measurement of Live Ammunition (Take 40m/s as an example)

The uncertainty evaluation of the live ammunition method is similar to the simulation method. Due to the limited space in this article, the specific calculation process will not be explained. Only the factors that affect the uncertainty evaluation and the final evaluation results are listed for everyone to communicate.

B.1 Summary of measurement uncertainty

The uncertainty of each standard is not related, summarized in the following table.

Table 4. Summary of live ammunition method speed measurement standard uncertainty at 40 m/s.

Serial number	source	Standard uncertain
$u(v_{y1})$	repeatability of readings	1.6×10^{-2} m/s
$u(v_{y2})$	reading resolution	2.9×10^{-2} m/s
$u(t_0)$	time interval measurement error	1.44×10^{-9} s
$u(l)$	uncertainty of velocity measurement interval	2.9×10^{-4} m
$u(\delta)$	photoelectric conversion time	3.68×10^{-8} s
$u(\theta)$	the direction of the bullet is not vertical	1.73×10^{-4} m

It can be seen from the above table that the standard uncertainty of resolution is greater than the standard uncertainty of repeatability, so the uncertainty component of repeatability can be ignored.

B.2 Synthetic standard uncertainty

Each standard uncertainty component is irrelevant, and the combined standard uncertainty is the square root of each uncertainty component of the output:

$$u_C = \sqrt{\sum_{i=1}^n u_i^2} \quad (21)$$

Then Synthetic standard uncertainty:

$$u_C = \sqrt{u_2^2 + u_3^2 + u_4^2 + u_5^2 + u_6^2} = 0.0298 \text{ m/s} \quad (22)$$

B.3 Extended uncertainty

Take the inclusion factor $k=2$, then expand the uncertainty Synthetic standard uncertainty:

$$U = ku_c = 2 \times 0.0298 \text{m/s} = 0.0596 \text{m/s} \approx 0.1 \text{m/s} \quad (23)$$

Which is $\Delta v_y = 40.0 \text{m/s}$, $U = 0.1 \text{m/s}$, $k=2$.

III.CONCLUSION

The bullet speed measuring devices are widely used in criminal investigation, judicial identification and gun performance research institutions. This paper provides a calibration method for it. The velocity is the most important measurement characteristic of the bullet speed measuring devices. In this paper, the simulation method and the live ammunition shooting method are used to calibrate it. For simulation method the signal generator with time base relative frequency deviation better than $\pm 5 \times 10^{-8}$ is selected for calibration and the speed calibration range is (10~1000) m/s. The live ammunition shooting method requires live ammunition shooting and time interval measuring instrument with time base relative frequency deviation better than $\pm 5 \times 10^{-8}$, and the speed calibration range is (40~250) m/s.

ACKNOWLEDGEMENT

We thank the reviewers' valuable comments and suggestions, which are valuable in improving the communication and also important for our future research.

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