A Novel Approach for Warhead Fragments Velocity Measurement Based on Laser Screen

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Abstract – The velocity of warhead fragment is key criteria to determine its mutilation efficiency. We have designed an opto-electronic system to accurately measure the average velocity of warhead fragments. The apparatus including two parallel laser screens spaced apart at a known fixed distance for providing time measurement start and stop signals. The large effective screen area is formed by laser source, retro-reflector and large area photo-diode with a central hole. Whenever a moving fragment interrupts two optical screen, the corresponding photometers senses the event, due to partial obscuration of the incident energy. Experiments have been performed to measure velocity of the different kinds of projectiles and fragments within various size and velocity ranges, including 7.62 mm bullet shooting experiments, prefabricated steel-ball exploding experiments. They were proved that the system is adequate to measure the velocity of larger than 5 mm, less than 1 000 m/s in the range, when fixed trajectory, test the velocity of the projectile average relative deviation is less than 4.21%. The system can perform satisfactorily with a lot of advantages such as larger effective light screen area, quick response speed, low uncertainty, strong repetition and reliability, etc.

Key words – ***non-contact measurement***; ***velocity measurement***; ***laser screen***; ***retro-reflector***

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1 Introduction

A great effort has been made recently to evaluate the damage of warhead. Fragments velocity is one of the important reference parameters. Many researches on velocity measurement technology have been carried out. Doppler radar and photographic systems can measure instantaneous velocity with high precision. Nevertheless, they are quite expensive, and it is not suitable for small subject[1-3]. The measurement technique for the Time of Flight(ToF) of a flier between two fixed points or planes is employed to determine the velocity of high-speed fliers. Speed measurement apparatuses using screens based on Infrared (IR)or optical radiation fields offer very high resolution and sensitivity while being immune to electromagnetic interference and incompatibility, but the measurement schemes of the prior art typically exhibit one or more of the following disadvantages[4-8]:

1) Instrument using frame structure is not suitable for warhead explosion experiments;

2) They are unreliable due to excessive false triggering, particularly when ambient lighting is used;

3) Effective area is small, suitable for testing the fixed track objects;

4) Signal processing is complex, not suitable for continuous test.

This paper will describe a laser-based system, employing two parallel laser screens for measurement of the speed of fragments moving up to 1000 m/s. The optical screens are spaced apart at a known or fixed distance for providing time measurement stat and stop signals. Each screen is constructed from a single source and does not require any expensive aspheric optical components. The system ensures accurate performance over a wide range of ambient light, temperature, and other environment conditions, including the high ballistic pressure and shock waves generated during measurements on high-speed projectiles.

2 Design and description of apparatus

2.1 Basic principle of system

The system comprises an optical unit, an electronic unit and a data acquisition & processing unit. Complete configuration is shown in Fig. 1. Whenever a fragment crosses either of the screens, the corresponding photodetector senses the event, due to partial or full obscuration of the incident energy. The change of light flux is transformed by photodiode into electronic signal. The weak signal is amplified and filtered by signal conditioning, then, sampled by data acquiring devices. Data processing is finished by special software in computer. As the

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distance between the screens being known, the velocity is displayed on a computer screen.

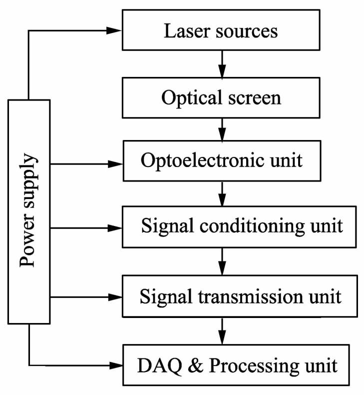


Fig. 1 Block diagram of the system

2.2 Large laser screen

The novel laser screen measurement system includes two parallel laser screens. Each screen consists of a laser diode, a large photodetector, optical filter and retro-reflector. Laser diode emits visible radiation at 635 nm wavelength. Photodetector assembled with a lot of PIN photodiodes which response time less than 10 ns has responsivity of 0.4 A/W. A slit of size 3×5 mm located in the center of photodetector. Optical output of the laser source is a collimated beam. The beam passes through cylindrical lens and the slit of photodetector to reach retro-reflector (a non-metalized microprismatic lens reflective sheeting). Based on the theory of remained divergence angle, the energy of light focuses on photodetector, as shown in Fig. 2.

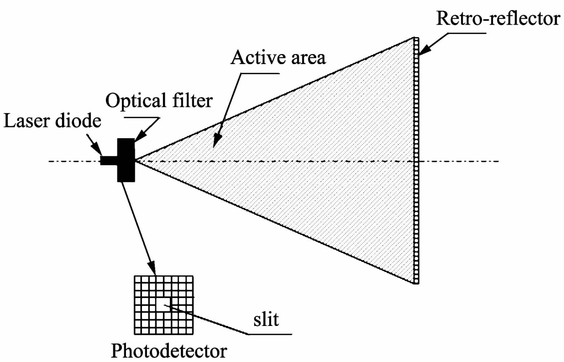
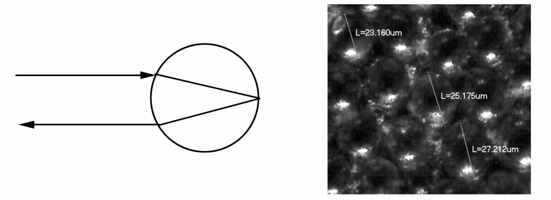


Fig. 2 Optical system schema

2.3 Retro-reflector

High intensity reflective sheeting, designed to reduce the weight and complexity of system, is that of non-metalized micro glass beads. The sheeting consists of many small beads. When the refractive index of glass beads $n=2$, the incident light returns to the original. It provides long-term reflectivity and durability. The structure of retro-reflector is shown in Fig. 3.



(a) Optical path of glass bead (b) Reflector image under the microscope

Fig. 3 The principle of reflector

2.4 Effective area analysis

After being expanded, the divergence angle of laser beam is 60°. The instrument was placed in 0.5 m underground. The distance between optical export and cooperation target is 2.5 m. Therefore, the height of overground screens is 2.0 m. After calculation, the effective area is 1.72 m^2, as shown in Fig. 4. In the figure, rectangular area has high sensitivity where the effective target is larger than 1 m^2.

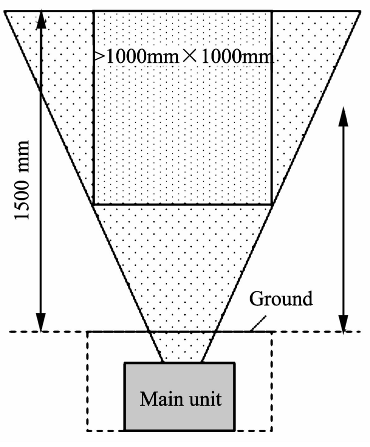


Fig. 4 Effective area of system

2.5 Electronic circuit and data acquisition system

Optical module connects two analogue channels. A preamplifier, a conditioning circuit and DAQ system are combined to compose photoelectric detection system of high sensitivity and quick response.

For high-speed components, the output noise of the photodetector increases exponentially with the speed of the fragment whereas the signal amplitude decreases, which reduces the signal-to-noise ratio (SNR). The preamplifier and signal-conditioning circuits are designed to minimize the noise, such as the noise produced by insects flying through the light screen. To increase the sensitivity of measurement, a variable dc reference voltage corresponding to ambient noise is subtracted from the signal. We used a preamplifier of AD8066, which is characterized by a high speed (145 MHz), low input voltage noise (7 nV/Hz$^{1/2}$), and wide supply voltage range (5 V ~24 V). The most important part of conditioning circuit is the main amplifier. As a main amplifier, we use AD8027, which is characterized by rail to rail input and output, wide dynamic signal range, and low noise (4.3 nV/Hz$^{1/2}$). After being processed by conditioning circuit, the signal of fragment passing through the screen is acquired by DAQ system. DAQ system based on the open industry-standard PXI (PCI extensions for instrumentation), which characteristic parameters including sampling rate at 10 Mbit/s, input resolution at 12 bits and with 32M memory, etc. Finally, output digital signals can be transmitted to the remote computer through 1 000 base Ethernet. Velocity data can be generated instantaneously by the computer based addition of appropriate software and displayed on a computer screen. The electronic circuit is sensitive enough to detect even 1% change in intensity. The system is an active system capable of detecting advancing objects, and does not require synchronization with the firing signal.

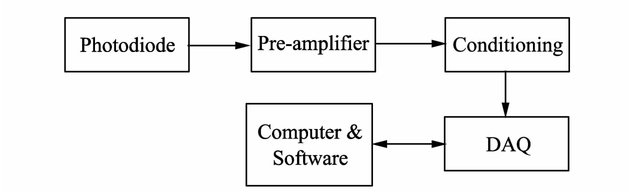


Fig. 5 Block diagram of electronic circuit

3 Instrument errors

The performance of the laser-based speed measurement system depends on how accurately the ToF and the distance between the screens, through which smallest fragment with the highest speed passes, are measured. The velocity of the fragment under test is measured as the ratio of the distance between the screens and the ToF, and the uncertainty in the measurement of the speed depends on these two parameters. The speed measured by ToF is governed by the following equation

$$v = S/t. \tag{2}$$

The relative error of the speed depends on the relative errors of the distance and time, and represented by the following equation

$$\frac{\Delta v}{v} = \frac{\Delta S}{S} - \frac{\Delta t}{t}, \tag{3}$$

where v is actual value of the speed, S is distance between the laser screens screen distance, t is time of flight.

The screen distance was kept at 250 mm and measured with an accuracy of 0.1 mm. There is parallelism error of 1 arcmin between the screens, which produces an inaccuracy of 0.08 mm in the screen distance. There can be an error in the screen distance because of the deviation angle of the fragment. Different sizes can be introduced with an error of 0 ~ ±0.05 mm in the screen distance. The ToF is recorded by data acquiring devices (DAQ) with an accuracy of 0.2 μm. Taking into consideration all the mentioned errors, the speed estimation error is 0.1%, excluding experimental errors.

4 Measurement results

4.1 Performance of the system

A number of experiments were performed using different warhead fragments. The warheads were placed at a distance of about 10 m from the system, as shown in Fig. 6. The laser screen, was properly aligned, with laser screen of 1 000×1 000 mm and a distance between two screens of 250 mm. The main unit includes laser source, optoelectronic unit and signal conditioning unit underground. Thus, the equipment avoids being hit by fragments. The measured typical results are shown in Fig. 6 and Tab. 1. The results are within the ranges supplied by manufacturers, which validate the measurement.

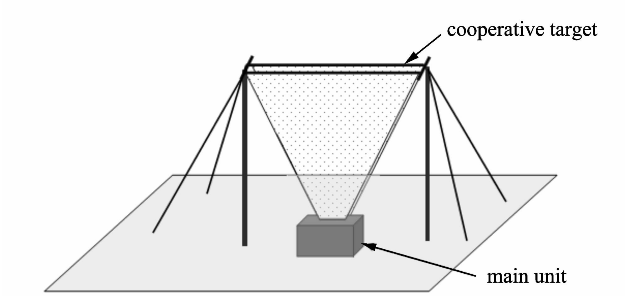


Fig. 6 Distribution of measurement system

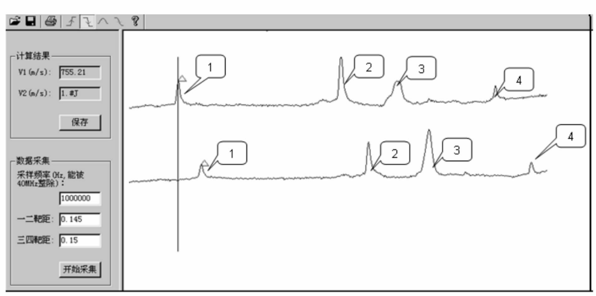


Fig. 7 Waveform of fragments

Tab. 1 Welocity data of warhead fragments (System sampling frequency at 5 MHz, distance between two screens at 250 mm)

NO.	v_1 (m/s	v_2 (m/s)	v_3 (m/s)	v_4 (m/s)	v_5 (m/s)
1	755.21	625.00	533.09	464.742	
2	740.74	714.29	719.42	600.24	543.46

4.2 Repeatable accuracy

To inspect the repeatability of the system, two systems were located in the same trajectory. The distance between the two systems is 4 m, as shown in Fig. 8. The rifles were rigidly mounted on a table placed at a distance of about 20 m from the system. Typical result is shown in Tab. 2.

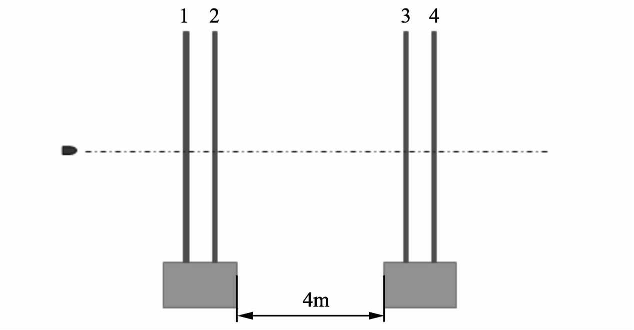


Fig. 8 The placement of the experimental system

Tab. 2 Results of test 2 speed data of 54 automatic rifle(7.62mm)

NO.	v_{14} (m/s)	v_{23} (m/s)	$\Delta_1 = v_{14} - v_{23}$ (m/s)
1	738.759	738.706	0/053 0
2	733.790	733.725	0.065 0
3	734.257	733.787	0.470 0
4	730.883	730.471	0.412 0
5	735.306	734.963	0.343 0
6	738.682	738.361	0.321 0
$\bar{v}$ = 735.140 8 $\bar{\Delta}_1$ = 0.277 3 Δ_{max} = 0.470 0 S_1 = 0.177 1 $S_1/\bar{v}$ = 2.41%			

NO.	$v = \frac{v_{14} + v_{23}}{2}$ (m/s)	v_{12} (m/s)	$\Delta_2 = v_{12} - \bar{v}$ (m/s)
1	738.732 5	740.065	1.332 5
2	733.757 5	735.491	1.733 5
3	734.022 0	730.277	1.255 0
4	730.677 0	731.630	0.953 0
5	735.134 5	736.063	0.928 5
6	738.521 5	739.520	0.998 5
$\bar{v}_{12}$ = 736.341 0 $\bar{\Delta}_2$ = 1.200 2 Δ_{2max} = 1.733 5 S_2 = 0.310 0 $S_1/\bar{v}_{12}$ = 4.21%			

4.3 The tests of the system under different illuminations

The system has been tested in different ambient light conditions using different-caliber guns. A number of experiments have been performed in an outdoor range with ambient light of about 100 000 lx, in an indoor range with an artificial floodlight of about 2000 lx directed towards the system, and in a darkroom. The results show that the system yields consistent readings, which ensure that the system can perform satisfactorily in outdoor and indoor ranges with a wide range of ambient light conditions.

5 Conclusions

Large amount of experiments have been performed to measure the velocities of different kinds of projectiles in various velocity ranges, including small fragments, 7.62 mm bullet, different shells, etc. All experiments acquired effective data. The results show that the system works properly, non-occurrence of false triggering. Main advantages of the reported system in comparison with commercially available ones are as follows:

1) The use of visible laser makes the alignment easier;

2) The optical screens can be used at indoor or outdoor ranges equally effective;

3) The system has a lot of advantages such as larger effective light screen area, quick response speed, low uncertainty, strong repetition and reliability, etc;

4) The system also can be used to measure the velocity of projectile and other high speed objects.

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