Optoelectronic System for Measuring Warhead Fragments Velocity

Ji Liu\(^1\,2\,3\), Donge Zhao\(^1\,3\), Yangjun Li\(^1\) and Hanchang Zhou\(^1\,2\)
\(^1\)National Key Laboratory on Electronic Testing Technology, Taiyuan, 030051, China
\(^2\)Education Ministry Key Laboratory on Instrumentation Science and Dynamic Testing, Taiyuan, 030051, China
\(^3\)School of Information and Communication Engineering North University of China, Taiyuan, 030051, China

E-mail:gdcs2009@sina.com

Abstract. High-speed warhead fragments velocity measurement is one of the key technologies in investigating damage efficiency of warhead. We have designed and constructed a system to accurately determine the velocity of warhead fragments by measuring the time of flight between two parallel laser screens is presented. Each screen is formed by a laser source, a large photodetector and a retro-reflector. Optical output of the laser source is a collimated beam. The beam passes through cylindrical lens and the slit of photodetector reach to retro-reflector. The energy, reflected by retro-reflector; focus on the active area of photodetector. The system utilizes reflected ray by scotchlite retro-reflector as the start and end signal. And utilizes wideband circuit and data acquiring system to condition and sample signals. Experimental results show the system can measurement velocity are within the range from 20m/s to 2000m/s on target area of 1m\(^2\) and can perform satisfactorily with a wide range from 2000 lx to100,000lx. The measurement system also can be used to test velocity of projectile.

Keywords: laser screen; non-contact measurement; fragment velocity; retro-reflector; external ballistics

1. Introduction

Various means have been used in the prior art to determine the velocity of fragments undergoing development. The technique of measurement of the time of flight (ToF) of a fragment between two fixed points or planes is routinely employed to determine the speed of fast-moving fragments. The passage of the fragment creates a field perturbation that can be sensed in terms of some measurable quantity such as the pressure, electric or magnetic field, or radiation field. The Doppler frequency-shift measurement technique is also used for measurement of the velocity of projectiles, but it is not suitable for small-caliber fragments. Speed measurement apparatus 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 typical exhibit one or more of the following disadvantages:

(1) They require larger optical components to construct larger screens, whose sensitivity is not uniform over the entire screen area.
(2) They need careful alignment during installation.
(3) They are unreliable due to excessive false triggering, particularly when ambient lighting is used.
(4) Systems employing sunlight as the source cannot be used indoors, and the precision and accuracy of such systems are very much dependent on the intensity fluctuations of the sunlight.

Foundation items: Project supported by the National Key Laboratory on Electronic Testing Technology, China (Grant No.9140C1204041009) and National Key Laboratory on Electronic Testing Technology Fund for Young Scholars, China

Published under licence by IOP Publishing Ltd
This paper will be described a laser-based system, employ two parallel laser screens for measurement of the speed of fragments moving up to 2000 m/s. The optical screens are spaced apart at a known or fixed distance for providing time measurement start 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 system

2.1. Basic Principle of System
The system is comprised of an optical unit, electronic unit, and a data acquisition & processing unit. Complete configuration, as 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 an electronic signal. The weak signal amplified and filtered by signal conditioning, then, sampled by data acquiring devices. Data processing is finished by professional software in computer. The distance between the screens being known, the velocity is displayed on a computer screen.

![Figure 1. Composition of system](image)

2.2. Large laser screen
The novel laser screen measurement system includes two parallel laser screens, each screen is formed by a laser diode, photo detector array and a retro-reflector. Laser diode emitting visible radiation at 650nm wavelength and having suitable power, which may vary from 5 to 50 mW depending on the size of the laser screen. Photo detector array assembled with lots of PIN photodiode which response time less than 10 ns, responsivity 0.4 A/W, typical at 635 nm. A slit of size 4x4mm in the center of photo detector. Optical output of the laser source is a collimated beam. The beam passes through cylindrical lens and the slit of photo detector reach to retro-reflector (a non-metalized micro-prismatic lens reflective sheeting). Based on the theory of remained divergence angle, the energy of laser source focus on photo detector. As shown in Fig.2.

![Figure 2. Optical system schematic](image)
2.3. Scotchlite Retro-reflector
Scotchlite is reflective sheeting has the property of directing a large fraction of the light reflected by it back toward the vicinity of light source. The optical elements of Scotchlite consist of small beads of transparent material with a metallic reflective coating, and are attached on their coated side to a backing sheet. In the Scotchlite sheeting, the beads are packed closely so as to effectively provide a continuous surface having the reflective characteristics of the beads which were used. The structure of Scotchlite, as shown in Fig.3. It provides long-term reflectivity and durability.

![Figure 3 Micro-prismatic lens schematic](image)

3. Electronic Circuit and Data acquisition system
Optical module connects two analogue channels, which contains a preamplifier, a conditioning circuit and DAQ system. The preamplifier amplifies the signal coming from the photodiode. For high-speed components, the output noise of the photodetector increases exponentially with the speed of the projectile whereas the signal amplitude decreases, which reduces the signal-to-noise ratio(S/N). The preamplifier and signal-conditioning circuits are designed to minimize the noise, such as insects flying through the light screen. To increase the sensitivity of measurement, a variable dc reference voltage corresponding to ambient noise, such as flicker of other light sources nearby, is subtracted from the signal. As a preamplifier we used an AD8066 (Analog Devices), which is characterized by high speed (145 MHz), low input voltage noise (7 nV/Hz^{1/2}), and Wide supply voltage range (5 V to 24 V). Conditioning circuit consist of a main amplifier. We use the AD8027, which is a high speed amplifier with rail-to-rail input and output that operates on low supply voltages (2.7V to 12V) and is optimized for high performance and wide dynamic signal range and low noise (4.3 nV/Hz1/2) and low distortion (120 dB @ 1 MHz). The signal, which output of conditioning circuit, proceeds towards the DAQ system, which consist of 4 analog channels, every channels sampling rate at 10 Mbit/s, input resolution at 12 bits and with 32M memory. DAQ system based on the open industry-standard PXI (PCI eXtensions for instrumentation) architecture deliver high-performance. Output digital signals can then be transmitted to the remote computer through 1000 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.

![Figure 4. Block diagram of electronic circuit](image)

4. Experimental results
4.1. Test 1

A number of experiments were performed using different warhead fragments. The warheads were placed at a distance of about 10m from the system. The laser screen, properly aligned, with each laser screen of size $1000 \times 1000 \text{mm}$ and a distance between two screens of 250mm. The main parts, include laser source and photo detector, are underground. Thus, equipment to avoid being hit by fragments. After the experiment, apparatus is intact, although covered by some dust, shown in Fig.5. The measured typical results are shown in Fig.6 and Table1. The results are within the ranges supplied by the manufacturers, which validate the measurement.

![Figure 5. Apparatus after the experiment](image)

![Figure 6. Signal waveform of fragments.](image)

| Table1. Velocity data of warhead fragments. |
|-------------------------------------------|
| $v_1$ | $v_2$ | $v_3$ | $v_4$ | $v_5$ |
| 1332.7 | 1292.4 | 1192.6 | 1192.4 | 1091.9 |
| 2 | 740.74 | 714.29 | 719.42 | 600.24 | 543.46 |

System sampling frequency at 5 MHz, distance between two screens at 250 (mm)

4.2. Test 2

Laser-based apparatus can be use to measure velocity of repeating rifle projectiles. The rifles were rigidly mounted on a table placed at a distance of about 20m from the system. The measured typical results are shown in Table 2. The results show that the system working properly, non-occurrence of false triggering.

| Table 2. Results of test 2 speed data of AK-47 rifle (7.62mm) |
|---------------------------------------------------------------|
| Velocity(ms$^{-1}$) |
| 1332.7 | 1292.4 | 1192.6 | 1192.4 | 1091.9 |
| 2 | 740.74 | 714.29 | 719.42 | 600.24 | 543.46 |

Laser-based apparatus can be use to measure velocity of repeating rifle projectiles. The rifles were rigidly mounted on a table placed at a distance of about 20m from the system. The measured typical results are shown in Table 2. The results show that the system working properly, non-occurrence of false triggering.

| Table 2. Results of test 2 speed data of AK-47 rifle (7.62mm) |
|---------------------------------------------------------------|
| Velocity(ms$^{-1}$) |
| 1332.7 | 1292.4 | 1192.6 | 1192.4 | 1091.9 |
| 2 | 740.74 | 714.29 | 719.42 | 600.24 | 543.46 |
4.3. Test 3
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 amounts of experiments have been performed to measure. All of experiments acquired effective data. The results show that the system working properly, non-occurrence of false triggering. The main advantages of the reported system in comparison with commercially available systems are as follows:
(1) Optical screens can be used at indoor or outdoor ranges equally effectively.
(2) A lot of advantages such as larger effective light screen area, quick response speed, high sensitivity, low uncertainty, strong repetition and reliability, simple and easy to set up etc.
(3) Its speed range covers subsonic to supersonic.
(4) The measurement system also can be used to test velocity of projectile.

References
[1] Zhao Donge 2003 Laser screen measuring system for gun velocity, ISTM 5, Bei Jing.
[2] Lu, S.T., Chlou, C., Lee, M.C. and Wu, Y.P 1993 Electro-optical target system for position and speed measurement, IEE Proceedings-A,140(4), 252-256.
[3] C. C. Chang, H.C. Chang, L.C. Tang, W.K. Young, J.C. Wang, K.L 2005 Huang Hybrid-integrated prism array optoelectronic targeting system, Opt Laser Technol;"37:591–596.
[4] Han Feng, Liu QunHua, Sun GuoBin, 2008 Study on Measurement Method for Projectile Location Based on Light Screen, Proc. SPIE. 7155, 71552K.
[5] J. M. Sánchez-Pena, C. Marcos, and M. Y. Fernández 2007 Cost-effective optoelectronic system to measure the projectile velocity in high velocity impact testing of aircraft and spacecraft structural elements, Opt. Eng.; 46(5), 051014.
[6] R. C. Kalonia, G. Mitra, and A. Kumar 2007 Laser-based projectile speed measurement system, Opt. Eng., 46(4) 044303.
[7] Q. Liu, H. Shi, B. Yan, F. Han, and R. Cai 2004 The infrared light screen system and accuracy analysis, Acta Photonica Sin 33(11), 1409–1411.
[8] Zhexin Jia, Ke Gong, Yujing Huo 2009 Optoelectronic system for high-speed flier velocity measurement based on laser scattering, Opt. Eng.; 48(4), 043601.

Acknowledgments
The authors would like to thank National Key Laboratory on Electronic Testing Technology (Grant No.9140C1204041009) and National Key Laboratory on Electronic Testing Technology Fund for Young Scholars for providing funds for this project.