"HIGH SPEED PROJECTILE RECORDING SYSTEM"

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Abstract

Optical techniques are most suitable for speed measurement of fast moving projectile, particularly when the projectile is of small size and speed is to be measured in the vicinity of the projectile. The design and construction of a system to accurately determine speed of a projectile (bullet) by measurement of time of flight between two parallel laser screens is described. Each screen is formed by a laser source. At the detection end of both the screens, a collector lens focuses the incident laser light beam on to a photo-detector. The collector lens and detector are kept in a recess so that no stray or ambient light falls on the photo-detector. Whenever a projectile crosses any of the screens, the corresponding photo-detector senses the event due to partial or full obscuration of the incident energy. Appropriate electronic circuit is used to accurately record the time when the projectile crosses each screen and time interval gives the time of flight. The distance between the screens being known, velocity is displayed on computer screen.

Key Words: Laser screen, opto-electronic unit, beam expander-collimator, time of flight, speed of projectiles.

I

Introduction

The technique of the measurement of time of flight (TOF) of a projectile between two fixed points or planes is widely employed to routinely determine the speed of fast moving projectiles such as those fired from small caliber guns. The passage of the projectile creates a field perturbation that can be sensed in terms of some measurable quantity like pressure, electric or magnetic field or radiation field. Doppler frequency shift measurement technique is also used for measurement of the speed of projectiles but it is not suitable for small caliber projectiles as it requires a user to focus the device on the target, and it cannot be operated effectively without human intervention unless the target is guaranteed to cross the path of the device.

Speed measurement apparatus using screens based on infrared (IR) or optical radiation fields offer very high resolution and sensitivity while being immune to EMI/EMC. Many researchers have described optical screen using either visible or near IR wavelengths. The variations exist in the number of sources/detectors (single or multiple) used and construction of the screen (either refractive collimator/beam-expander type or parabolic). The common drawbacks of these apparatuses are that the screen provides small effective screen size and sensitivity is not same throughout the screen. These systems measure the muzzle speed accurately. To measure the speed of a projectile at a larger distance from the muzzle, a system with larger screen area is required as the projectile deviates from the linear path during the flight. For such measurements the existing apparatus suffer from the following shortcomings:

- They require larger optical components to construct larger screens whose sensitivity is not uniform in the entire screen area. This leads to large measurement errors
- These systems need careful alignment during installation.
- They can't be moved from indoor to outdoor frequently.
- In these systems, up-scaling of the effective screens is quite expensive.
- The systems employing sunlight source cannot be used in indoors and the precision and accuracy of systems are very much dependent upon the intensity fluctuations of sunlight.

In this paper, we describe a laser based system, employing innovatively designed two similar optical screens for measurement of speed of small caliber projectiles moving in the range of 1m/sec to 2500 m/sec. The optical screens provide better uniform sensitivity throughout the screen area as compared to the screens used in the existing prior photonics based instruments/apparatus. Speed of the projectile is computed using the TOF recorded by an electronic circuit employing high slew rate components. Design of the screen is modular in nature and it can be easily up scaled or down scaled. Similarly, inter-screen distance can be changed easily. Each screen is constructed from a single source and does not require any expensive aspheric optical components like parabolas, cylindrical lenses etc. No elaborate alignment is required during installation of the system and it can be easily 'picked up and placed' for usage in indoor or outdoor ranges. The system ensures accurate performance in the wide range of ambient light conditions, temperature and other environment conditions like high ballistic pressure and shock waves generated during the measurement of the high speed projectiles.

II
Design and Description of System

The system comprises of an optical unit, an electronic unit and a data acquisition & processing unit. The optical unit incorporates two similar laser screens which are shown in Fig.1. Each laser screen consists of a laser- beam expander-collimator called source assembly

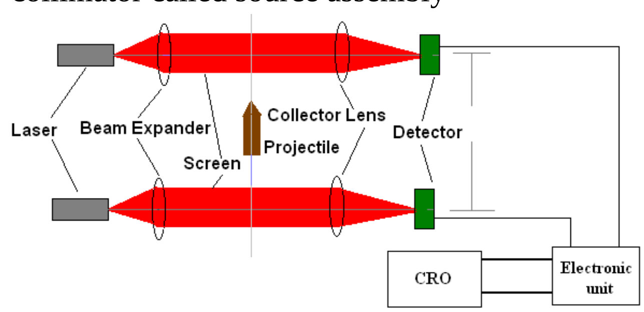

Fig.1 Two LASER screen setup

When the projectile successively crosses through the first and the second laser screen, the start and stop pulse signal can be obtained as the triggering signal for the timer. To measure the time interval between the start and stop pulse signals, the time of flight (TOF) can be obtained and by processing and calculating, the average velocity of the flyer will be acquired. Comparing with the conventional laser screen method, the benefit of the new design is obvious. Since the laser screens do not direct onto the photo-detectors, avoid the saturation state of the photo-detector at the time when the projectile does not pass through the laser screen. Then, the high-power laser and high-sensitive photo-detector can be used to measure the velocity of small-caliber flyer (1mm or smaller in diameter). Therefore, this improvement will be suitable for high-speed small-caliber flyer velocity measurement.

The system consists of two units:

1) Optical and Sensor unit
2) Data- acquisition and Electronics unit

III

Measurement Error Analysis

Performance of the photonics based speed measurement system depends upon the how accurately the TOF and the distance between the screens, through which smallest projectile moving with the fastest speed passes, are measured.

Speed of the projectile under test is measured as ratio of the distance between the screens and TOF which are shown in Fig.2. The uncertainty in the measurement of the speed depends on these two parameters.

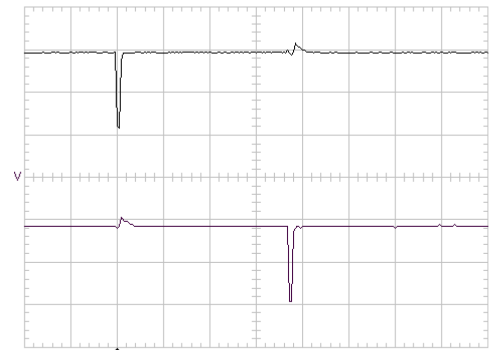

Fig.2 Interrupt signals of two LASER screen

The speed measurement based ToF is governed by following equation;

$$s = x/t \quad (1)$$

The relative error in the speed depends upon relative error of distance and time and represented by the following equation;

$$ds/s = dx/x + dt/t \quad (2)$$

where

s : Actual value of the speed

x : Distance between the laser screens(or screen distance)

t : Time of Flight (TOF)

dt and **dx** are the errors in the measurement of TOF and distance between two screens respectively and which in turn produces **ds** error in the measurement of speed according to the equation (2).

There are two types of errors viz. instrumental error which depends upon accuracy of the components & assemblies besides alignment errors and experimental error which depends upon the deviation of the projectile trajectory from the direction perpendicular to the screens.

Instrumental Errors

- The screen distance is measured with an accuracy of 0.1mm.
- There is parallelism error of 1 minute of arc between the screens which produces

an inaccuracy of 0.08mm in the screen distance.

- The Time of Flight is recorded with an electronic circuit with an accuracy of 0.2 µsec

Experimental Errors

There can be an error in the screen distance because of deviation angle of the projectile for different type of calibers deviation angle can be in the range ± 0.005^{O} to ± 0.567^{O}, which introduces an error of 0 to ± 0.05 mm in the screen distance.

Measurement Errors

For example, measurement error in speed is calculated for a projectile with maximum speed of 2500m/sec and 1000mm as the screen distance. Taking into consideration all the above mentioned errors, speed estimation error is 0.233%, excluding experimental error. However, accuracy in speed measurement can be further improved, if the screen distance is increased and the existing timer card is replaced by a timer card of higher frequency.

IV

Conclusions

Main advantages of the reported system in comparison with commercially available systems are as follows:

- Design of the laser screen is innovative and modular in nature which can be scaled easily with minimum cost.
- A collimated beam of very small height in comparison to the height of the screen is used to construct the whole screen, which produces a screen of uniform illumination throughout the area.
- Same system can be used for indoor and outdoor ranges because there is no effect on the performance due to the ambient light conditions because of novel design of the system.

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