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# Non-Destructive Method for Velocity Estimation of Small Caliber Projectile

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## Abstract

This work presents the development of a novel non-destructive approach for the measurement of high-speed small caliber projectiles with desired accuracy level. The velocity of the projectile is computed from the time taken by the projectile to travel a predefined fixed distance between any two locations under observation. The system development mainly encompassed the design and testing of an electronic circuit for processing the optical signals from the primary optical sensors. The system so developed exhibited an accuracy of ±1% during the trials with projectiles of different calibers traveling in a velocity band of 390 m/s to 912 m/s.

**Disciplinary**: Instrumentation Engineering, Physics.

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## 1 Introduction

Non-destructive measurement techniques are widely used for measuring the velocity of high-speed projectiles. Numerous kinds of systems presently used for accurate determination of projectile speed can deliver under a diverse set of circumstances and ambient conditions. The gamut of high-speed estimation methods is so wide that six to seven classification levels are used to quantify the span ranging from low to high speeds. Low-speed applications include event measurement in sports, instrument vibration analysis and measuring revolutions per minute for rotating shafts (Joshi and Gangal, 2002; Zhexin *et. al.*, 2009). An extensive variety of instruments based on diverse methods populate this span of measurement in this range, but on moving towards the upper end of the range the procedures adopted as well as the application areas are not the same compared to mainstream methods adopted for general-purpose velocity measurement applications. Methods for high-speed velocity estimation are widely employed in detonation physics for efficient estimation of detonation speeds (Decker *et. al*., 2017). They also find their increasing applications in ballistics and forensic sciences. Such types of instruments have been increasingly utilized for the estimation of the velocity of small caliber projectiles. In this work, an attempt has been made towards the development of an instrument for the estimation of velocity of small caliber projectile traveling at ultra-high speed using a non-destructive approach.

The novelty of the proposed method lies in the approach followed for capturing the signal at the preliminary stage. During the initial period, the measurement systems predominantly involved paper breakage or wire breakage methods. The wire breakage system suffered from a serious drawback of elongation of the wire due to its elastic nature before breaking off, thereby introducing an error due to the extension of the wire. Similarly, the protruding of paper before its destruction on being hit by the projectile also leads to the introduction of error. These deviations in physical dimensions of either wire or paper before destruction were random and non-recurring in nature. Such variations introduced an error component in measurement as these methods primarily focused on the calculation of time taken by the projectile to travel a fixed distance between two sensors placed in a straight line of travel. Subsequent developments led to the evolution of advanced methods like the parabolic approach, light gate method and Ballistic pendulum (Sanders, 2020; Milutinovic, 2019). These methods essentially being analytical in nature, lacked the ability to provide to evolve into a direct readout device. In the present work, an attempt has been made to estimate the time of arrival of the projectile at two sites of interest and thereby evaluating its speed using a dual sensor system.

## 2 Experimental Set-up

Photonics-based instruments have been widely used for analysing the motion of small caliber projectiles, particularly, before the event and just after it hits the target. The proposed instrumentation system estimates the speed of the projectile principally by determining the time taken by it to pass through a constant distance between two points. As the distance between these two points is fixed, the speed of the projectile can be simply estimated by measuring the time taken by the projectile to travel through this distance. In this setup, the projectile interrupts the beam of the laser when it passes through two channels positioned 300mm apart as shown in Figure 1.

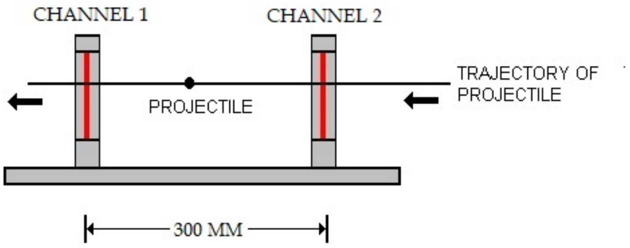

**Figure 1:** Experimental Setup.

When the projectile intercepts a continuous beam from the source to the laser it produces a variation in the signal intensity level at the detector. A source of laser is mounted at the lower end of each of the channels and a detector is installed at the top end of each of the channels. Each channel is made of two vertical columns rigidly fitted with retro-reflected right-angled prisms. This setup forms a virtual screen of laser (Figure 2) and anything passing through this curtain will eventually block the path of the laser beam between the source and detector.

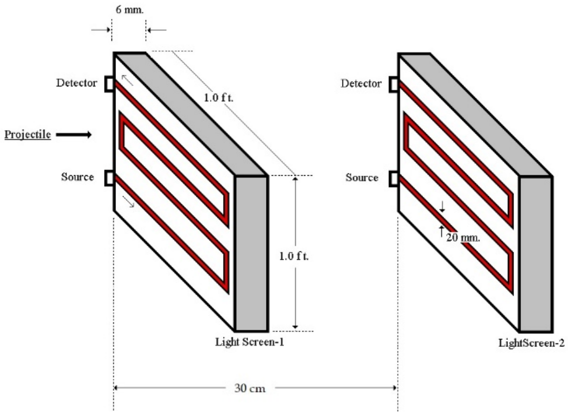

**Figure 2:** laser Screen

In the absence of any obstruction, the beam of laser is reflected, back and forth, by these prims and is laterally displaced till it falls on the detector. A self-triggering mechanism, actuated the system if any object, moving or stationary, obstructs the beam from reaching the detector. As soon as the projectile enters the active area between the channels, it intercepts the laser beam and obstructs the continuity of the beam from the laser to the detector. The schematic diagram of the complete setup is presented in Figure 3.

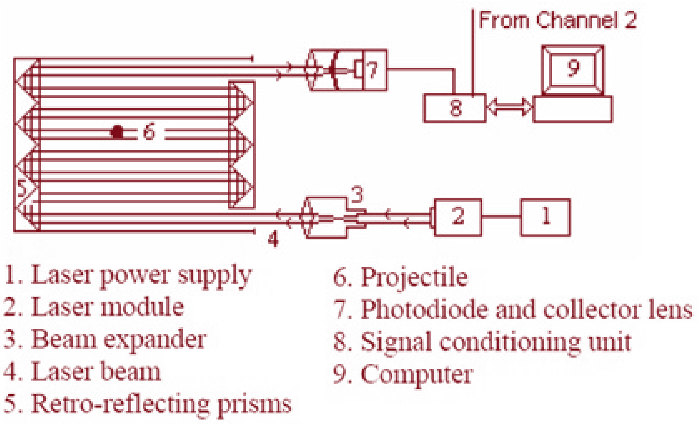

**Figure 3:** Building Blocks of the System

The development of channels using retro-reflecting prisms is a complex and iterative procedure as their alignment, with their hypotenuse faces parallel, is a tedious task. Their number, size and constructional accuracy determine the accuracy of the measurement. The system designed is rigid enough to withstand the shock wave traveling with the projectile as it passes through it, to ensure the repeatability of results in the long run. The system has been designed to detect a projectile of the minimum size of 5mm traveling with a maximum velocity of 912 m/s.

# 3 Methodology

During the measurement when the projectile enters the first channel, it partially obstructs the laser beam and reduces the signal intensity reaching the detector of the first channel. As the projectile moves towards the center of the first channel the detector exhibits a sudden drop in the output signal, which was held at a constant level prior to that. Further, as the projectile moves away from the center of the first channel, the detector output again exhibits an increase till it reaches its constant normal value as shown in Figure 4. This event is again exhibited in a similar manner when the projectile passes through the second channel.

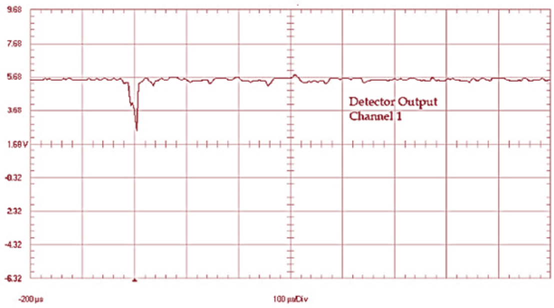

**Figure 4:** Detector output at Channel 1

Detector outputs from both the channels are amplified using a preamplifier followed by a two-stage amplifier. Optimization of the dual-stage preamplifier comprising a current to voltage converter and an amplifier has been the most challenging aspect of circuit design (Jain, 2000; Gayakwad, 2000; Walt, 1996). Further, the amplified signals containing a substantial amount of noise were passed through a comparator stage giving rise to a train of pulses at the output of the comparator. Monoshot was triggered using the first rising edge of the comparator outputs for both the channels, thus obtaining clean pulses at the output of monoshot in response to the obstruction of projectile at both the channels (Figure 5).

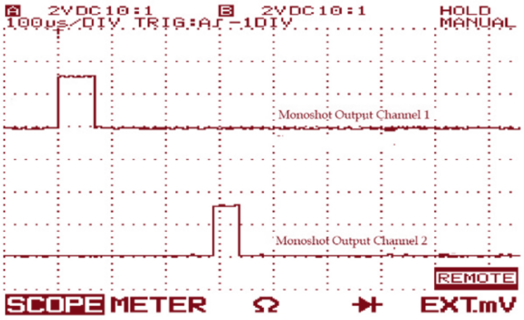

**Figure 5:** Output of monoshot for both the channels

The signal from the monoshot of channel 1 has been used to set the D latch and the signal from the channel 2 monoshot has been employed to reset the D latch and the pulse thus received has been used to compute the velocity of the projectile by means of the timer interfaced with the computer (Hickman, 2016).

# 4 Conclusion

The proposed non-destructive system for measuring the velocity of small caliber projectiles exhibits an accuracy of as high as ±1%. During the trials the projectiles of different calibers varying in velocities from 390 m/s to 912 m/s were tested with the proposed set up and the results were found to be highly satisfactory. During the trials and testing it was observed that such systems demand a high level of structural rigidity as the pressure waves moving with the high-speed projectiles have enormous potential to shake the system and produce shock waves in the structure which in turn can introduce noise in the electronic circuit was well. Further, the accuracy can be remarkably enhanced by the introduction of multiple channels in the existing two channels design thereby generating more information for the same event. Also, the ultimate speed can be taken as an average of these measurements. Also, an increase in separation of channels is expected to yield better results as optical interference between the light sources and the detectors of different can be considerably reduced with an increase in channel spacing. The reflection from the surface of the structural members can be reduced using non-reflective paints or a mask.

# 5 Availability of Data and Material

Data can be made available by contacting the corresponding author.

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