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Development of Velocity Measurement Device and Calibration Using SHPB and Ballistic Impact Setup

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ABSTRACT

A velocity measurement device was developed to measure the velocity of the striker bar of Split Hopkinson Pressure Bar (SHPB) set up. It measures the range of velocity magnitudes for different size of striker bars. The velocity measurement device measures velocity of the striker bar for varying pressure values. The readings were calibrated under freefall, SHPB and also using a ballistic impact testing setup present at the authors facility. The device was developed to produce consistent readings and these readings were tabulated.

Keywords: IR sensors, velocity measurement, Arduino, striker bar, SHPB, ballistic impact.

I. INTRODUCTION

In engineering, it is very essential to characterize material properties. Some of the most essential mechanical properties are Modulus of Elasticity, Yield stress, and Fracture toughness. Conventionally, determination of such is possible in materials testing laboratories, at low speeds only (Quasi-static). To ensure product quality and reliability under impact conditions such as those encountered in dropping of personal electronic devices, vehicle collision, and sports impact, the mechanical responses of materials under such loading conditions must be characterized accurately. However, high-rate loading conditions are beyond the scope of conventional material testing machines. A Kolsky bar, also widely known as a split Hopkinson pressure bar (SHPB), is a characterization tool for the mechanical response of materials deforming at high strain rates ($10^2 - 10^4\ s^{-1}$). Split Hopkinson Pressure Bar has been extensively used for the characterization of material properties at high rates, where the results are a family of stress-strain curves with the strain rate as a parameter [Zhao, H., Gary, G) [1996][1]. Generally, material response depends on the rate of deformation. In seemingly slow rates of loading (global) the rates of deformation can be very high locally. Knowledge of material behaviour at high strain rates is essential. Such studies started in 1940s by Hopkinson and Kolsky. It was evident that, the material properties vary with strain rate [Bo Song and Weinong Chen][2]. The Hopkinson pressure bar was first suggested by Bertram Hopkinson in 1914 as a way to measure stress pulse propagation in a metal bar. Later, in 1949 Herbert Kolsky refined Hopkinson's technique by using two Hopkinson bars in series, now known as the Split-Hopkinson bar, to measure dynamic stress-strain response of materials. Split Hopkinson Pressure Bar (SHPB) is a well-established experimental technique for testing of materials under high strain-rates [Frantz, C.E, Follansbee, P.S, Wright W.J][3]. Parameters and performance of the experimental setup have to be tailored for the tested materials as for SHPB with gas-gun the maximal strain and maximal strain-rate achievable in the specimen are very limited. Strain in the specimen is proportional to the wave length of the incident pulse and to its amplitude whereas strain-rate is proportional to the incident pulse amplitude [Rohrbach et al., 2011][4]. Thus, these two most important parameters are proportional to the length of the striker bar and its impact velocity. In this paper, a simple analytic prediction model for calculation of the striker bar velocity is introduced.

1.1 SHPB SETUP

The Split Hopkinson Pressure bar setup consists of a striker bar, incident bar, transmission bar and the striker bar is made to impact one end of the incident bar by using pressurized air through a gun barrel. Measuring the velocity of this striker bar is very essential while determining the mechanical properties of a particular material during its analysis in SHPB setup.

The Split Hopkinson Pressure Bar experimental technique, consists of a specimen, the tested material, sandwiched between two elastic bars. A right-traveling compressive stress pulse is generated in the input bar. When the pulse reaches the bar-specimen interface, it is partially transmitted through the specimen and partially reflected. The reflected and transmitted pulses are measured by strain gauges located in the input and output bars. The recorded signals can be used in the data analysis to determine the strain history of the specimen. The compressive pulse is generated by the impact of a striker bar against the input bar. The striker is usually accelerated by a gas gun specially developed for this purpose. Since its invention, the SHPB has undergone several modifications. It was adapted to do tensile tests [Lindholm et al., 1968][5], torsion tests [Bassim et al., 1999][6], among other variations presents several of these variations the SHPB has undergone over the time. As part of a program to characterize material behaviour under dynamic conditions, a SHPB is being designed in the authors institution, which demanded for a mathematical analysis of the striker bar velocity.

1.2 STRIKER BAR SPECIFICATIONS :

Material – Stainless steel 416
Young's modulus – 200 GPa
Density – 7700 kg/m^3
Mass of striker bar – 0.707 kg

Fig.1.2 Striker bar

II. DESIGN METHODOLOGY

- Setting range of IR sensors
- Programming the Arduino board
- Experimental testing of the velocity measurement under freefall, SHPB setup and ballistic impact setup.
- Tabulation of the readings and checking for consistency.

III. EXPERIMENTATION

Based on the design methodology, the first step towards the development of a velocity measurement was selecting the desired sensors for velocity measurement. [T. Fila, 2018][7], consideration of pressure loss and coefficient of friction between the striker bar and gas gun are negligible and working according to adiabatic process with drag effects for deriving the velocity of the striker bar.

3.1 IR SENSORS

Two photodiodes or Infrared sensors are being used for the velocity measurement

Fig.3.1 IR sensors mounted near the gun barrel

IR sensor specifications :

- Sensing range: 0.03 – 0.8 m.
- Input voltage: 5V DC.
- Current consumption: 300mA.

The gun barrel which contains the striker bar has a length of 1000 mm and has 2 holes at the end of the barrel. The IR sensors are mounted next to the holes provided on the gun barrel as shown in the figure 3.1. The center distance between these two holes is 50 mm. Setting a definite range to pick signals is a very crucial step while mounting the sensors. The range of these sensors were set to a required limit, in other words, it was made to sense the surface of the Teflon present on the striker bar as shown in figure 1.2 as it passes through the gun barrel.

3.2 CIRCUIT DIAGRAM OF THE VELOCITY MEASUREMENT DEVICE

Once the range in the IR sensors were set and mounted, the necessary circuitry connections were made within the velocity measurement device.

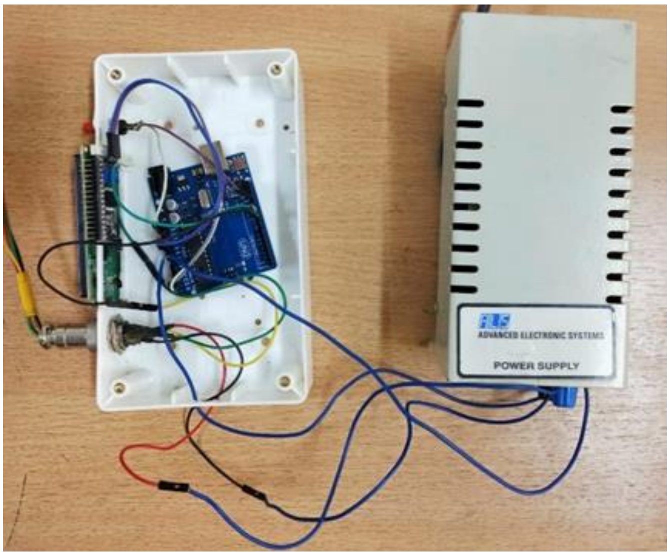


Fig 3.2a Image of the velocity measurement

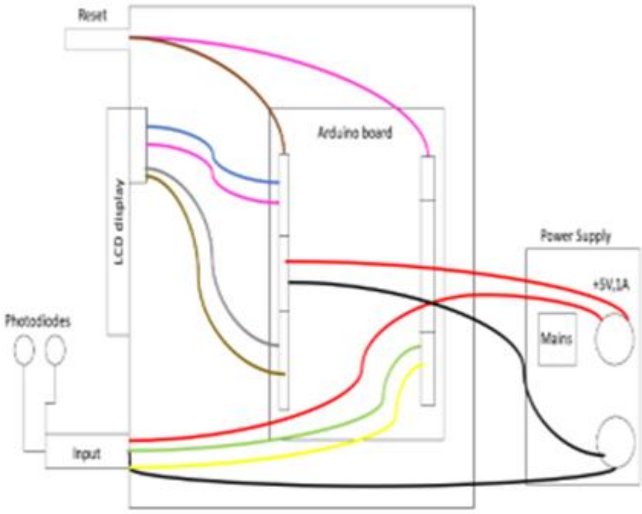


Fig 3.2b Circuit diagram of the velocity measurement device

Figure 3.2b gives an easier understanding of the necessary circuitry connection made within the velocity measurement device which has input from the two sensors mounted next to the gun barrel and also connected to a +5V, 1A power supply.

3.3 ARDUINO PROGRAMMING

An Arduino based velocity measurement device was opted as it has better reprogrammable capabilities. For this, an Arduino UNO board was used. A program was manually coded using the Arduino software and input into the Arduino board present in the velocity measurement device with the help of and Arduino cable. The Arduino program takes in input from the IR sensors. When the striker bar passes with-in the range of sensor 1, it gets turned ON and when it passes within the range of sensor 2, sensor 2 picks up the signal. The input sent to the Arduino board by these sensors is the time taken by the striker bar to pass within the range of the 2 sensors. The distance between the 2 sensors is input into the Arduino board that is, 50 mm. Using a simple formula of velocity $v = \frac{d}{t}$, distance being 50mm and time being the input from the sensors, the velocity is calibrated by the Arduino board and it is displayed onto a 16x2 LCD display. It is also essential to have software libraries installed in the Arduino software such as Liquid crystal library for displaying the results obtained onto an LCD display.

3.4 Calibration of the Velocity Measurement Device

The velocity measurement developed was calibrated by measuring the velocity of a freely falling object. The object of a known weight was dropped from a known height as shown in the figure 3.4a and 3.4b. A set of trials were carried out and consistent readings were obtained during this process. The analytical readings were then compared with experimental readings.

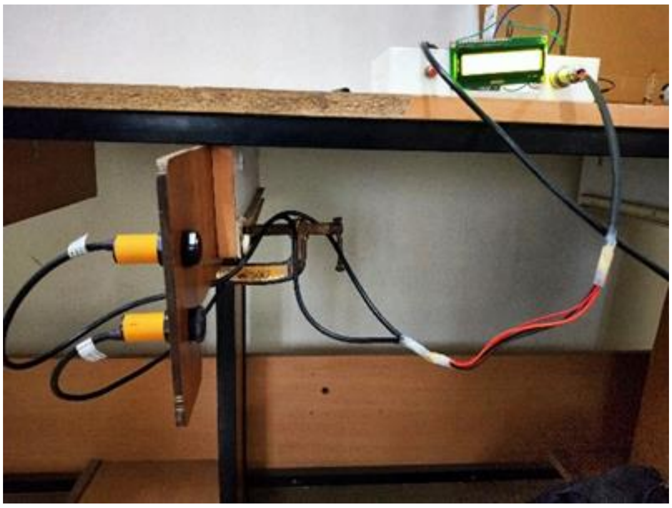


Fig – 3.4b Setup used to measure velocity of freely falling object

The analytical formula used here is, $v = \sqrt{2gh}$
Where, g - acceleration due to gravity, h - height
The height being 0.3 m and g is 9.8 m/s^2
The readings were then tabulated along with the analytical readings.

Experimental velocity of a freely falling body in m/s	Analytical reading
2.33	2.62
2.40	
2.41	
2.47	
2.43	
2.36	
2.42	
2.46	
2.75	
2.51	

3.5 CALIBRATION OF VELOCITY MEASUREMENT DEVICE USING BALLISTIC IMPACT SETUP

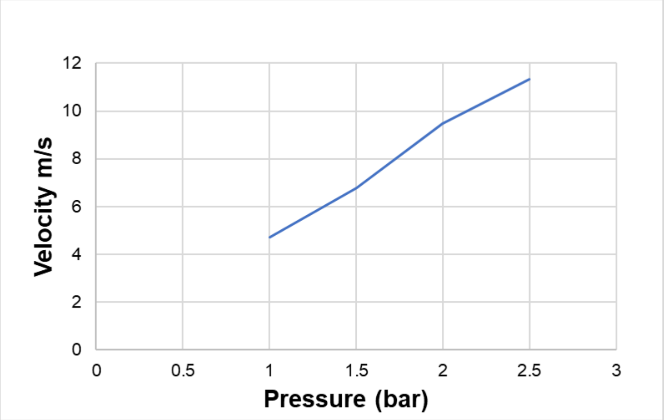
The velocity measurement device was tested on the ballistic impact testing setup to determine the velocity of the bullet when passing through the gun barrel. It was observed that the experimental readings obtained from this procedure yielded consistent results for varying pressure values. The results were tabulated.

Pressure (bar)	Experimental Velocity (m/s)
0.5	14.86 15.43 13.80 13.94 14.10
1	19.78 20.13 23.45 22.08 19.03
1.5	25.05 27.54 28.28 26.90 24.67
2	31.97 30.79 33.16 30.94 31.97
2.5	35.01 39.18 37.88 39.20 38.25
3	48.02 51.96 50.82 47.41 48.60

3.6 CALIBRATION OF VELOCITY MEASUREMENT USING SHPB SETUP

The velocity measurement device was also used in the SHPB setup to determine striker bar velocity in the gun barrel. It was observed that the velocity measurement device yielded consistent readings for varying pressure values. The readings were tabulated.

Pressure (bar)	Velocity(m/s)
1	4.70
1.5	6.79
2	9.46
2.5	11.32



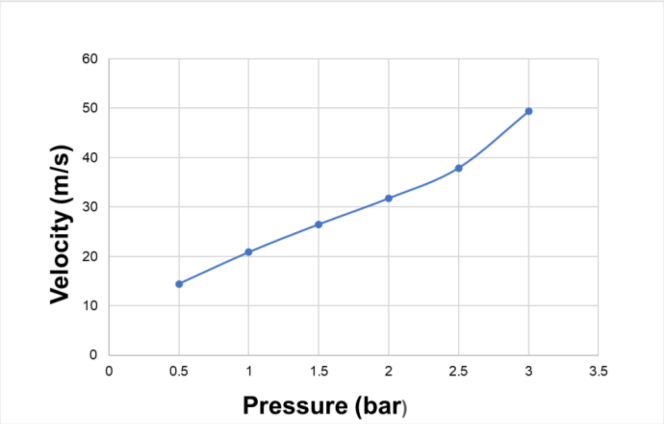
Pressure-Velocity graph for readings obtained from SHPB setup

Specifications of SHPB :

Mass of striker = 0.727 kg
Striker bar length = 0.3 m
Striker bar cross sectional area = 3.22 x $10^{-4}\ m^2$
Gun barrel length = 1 m
Barrel diameter = 0.025 m
Distance travelled by striker = 0.7 m
Diameter of striker bar = 0.02025 m

IV.RESULTS

Pressure vs velocity graphs were plotted for the various readings obtained from the above experiments in order to observe the consistency of the velocity measurement device.



Pressure-Velocity graph for readings obtained from Ballistic impact apparatus

V. CONCLUSION

A velocity measurement device was developed and it has specific applications in areas that include high speed or dynamic impact, (High strain rate domain) namely SHPB and ballistic impact.

- The velocity readings were calibrated under freefall, ballistic impact setup, SHPB apparatus and it was observed that the velocity measurement device generated consistent readings for various pressure values.
- The IR sensor with a better range was used for better accuracy.
- The Arduino board was programmed to ensure that the IR sensors detect signals even in micro seconds to detect signals at high velocity due to higher pressure.
- The velocity measurement device can be used in the SHPB setup for further testing and research.
- The device can be optimized by implementing better sensing devices.

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