Strain measurement due to impact in a split Hopkinson pressure bar

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ABSTRACT

In this work the measurement of strain generated by impact loads is proposed. Some impact tests are listed, from which the Hopkinson Split Pressure Bar (SHPB) is selected. We present the design of the equipment manufactured and used in this work. The materials and equipment needed to carry out the impact test are proposed, as well as how the strain measurement system should be installed. In the test performed, it is identified that the elements of the SHPB are similarly deformed when tested independently. Thus, there is evidence on the feasibility of measuring strain and that the system shown can be improved in future developments for impact load.

KEYWORDS

Hopkinson Split Bar, Experimental Stress Analysis, Virtual instrument, Impact loading.

1. INTRODUCTION

Certainty an induced stress in a material through impact loads is an important factor consider about during the manufacture of a part or instrument (Pettarin & Frontini, 2011). Therefore, in recent years the demand for tests that simulate accurately the final conditions of use has increased. A finished part can suffer bumps or shocks of different nature and various characteristics, being the impact the most severe state of load to which a part in service is exposed. For this reason, the impact test has become of vital importance to determine the behavior of a material at high strain rates.

For this purpose, impact test equipment is used. The classic impact pendulums determine the energy absorbed in the impact by a standardized test piece, measuring the elevation height of the hammer of the pendulum after the impact. Some of the most common test methods are: Charpy, Izod (impact tensile test) and Dynstat (impact bending test) and Hopkinson's split bar. In this project a Split Hopkinson´s Pressure Bar (SHPB) is designed and used to determine the constants of materials under dynamic conditions.

This equipment was named after the British engineer Bertram Hopkinson, who was the first to propose this type of measurement test in 1914 (HBM Test and Measurement, 2010). Later in 1949, Herbert Kolsky modified his design in London (Kolsky, 1949), for what is also called Hopkinson- Kolsky bar.

In this kind of test, the specimen of material is placed between two segments of the Hopkinson's bar: the incident bar and the transmission bar. A hammer strikes the incident bar resulting in an impact impulse. The impact generates waves that are transmitted between the bars and through the test tube, these generate deformation, which in turn is measured by strain gages (see figure 1).

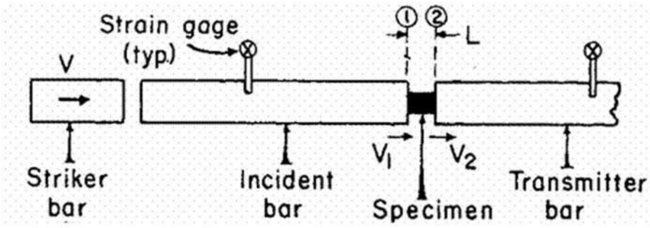

Figure 1. Schematic of a SHPB (Singh, 2009)

In this project, only the impact waves and how they are transmitted between the bars is studied, the characterization of a specimen was left for future work. So, in the next section we describe the development of the equipment and the tests carried out.

2. MATERIALS AND METHODS.

In this section it is described the design of the SHPB, the instrument selection and the development of the tests.

2.1 Design of the SHPB.

The design of the SHPB is based on the ratio-diameter minimum relation required length described by Cheng and Song (2011), they suggest a bar length – diameter ratio (L/D) of 20, and a striker length equal to L/2.

Therefore, the bars were designed to be 304.8 mm long and 12.7 mm diameter, with brackets spaced at 228.6 mm on a rectified straight base, and the striker is 152.4 mm long. These elements were machined from AISI 1018 steel. As described by Chen and Song (2011), this relationship is necessary to avoid the overlap of the waves, as well as their dispersion. This encourages them to arrive as clean as possible to the central part of the bars, where the strain gages are placed.

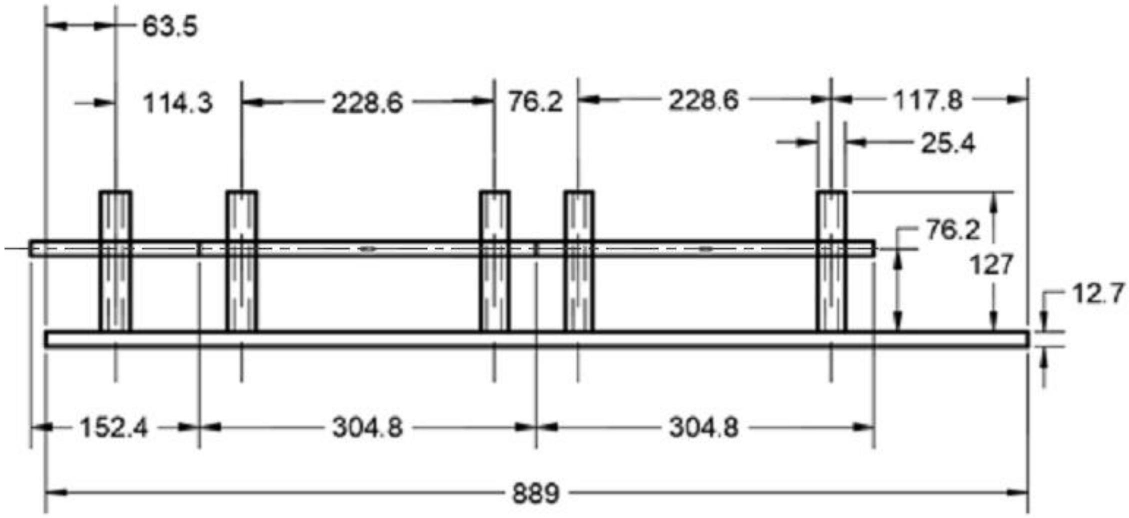

Figure 2. Designed SHPB in mm.

2.2 Equipment selection.

Considering that the test involves an impact load, the strain gages and the data acquisition card have been selected considering the high frequency that the impact loads generates.

The strain gages type selected was type CEA-06-032UW-120 mounted in the central part of the incident and transmitter bars of the SHPB. M-Bond 600 glue was used and the procedure recommended by Vishay® was followed to place the strain gages (Vishay Precision Group, 2014). This procedure includes the curing of the adhesive an oven for 2 hours at 100 ° C.

In order to register the data generated during the test, a data acquisition card with a capacity of 100 kHz is used, according to the recommendation of Baranowski *et al*. (2014). In this project, the NI 9237 card was used, with a capacity of up to 120 kHz. The strain gages, were connected to NI 9944 modules; these transmit the data through RJ45 USB cables to the aforementioned card, mounted on an NI 9162 chassis, finally the chassis was connected to a computer.

Typically, sensors and transducers connected to DAQ devices generate signals that must be conditioned before the device can accurately acquire the signal. This process, known as signal conditioning, includes multiple functions such as amplification, filtering, and electrical isolation, which are programmed in a virtual instrument (VI) developed in LabVIEW ®. Particularly in this test, it was necessary to use a bandpass filter with a range from 8.3 to 8.7 kHz.

Figure 3 shows the various equipment and materials used already connected to perform the tests. Instead of the SHPB striker a Newton's cradle was used, with spheres of 21.03 gr and diameter of 17.47 mm to generate the impact.

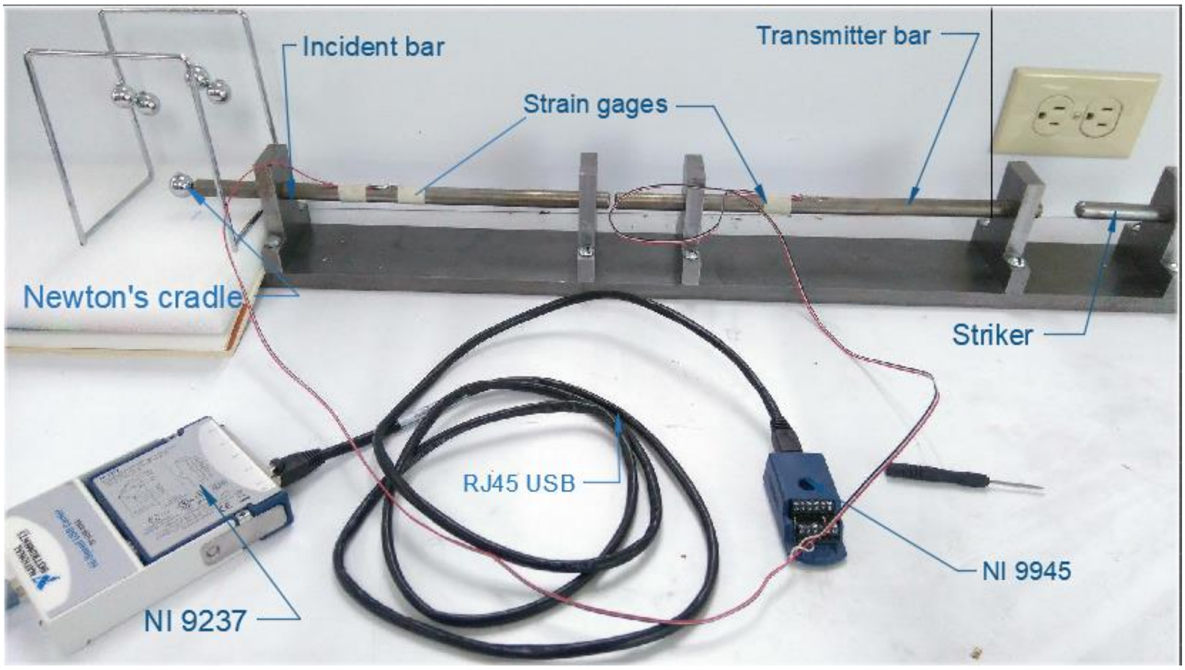

Figure 3. Equipment connected.

2.3 Experiment design

The aim of this first test was to verify that the bars register similar values of strain, through a hypothesis test, this was evaluated with the bars without contact and with the data acquisition card connected a quarter of bridge.

The second test consider the bars together and 9 repetitions of the impact. Its aim was to evaluate the behavior of the impact wave when it is transmitted between the two bars. For this test, the connection to the data acquisition card was also a quarter of bridge, but the VI was modified to generate a graph for each bar.

3. RESULTS AND DISCUSSION.

In Figure 4, the signals obtained from the first repetitions are shown in the tests performed.

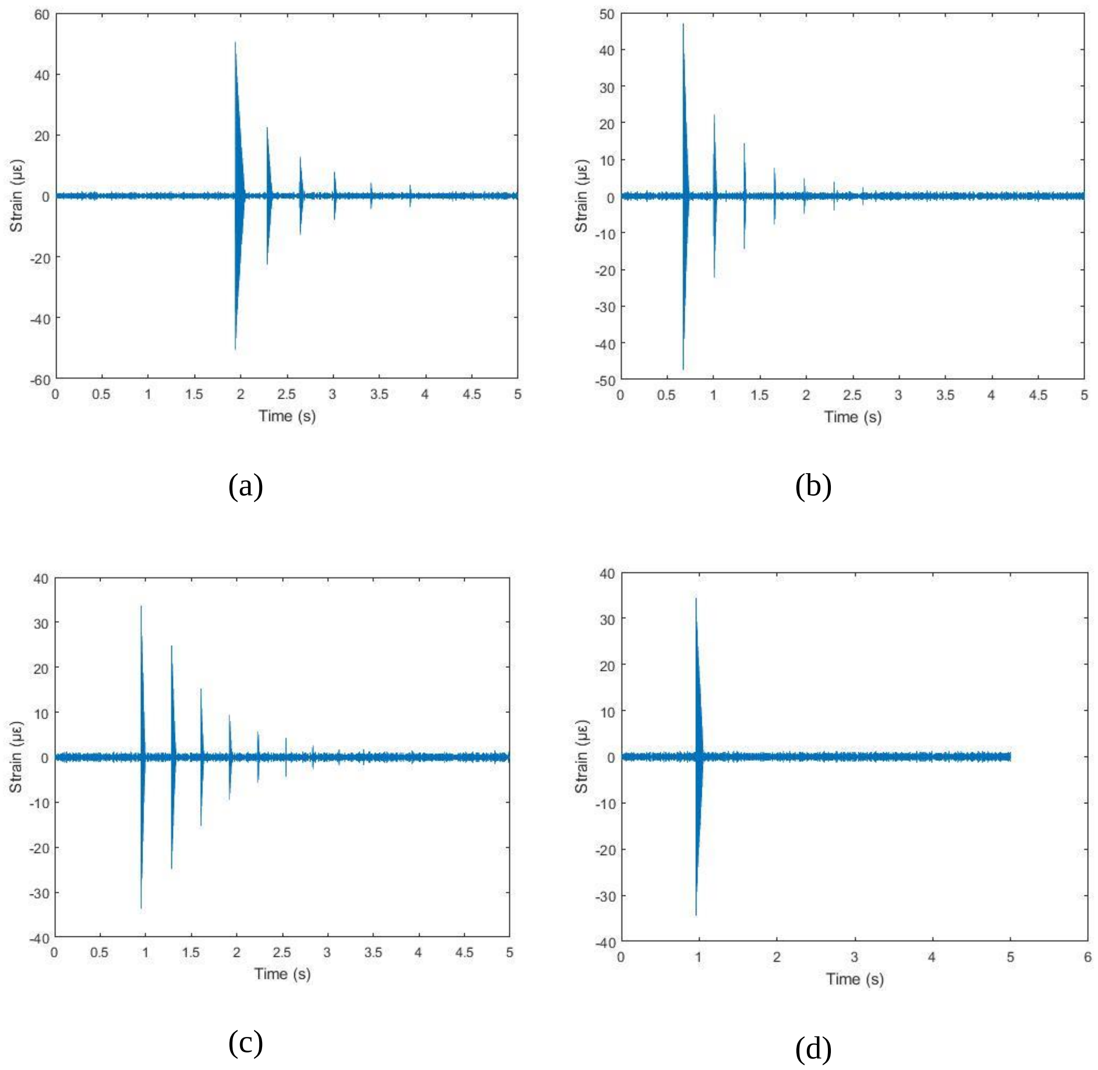

Figure 4. The graphs (a) and (b) shown the variation of strain through time in the incident and transmitter bar without contact; (c) and (d) shown the variation of strain with the bars in contact, (c) the incident bar and (d) the transmitter bar.

The results of the first test are shown in Table 1. Here, strain average values and similar standard deviations are observed. In Table 2, the results of the test are listed with the separate bars. These do not present a behavior as in the case of the first test.

To make statements about the results of tables 1 and 2, statistical tests are performed on the calculated values.

3.1 Hypothesis testing.

For this part it was decided to use a *t*-student test, to compare the means of the deformations of each bar. The hypothesis was:

$$Ho- \ \mu1=\mu2$$

$$Hi- \ \mu1\neq \mu2$$

Table 1: Results of the tests with bars without contact.

Repetition	Strain bar 1 [με]	Strain bar 2 [με]
1	50.93	47.47
2	50.45	47.13
3	52.86	47.17
4	56.86	47.96
5	53.28	52.18
Average	52.77	48.38
Std. deviation	2.33	2.14

Table 2: Results of the tests with bars in contact.

Repetition	Deformation bar 1 [με]	Deformation bar 2 [με]
1	28.53	33.72
2	27.80	33
3	28.21	32.46
4	27.37	33.79
5	27.20	35.20
6	26.88	37.94
7	27.47	31.56
8	27.60	36.63
9	27.88	35.84
Average	27.66	34.46
Std. deviation	0.51	2.08

t-student test required the standard error of difference between the two means (t_o) ec. (1); this term is compared with the test statistic *t* to determine if the null hypothesis is accepted or rejected. Here, a significance value of 0.01 was considered, in order to have a reasonable safety factor.

$$t_0 = \frac{\overline{y_1} - \overline{y_2}}{S_p\sqrt{\frac{1}{n_1} + \frac{1}{n_2}}} \tag{1}$$

Where; $\overline{y_1}$ y $\overline{y_2}$ are the sample means fot bar 1 and bar 2 respectively; and S_p is calculated by ec, (2).

$$Sp^2 = \frac{(n_1 - 1)s_1{}^2 + (n_2 - 1)s_2{}^2}{n_1 + n_2 - 2} \tag{2}$$

Where S_p is the estimator of the common standard deviation (between the standard deviations of the 2 samples) and S_p is the variance.

3.2 Tests with the separate bars.

In the hypothesis tests to the bars alone, a result of *t* = -3.0944 was obtained. This value is compared with the test statistic t (Montgomery, 2017), *t* = 3.747 for a reliability of 0.01. Since the test statistic is greater than t_o, the null hypothesis is accepted. Therefore, the deformation created by the impact of the ball, is the same in both bars.

3.3 Test with the bars in contact.

Here *t* was 6.9481, which is greater than the value of the test statistic, *t* = 2.896 (Montgomery, 2017). So, the null hypothesis was rejected, therefore, the means of deformation are different

4. CONCLUSIONS

In this paper we described the types of basic tests for impact loads. Of these, the SHPB was selected due to the unusualness of this particular test, in addition to the fact that the University of Guanajuato has the necessary equipment to implement it.

The basic design criteria for SHPB was mentioned. Also, the equipment and materials necessary to perform the strain measurement in impact tests are presented. In addition, a description of the interconnection of these components was included.

Two tests were proposed to evaluate the system presented. On the first test, with the separated bars, it is concluded that they generate similar signals and similar strain were obtained, under the conditions described. As for the second test, it cannot be asserted that they are generating the same signals. It can be assumed that the bars have not been subjected to the same phenomenon, because when the two bars are in contact, the bar 1 is affected to the wave when going to bar 2.

At the end of this stage of the project, it can be concluded that it is possible to measure the strain due to impact loads with strain gages. For this, it is necessary to have a cleaner signal of the impact wave, in this paper the use of a band pass filter with a range of between 8.3 and 8.7 kHz was used, since the frequency of the generated impact is between 8.4 and 8.6 kHz. These frequency ranges were obtained by analyzing the graphs obtained by the tests.

For future work we proposed the design of another SHPB, with the difference that this one is going to be designed selecting a material and making use of the wave propagation velocity equations. Also, a simulation of both SHPB it can be very helpful to see the wave dispersion and prove the deformation values obtained during this work.

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