Primary shock calibration of accelerometers at Inmetro

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Abstract. This paper presents the primary shock calibration system developed at Inmetro to obtain the shock sensitivity of accelerometers and acceleration measuring chains. The shock exciter employs a pneumatic driver and is based on the mechanical shock between two rigid bodies guided by air bearings. The system follows the ISO standard 16063-13. The shock acceleration is measured by laser interferometry. Details of the calibration system, including the shock machine, data acquisition and signals processing are presented and some measurement results are discussed by the authors.

1. Introduction
Mechanical shock (impact) tests are used worldwide in several areas, as for instance: drop tests of consumer goods, crash tests of vehicles, design of packaging, etc. Assessment of the resistance of products to specific levels of mechanical shock and evaluation of protection level provided by safety equipment, requires the ability to measure shock excitation amplitude and characteristics, which includes shock duration.

Motorcycle helmets commercialized in Brazil need to be tested according to national standards and affix a label to show its compliance with safety requirements. An impact test is performed to measure the acceleration level transmitted to the user head when the helmet is dropped from a fixed height. These tests are carried out by accredited testing laboratories, which demand for traceable calibrations of the accelerometers used.

Inmetro has been providing shock calibration of accelerometers for more than a decade and has its Capabilities of Measurement and Calibration (CMCs) for shock calibrations by using the comparison method published in the Appendix C of the Mutual Recognition Arrangement (MRA) since 2004 [1]. The traceability was being obtained using sinusoidal calibration of the reference acceleration chain and considering the effect of potential linearity differences in the uncertainty budget. The calibration of the reference chain using the same type of impulsive excitation would yield on elimination of some components of uncertainty and consequently improve the quality of the final result obtained.

National Institutes of several countries have developed their shock apparatus for low-intensity primary calibrations of accelerometers [2-4]. Therefore, Inmetro have decided to develop its own shock calibration system, which implementation was recently finished. This system currently allows the determination of charge shock sensitivity and voltage shock sensitivity of standard accelerometers and acceleration measuring chains from 500 to 5000 m/s² in accordance with the requirements of standard ISO 16063-13 [5].
The system was developed to furnish improved traceability to comparison shock calibrations provided by Inmetro, accredited calibration and testing laboratories and industry. It was used to obtain the results reported by Inmetro to the key comparison CCAUV.V-K4.

The experimental setup will be presented in details and some experimental results will be discussed.

2. Experimental setup

The shock machine is based on rigid body motion of an anvil which is impacted by a hammer, following the requirements of ISO standard 16063-13. The hammer is pushed by a pneumatic cylinder which has its stroke length and velocity adjustable. Air bearings are used to guide the motion of both the stainless steel hammer and anvil while acceleration is measured by laser interferometry. The shape, amplitude and duration of the shock are interdependent parameters which are controlled by adjustment of the pneumatic actuator settings together with a choice of a pulse shaper element to be used between the anvil and hammer.

The shock machine and interferometer are placed on different tables to avoid excitation of the optical parts by the mechanical shocks generated, as shown in figure 1. Detailed views of the interferometric setups and of the accelerometer under test mounted to the anvil are given in figure 2.

![Figure 1. Overview of the primary shock calibration system.](image1)

![Figure 2. (a) Interferometric set up and (b) detail of a BTB accelerometer with dummy loading mass mounted on the anvil.](image2)
Two different interferometric setups can be used with the calibration system:

- **SETUP 1** – this configuration uses a commercial Polytec Sensor Head OFV 505 which is mounted on a bi-dimensional translation stage. The baseband I&Q signals are provided by a Polytec OFV-5000 vibrometer controller in conjunction with a junction box VDD-Z-011.
- **SETUP 2** – this configuration uses a conventional heterodyne interferometer based on a 40 MHz optomodulator, which is mounted on an optical breadboard.

3. Resultant shock pulses

Typical shock pulses generated by the shock machine from 500 to 5000 m/s² are shown in figure 3. In each shock, a different combination of pulse shapers and pneumatic actuator settings were applied. After the demodulation of the interferometric signals and the obtainment of the displacement history, it is applied on the signal the central differentiation method twice interleaved by a 2\textsuperscript{nd} order Butterworth low-pass digital filter with a cut-off frequency of 5 kHz to evaluate the acceleration curves.

![Figure 3](image.png)

**Figure 3.** Typical acceleration shock pulses generated by the shock machine and measured by the interferometric system – curves were time-shifted for better view.

The repeatability of the system can be evaluated by the distribution of repeated shocks generated at specified peak amplitudes and shock durations. Each condition presented in figure 4 was repeated about 70 times. These conditions match the requirements of the CCAUV.V-K4 protocol.

![Figure 4](image.png)

**Figure 4.** Distribution of shocks generated with the shock machine at the specified peak amplitudes and durations of the acceleration pulses – approximately 70 measurements per condition.
Voltage signals from the vibration measurement chain, usually composed by an accelerometer and a signal conditioner, are also acquired to evaluate its shock sensitivity. Typical voltages signals and its magnitude spectrum are presented in figure 5 for 5000 m/s². As the sensitivity is calculated by the ratio of the peak amplitudes of the accelerometer and interferometric signals, the same low-pass digital filter with a cut-off frequency of 5 kHz is applied on the vibration measurement chain signals. A comparison between the original and filtered signals can be done by observing the curves in figure 5.

![Normalized Accelerometer Signal](image1)

![Normalized Magnitude Spectrum](image2)

**Figure 5.** Filtered and non-filtered acceleration pulses obtained by the vibration measurement chain (accelerometer and signal conditioner) at 5000 m/s² represented by (a) time history and (b) magnitude spectrum.

Two data acquisition boards are responsible to simultaneously sample the signals. The interferometric signals are acquired by a 14 bit resolution board at 100 MS/s and the accelerometer signals are digitalized at 250 kS/s by a second 16 bit resolution board. The estimated relative expanded uncertainty ($k = 2$) for accelerometer sensitivity using the developed system was evaluated to be 0.4 %. This includes all uncertainty components specified on the ISO 16063-13.

4. Discussion and Conclusion
This paper presents the low-intensity primary shock calibration system developed at Inmetro and used on the measurements of the key comparison CCAUV.V-K4. Two different interferometric system were implemented to enable comparisons of the results. Tests to evaluate the repeatability were performed and the results are in according to requirements of standard ISO 16063-13. The shape of the accelerometer pulses obtained by the machine is very smooth, indicating low resonances levels at the anvil or accelerometer. It was possible due to the performance of the system and the preliminary studies developed. Many tests were performed to obtain the best geometry and material for the pulse shapers for each amplitude level. It was conducted tests from 500 m/s² until 5000 m/s² but this is not the limit of the machine and higher amplitudes will be tested.

5. References
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