IMPLEMENTATION OF A PRIMARY SHOCK CALIBRATION SYSTEM IN LAVIB - INMETRO

Micheli G. B., Garcia G. A., Ripper G. P.
National Institute of Metrology, Standardization and Industrial Quality - Inmetro
Acoustics and Vibration Metrology Division, Vibration Laboratory
Av. N. Senhora das Graças, 50, 25250-020, Xerém, RJ, Brazil
Phone: 55 21 2679-9113, fax: 55 21 2145-3245, email: gbmicheli@inmetro.gov.br

Abstract: This paper presents the current status of the development of a primary shock calibration system in the Vibration Laboratory of Inmetro – Lavib. The shock facility was designed and now it is being manufactured. The working principle used is the rigid body shock between a hammer and an anvil, according with the ISO standard 16063-13. The measurement system is ready and it consists of a Mach-Zender interferometer and an analog-to-digital signal acquisition module. The software developed employs an undersampling technique for down-conversion of the high frequency heterodyne signals. Some results using sinusoidal inputs are presented to demonstrate the undersampling method used.

1. INTRODUCTION

Aiming the improvement of traceability for comparison shock calibrations and to answer to the increasing demand for smaller uncertainties from the industry and from calibration and testing laboratories, the Vibration Laboratory of Inmetro – Lavib – started the development of a primary shock calibration system.

Other NMIs have already developed their primary shock systems. The National Metrology Institute of Japan (NMIJ) vibration group built a machine able to calibrate shock transducers in acceleration range from 200 m/s² to 5000 m/s² [1]. This machine is based on rigid-body collision between a hammer and an anvil. The shock pulse is conformed through the use of an appropriate rubber pad between the bodies. Nozato *et al.* [1] have also reported about the influence of the rubber hardness and the dependence of the cut-off frequency of a low-pass digital filter. The National Measurement Laboratory (NML) of the R.O.C. is developing its low level primary shock calibration system referring to the NMIJ [2]. CENAM / Mexico has developed two versions of primary shock calibration systems. The PTB / Germany has a large experience in this field, including mid-level and high-level shocks.

In this paper, the current status of the development of a primary shock calibration system in the Lavib is described. This system was designed to comply with the requirements of ISO 16063-13 “Methods for the calibration of vibration and shock transducers” [3]. The aim of this project is to extend the laboratory calibration capability by including a primary metrological system able to calibrate accelerometers with half-sine squared shaped pulses up to 5000 m/s². The design of the system is composed of a shock machine, which is based on rigid motion of an airborne anvil accelerated by the impact of an airborne hammer. The motion will be measured with a laser interferometer and a signal acquisition and digital processing system.

2. SHOCK APPARATUS

The shock machine apparatus, Fig. 1, consists essentially of two 40 mm diameter airborne steel cylinders (hammer and anvil), a pneumatic exciter system and stoppers to mitigate the energy and to limit the strokes.

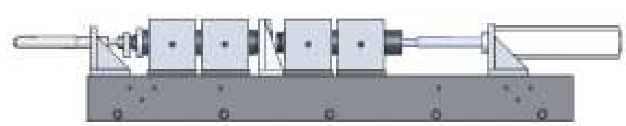

Fig. 1 *Shock machine CAD design.*

A pneumatic cylinder pushes the hammer which shocks against the anvil. A soft interface is needed to shape the acceleration pulse properly. The accelerometer under test is fixed on an adaptor at the other end of the anvil.

The pneumatic scheme of the exciter can be seen in Fig. 2. A 0.8 MPa air pressured source is connected through a filter and an electronic pressure regulator valve to a 5 dm³ reservoir chamber. A fast switching solenoid valve controls the air flow to move the pneumatic cylinder. This action yields on the hammer acceleration and consequent shock event against the anvil.

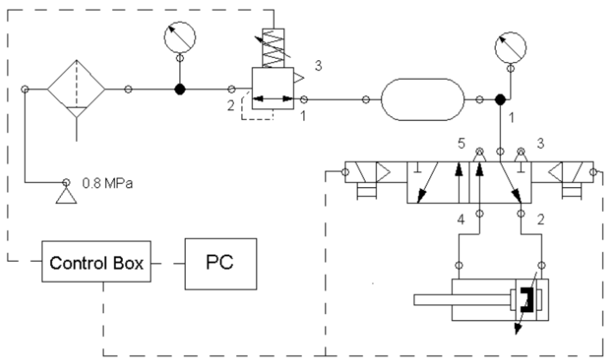

Fig. 2 *Pneumatic exciter system design.*

The standard pneumatic cylinder is 40 mm diameter and 100 mm stroke and can provide 750 N at 0.6 MPa supply. Both hammer and anvil cylinders are 200 mm length and supported by two air bearings. The air bearing bushing can stand a maximum radial load of 645 N when it is supplied with 0.4 MPa air pressure.

The accelerometer is fixed at the other end of the anvil by an adaptor. The anvil motion is stopped after the shock by a damper system. Two hydraulic shock absorbers with adjustable damping are responsible for mitigating the kinetic energy of the anvil. Each absorber is capable of absorbing 32 J (until 3 m/s) with a stroke of 20 mm.

2.1 Modal Analysis

In accordance with the standard ISO 16063-13 [2], in order to measure a shock pulse with duration T, the hammer and the anvil resonance frequencies shall be at least 10/T. For a cylindrical hammer and anvil, this frequency can be analytically evaluated from solving the vibration differential equation of a circular cross section beam. The free ends condition yields on the equality [4]:

$$\sin \frac{\omega_n}{\sqrt{\frac{E}{\rho}}} L = 0 \rightarrow \frac{\omega_n}{\sqrt{\frac{E}{\rho}}} L = i\pi, \qquad i = 1,2,3,\ldots \tag{1}$$

where ω_n is the nth frequency (rad/s), E is the Young Modulus, ρ is the mass density and L is the anvil length. The fundamental frequency, ω_{n1} and the correspondent frequency in hertz, f_{n1}, are then determined by

$$\omega_{n1} = \frac{\pi}{L}\sqrt{\frac{E}{\rho}} \rightarrow f_{n1} = \frac{1}{2L}\sqrt{\frac{E}{\rho}} \tag{2}$$

Assuming a 40 mm diameter and 200 mm length steel shaft, this equation gives a fundamental frequency of 12930 Hz. The actually designed hammer and anvil have a recess at one end and to evaluate the correct frequency value, a numerical modal analysis was applied using the finite element method.

Two kinds of finite elements were used to identify possible mesh dependency errors on the results: axisymmetric quadrilateral and tetrahedral solid elements, Fig. 3. The axisymmetric elements with reduced integration define a bidimensional mesh which takes into account the symmetry of the cylinders simplifying the analysis. The tridimensional mesh was generated with a linear eight-node brick element with reduced integration. Simulations of a cylindrical form shaft without recess confirm the analytical values with differences of 0.26%. Applying the actual anvil shape yields on the frequencies of 13176 Hz and 13179 Hz for the 2D and 3D analysis respectively, yielding on minimum pulse duration, which can be measured by the designed apparatus, of 0.76 ms, according to the ISO standard.

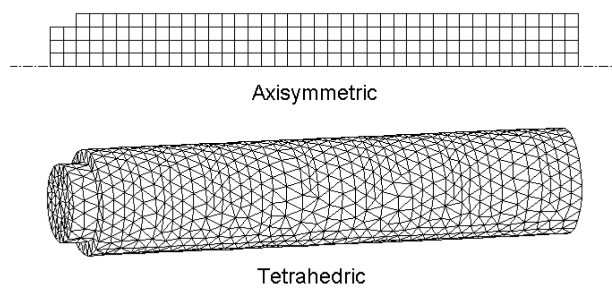

Fig. 3 *Finite element meshes for numerical modal analysis.*

3. INTERFEROMETER SYSTEM

Laser interferometry will be used to measure the displacement history of the surface where the accelerometer is fixed. A Mach-Zender heterodyne interferometer has been built with a He-Ne laser and an acoustic-optic modulator, Fig. 4. The high speed photodetection unit used includes a 1 mm² silicon photodiode and a low-noise current-feedback amplifier. This unit presents a response bandwidth higher than 70 MHz.

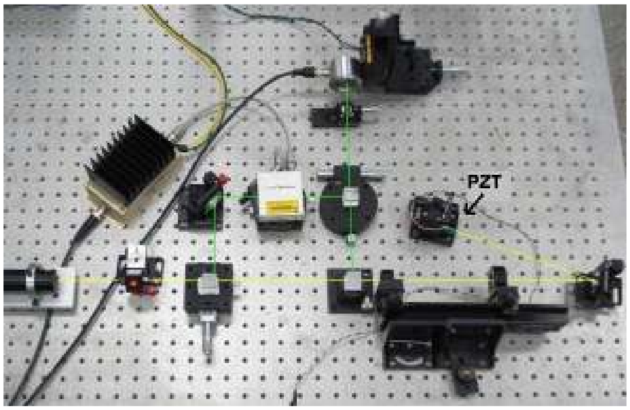

Fig. 4 *Mach-Zender heterodyne interferometer.*

The photodetector signals are digitized by a PXI acquisition board with 14 bits resolution and 100 MSa/s maximum sampling rate. This board has two simultaneous-sampling acquisition channels and 32 Mbytes of memory.

To optimize the frequency resolution of the acquired signal, an undersampling technique with an adjustable sampling rate can be employed. This technique utilizes the aliasing effect shown when a signal of determined frequency content is acquired with sampling rate lower than the Nyquist frequency. The synchronization of the equipments plays a very important role in this process, making possible the alias frequency identification.

Fig.4 illustrates the interferometric system with the undersampling technique applied to measuring the displacement of a PZT actuator vibrating sinusoidally at 80 kHz. The sampling rate was set to 4 MSa/s and the RF modulator frequency to 39 MHz. This condition yields on a carrier aliased frequency at 1 MHz, as shown in Fig.5. This figure presents the magnitude spectrum of the acquired signal which can be represented by

$$u_{mod}(t) = A_{mod}\cos[\omega_{c,alias}t + A_M\cos(\omega_M t + \varphi_0)] \quad (3)$$

where M is related to the PZT movement, mod to the modulated signal and c to the carrier frequency of the acoustic-optic modulator. Multiplying this equation by the digitally generated terms $\sin(\omega_{c,alias}t)$ and $\cos(\omega_{c,alias}t)$ and applying a low-pass digital filter, we obtain the quadrature signals [5]

$$u_1(t) = \frac{A_{mod}}{2}\cos[A_M\cos(\omega_M t + \varphi_0)] \quad (4)$$

$$u_2(t) = \frac{A_{mod}}{2}\sin[A_M\cos(\omega_M t + \varphi_0)] \quad (5)$$

After obtaining the in-quadrature signals (I&Q), it is possible to reconstruct the original vibration signal by applying the arctangent demodulation scheme. Fig. 6 shows the displacement spectrum of the PZT actuator, where the original 80 kHz component can be noted. The results obtained so far indicated that the aliasing technique implemented can be used to improve the frequency resolution for measurement of shock pulses.

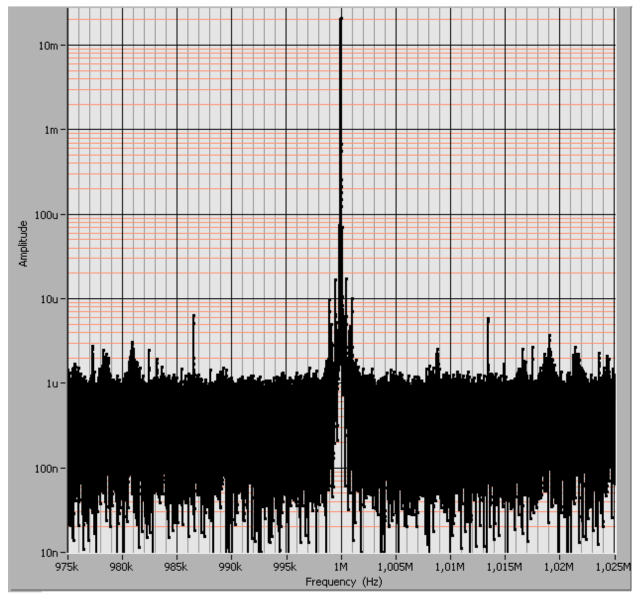

Fig. 5 *Magnitude spectrum of the heterodyne modulated signal acquired with the undersampling technique.*

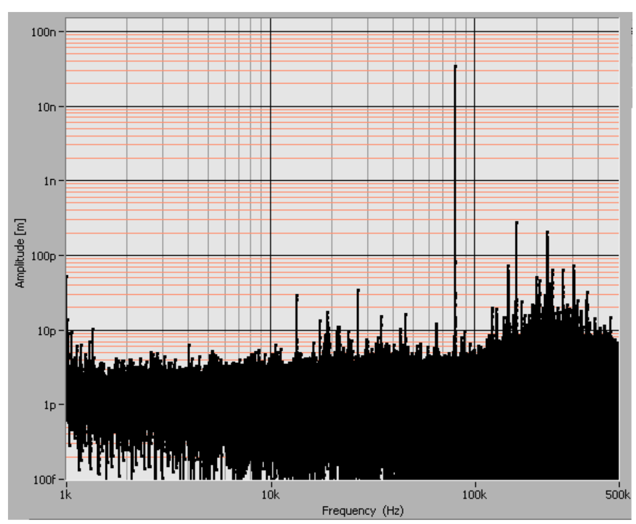

Fig. 6 *Reconstructed displacement spectrum of the PZT actuator vibrating at 80 kHz.*

4. CONCLUSION

This paper presented the current status of the development of a primary shock calibration system in Lavib. The system includes a shock machine, a laser interferometer, a signal acquisition system and a digital signal processing software.
The outline of the machine design was described and analytical and numerical analyses were employed to evaluate the fundamental resonance frequency of the hammer and anvil. The heterodyne interferometer system is working properly as shown by the experimental result presented here. Some mechanical components are currently being manufactured at Inmetro´s machine shop. The next step will be to assemble the shock machine and to verify its mechanical properties. Then some practical measurements will be carried out.

REFERENCES

[1] Nozato H., Usuda T., Oota A., Ishigami T. and Kudo K., *Development of Shock Acceleration Calibration Machine in NMIJ*, IMEKO 20th TC3, 3rd TC16 and 1st TC22 International Conference, 2007.

[2] Chen J., Chen C.J., Huang Y.J. and Ho H.C., *Two Shock Machine Simulations Prestudy for Primary Low Level Shock Calibration System*, XIX IMEKO World Congress, 2009.

[3] ISO 16063-13, *Methods for the calibration of vibration and shock transducers – Part 13: Primary shock calibration using laser interferometry*, 2001.

[4] Almeida M. T., *Vibrações Mecânicas para Engenheiros*, Ed. EDGARD BLÜCHER LTDA, São Paulo – Brasil, 1987.

[5] Bauer M., Ritter F., Siegmund G., *High-precision laser vibrometers based on digital Doppler-signal processing*, Proceedings of SPIE, 4827, 50-61, 2002.