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A NEW SYSTEM FOR COMPARISON CALIBRATION OF VIBRATION TRANSDUCERS AT LOW FREQUENCIES

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Abstract − This paper presents a new system that was developed in the Vibration Laboratory at INMETRO for the calibration of vibration transducers and measuring equipments at low frequencies. The system is based on a long-stroke air bearing shaker and on a data acquisition board. Optionally, a piezoresistive accelerometer or a laser vibrometer can be used as reference transducers. Fully automated calibrations of vibration transducers are carried out in compliance with the international standard ISO 16063-21. Some experimental results obtained with this system will be presented herein.

Keywords: Vibration, Acceleration, Metrology.

1. INTRODUCTION

The Vibration Laboratory (LAVIB) at INMETRO recently improved its capability to perform calibration of vibration transducers and vibration measuring instruments at low-frequencies. The calibration system already available in the laboratory employs an exciter APS model 500, and is mostly applied for primary interferometric calibrations of transducers. Since this exciter has a small maximum load limit, of about 2.7 kg, and a load table sizing 79.5 x 79.5 mm, the capability to provide calibration services of massive low-frequency transducers and integrated measuring instruments was limited. Customers have been requesting INMETRO to calibrate data loggers for transportation monitoring, elevators, geological applications, etc. Unfortunately, many of these equipments could not be calibrated with the system formerly available without disassembling of the vibration sensors. Therefore, a new system had to be built to attend this specific metrological demand.

2. CALIBRATION SETUP

The new calibration setup is based on an electrodynamic exciter APS model 129. This exciter offers a stroke rating of 158 mm and allows the mounting of up to 23 kg on its load table measuring 254 x 254 mm. This table is fixed to a large area precision linear air-bearing stage of rectangular cross section. The driver unit employs permanent magnets and the moving coil is also guided by air bearings.

The driver unit and the rigid guide bar assembly are mounted on a common rigid aluminium base. This base is fixed to the top surface of a 1200 kg mass seismic block mounted on rubber pads. An independent and smaller seismic mass of about 700 kg is used to support an optical breadboard. Mechanical mountings and translation stages are fixed to the breadboard for holding and alignment of the laser head of a Polytec vibrometer model CLV.

The calibration system can be configured with the vibrometer, which provides an output proportional to velocity, or with an acceleration measuring chain as reference. In this case, a piezoresistive accelerometer Endevco model 2262A25 and a conditioning amplifier Endevco model 106 are used.

A piezoelectric accelerometer B&K 4370 mounted on the top of the load table of the shaker is used as feedback sensor for the servo control to maintain the acceleration amplitude selected for the calibration. This feedback accelerometer is used independently of the reference transducer chosen for the comparison calibration. It was preferred to use an accelerometer mainly for safety reasons. The output signal of the vibrometer may present spikes, depending on the quality of the optical alignment and on the reflectivity of the vibrating surface used to reflect the laser beam back into the laser head. These spikes impose difficulties to the setting of the vibration amplitude if broadband control is applied. By using a selective frequency control algorithm a robust adjustment result was achieved. Since the analog output of the vibrometer digital demodulator presents a higher delay than an accelerometer and this delay depends on the filter configuration chosen, it was decided to keep a fixed control acceleration sensor.

The piezoelectric accelerometer selected is very robust and has a good sensitivity for the purpose of use.

A function generator Agilent 33120A is used for generation of the sinusoidal driving signal at the desired measuring frequencies. A matched power amplifier APS model 124 provides the power required to feed the armature coil of the shaker APS 129 and generate motion.

The acquisition is made through a 16-bit, 333 kS/s multi-channel A/D converter National Instruments model NI-6052E. This is a multiplexed acquisition board without signal generation capability.

The calibration program was developed in LabVIEW environment. It controls the vibration amplitude, the acquisition of the measuring channels, presents the measured data on the screen and save them to an ASCII file for further post-processing in an Excel standardized spreadsheet. Graphs in time and frequency domain are available for monitoring both the reference and DUT channels during calibration. The program also presents the signal distortion during measurement.

A connector block NI BNC-2110 is used to connect all input signals to the acquisition board and an interface IEEE-488 is employed to control the function generator.

The calibration setups are schematically presented in Fig. 1 and Fig. 2. A picture of the shaker moving table with the mounting fixture used to mount the reference accelerometer and device under test (DUT) is shown in Fig. 3.

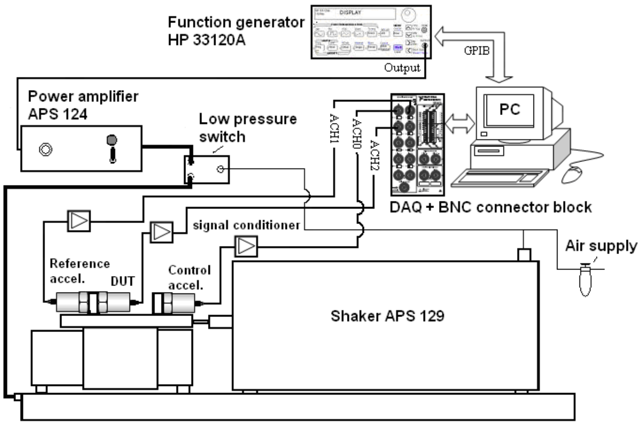

Fig. 1. Low-frequency acceleration calibration system with a accelerometer as reference

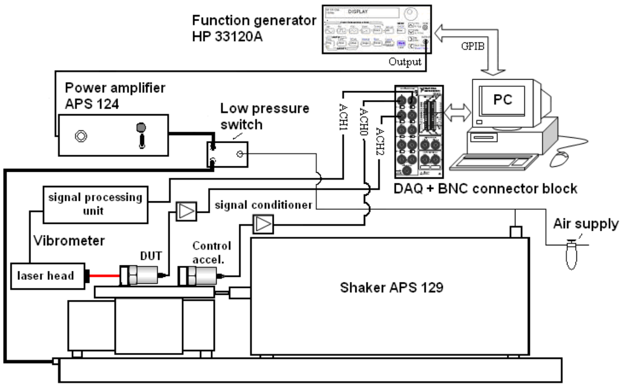

Fig. 2. Low-frequency acceleration calibration system with a laser vibrometer as reference

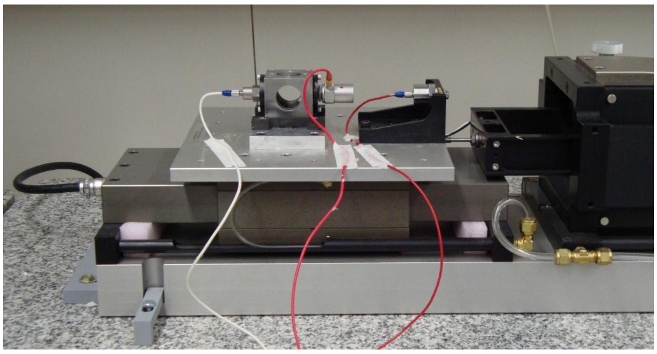

Fig. 3. Shaker table with mounting fixtures and accelerometers

The mounting system is shown schematically in Fig. 4. It is based on a aluminum cube with through holes for direct mounting of Q-Flex type servo-accelerometers or different adapters for in-line mounting of accelerometers, flat mirrors or solid glass retroflectors. An additional adapter can be mounted on the upper face of the cube to hold a retroflector. The retroflectors can be used for primary interferometric calibrations, which are beyond the scope of this paper. The cube includes a threaded hole pattern to allow different angular positioning of the adapters and two mountings of the servo-accelerometers, 180° apart from each other.

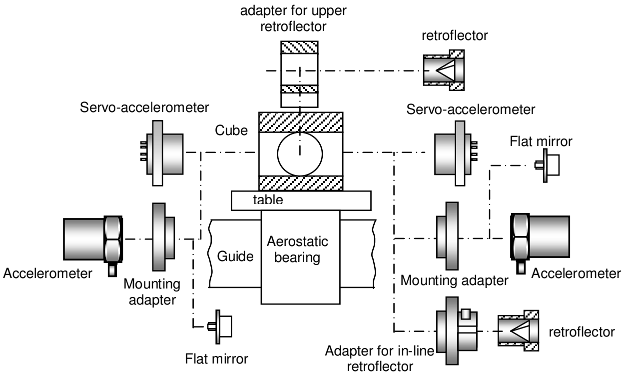

Fig. 4. Modular mounting system

3. CALIBRATION METHOD

The calibration is conducted in compliance with the international documentary standard ISO 16063-21 [1] using a stepped-sine excitation at 1/3-octave center frequencies from 1 Hz to 160 Hz. The acceleration level chosen for calibration is adjusted by the calibration program automatically. After a specified settling time for motion stabilization, the analog outputs of the reference channel and of the DUT are sampled sequentially due to the characteristics of the A/D conversion board used. The acquired data are presented in time and frequency domain graphs on the PC screen. Fig. 5 presents a typical time history of the reference accelerometer.

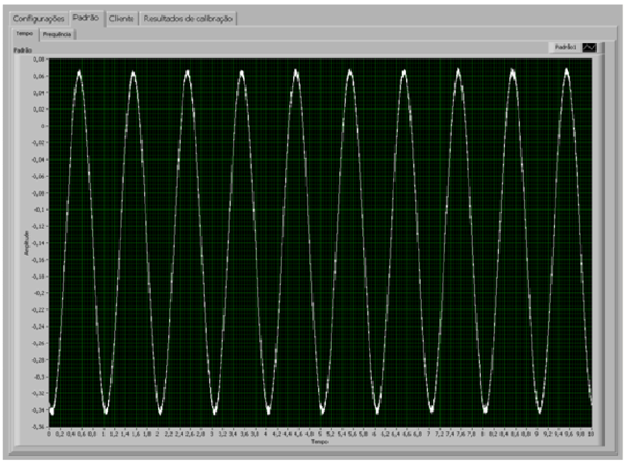

Fig. 5. Time history screen of the reference accelerometer.

The Discrete Fast Fourier Transform (DFT) is used to convert the acquired data to the frequency domain. The voltage values of the reference channel (u_{ref}) and of the DUT (u_{dut}) are measured then at the excitation frequency. A routine is also applied to measure the distortion of the acquired signals. This information is used for the evaluation of motion quality during calibration. The calibration frequencies, acceleration level, measured voltages and distortion results are presented on the screen and saved in the ASCII output file.

The sensitivity of the DUT is determined by applying the following formulae

$$S^{a}_{dut}(\omega) = \frac{S^{v}_{ref}(\omega)}{\omega}\left(\frac{u_{dut}(\omega)}{u_{ref}(\omega)}\right) \tag{1}$$

$$S^{a}_{dut}(\omega) = S^{a}_{ref}(\omega)\left(\frac{u_{dut}(\omega)}{u_{ref}(\omega)}\right) \tag{2}$$

where ω is the angular frequency, S refers to sensitivities and u to voltage outputs. Subscripts refer to the DUT and reference channels and superscripts a and v to acceleration and velocity, respectively. Equation (1) is applied when a laser vibrometer is used as reference and Eq. (2) when an accelerometer is used.

4. CALIBRATION RESULTS

This section presents some results obtained with the calibration system.

Fig. 6 presents the sensitivity of an acceleration measuring set calibrated by comparison against the laser vibrometer between 1 Hz and 160 Hz. This set consists of a piezoresistive accelerometer Endevco model 2262A25 and a conditioning amplifier model 106. The motion was measured at four points equally distributed on the surface of the mounting fixture close to the accelerometer. After concluding the measurements at one mounting position (m1), the process was repeated with the accelerometer remounted at a position (m2), rotated 180º apart. This figure shows the mean sensitivities determined at positions m1 and m2, and the mean value of the results obtained at these two mounting positions (Mean 1&2), which is taken as the final calibration result.

This averaging procedure described above is usually carried out to minimize the effect of coupling between the transverse acceleration generated by the shaker and the transverse sensitivity of the DUT. Fig. 6 shows that the dispersion between the results obtained at positions m1 and m2 is significant above 100 Hz, being of the order of 1% at 125 Hz and that the averaging procedure applied improves the quality of the final results.

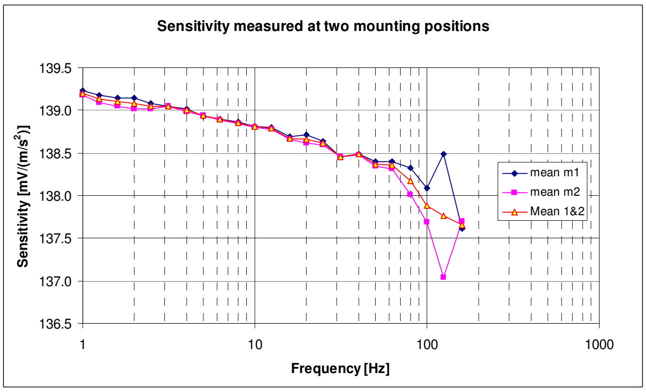

Fig. 6. Sensitivity of an acceleration measuring set determined by comparison against the laser vibrometer.

The relative transverse acceleration measured at the mounting place of the DUT with a triaxial accelerometer is shown in Fig. 7. It can be noticed that the transverse acceleration is lower than 5% from 1 Hz to 100 Hz, but increases to more than 20% at 125 Hz and 160 Hz.

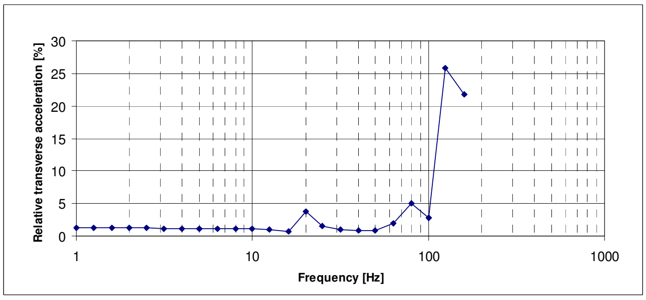

Fig. 7. Relative transverse acceleration measured at the mounting place of the DUT.

Fig. 8 compares the sensitivity results obtained for a servo-accelerometer Allied Signal model QA3000 by comparison calibration against the accelerometer Endevco 2262A25. This figure includes the voltage sensitivity of 16 runs and the total mean calculated from this data. The relative standard deviation of these sensitivities is presented in Fig. 9. Relative standard deviations lower than 0.1% were observed under 40 Hz and lower than 0.26% in the entire frequency range of analysis.

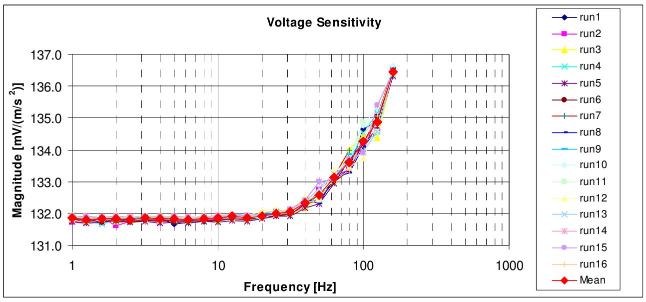

Fig. 8. Voltage sensitivity of a servo-accelerometer Allied Signal QA3000 measured by comparison against an accelerometer Endevco 2262A25.

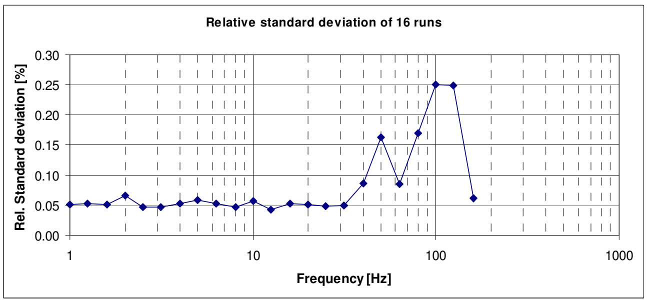

Fig. 9. Relative standard deviation of the voltage sensitivities shown in Fig. 7.

The calibration results of a low impedance piezoelectric accelerometer Endevco model 752A13 are presented in Fig. 10. This figure includes the results obtained for each of the two mountings of the DUT and the final mean sensitivity. It can be noticed that even for comparison calibrations against a reference accelerometer, the averaging procedure is beneficial. The final mean result presents a smoother frequency response function than the two individual measurements at 0° and 180° mounting positions.

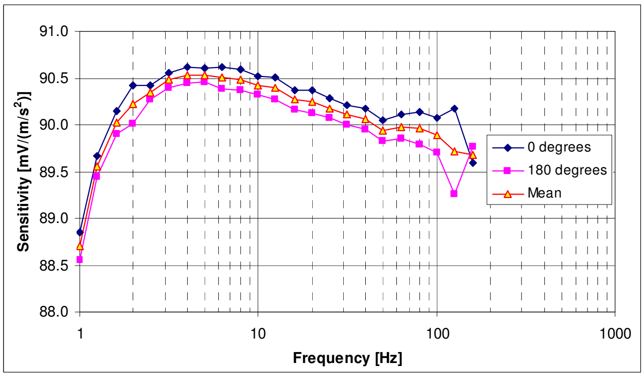

Fig. 10. Voltage sensitivity of an accelerometer Endevco 752A13.

Fig. 11 compares the sensitivity results furnished by the new low-frequency comparison system described in this paper with the ones available from other sources in the vibration laboratory of INMETRO. The curve FC LFS is a calibration result obtained by applying the fringe counting method in the low frequency primary calibration system. FC MFS refers to a result obtained by applying the primary interferometric fringe counting method in the mid frequency system. The result labelled as SAM was given by the homodyne quadrature system, which was recently intercompared with PTB, NIM and NPLI from 10 Hz to 10 kHz (interlaboratory comparison CCAUV.V-K1.1). Y bars were included to show that all these results lie within ± 0.5% of the sensitivity determined by comparison against the CLV laser vibrometer.

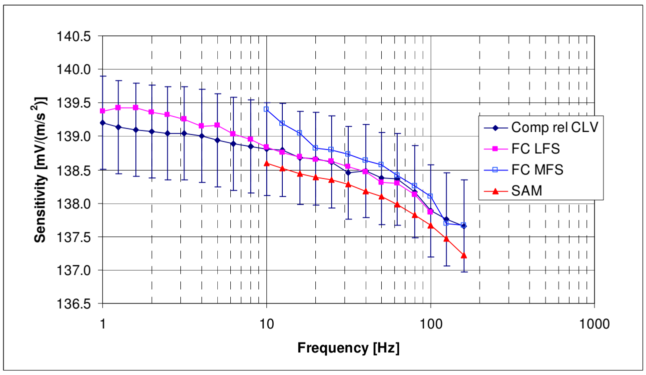

Fig. 11. Comparison of results between different systems available at INMETRO.

The calibration results obtained by carrying out comparison calibrations against the reference accelerometer Endevco 2262A25 are very close to the ones obtained by comparison calibrations against the laser vibrometer Polytec CLV. Fig. 12 shows that relative differences lower than 0.2 % were verified for a servo-accelerometer QA3000.

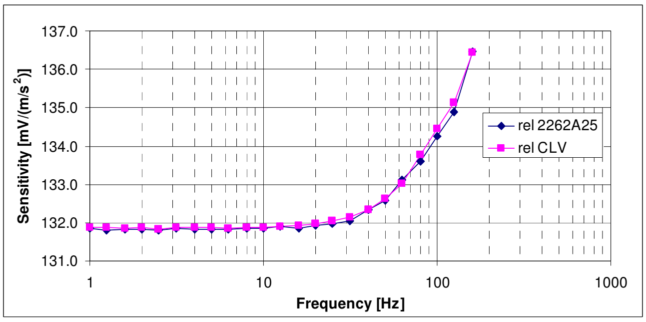

Fig. 12. Sensitivity of a servo-accelerometer QA3000 obtained by comparison against a reference accelerometer Endevco 2262A25 and against a laser vibrometer Polytec CLV.

4. UNCERTAINTY

Expanded uncertainties of the order of 0.5% are estimated for the magnitude of the sensitivity of high sensitivity/low noise accelerometers obtained by the low-frequency comparison calibration system from 1 Hz to 160 Hz, assuming a level of confidence of approximately 95% and a coverage factor $k = 2$.

These combined relative uncertainties were calculated in accordance with methodologies described in the Guide to the Expression of Uncertainty in Measurement [2] using

Type A and Type B evaluations of uncertainty components, including those contained in the international standard ISO 16063-21:1999 [1].

Uncertainties under 5% are estimated for integrated measuring instruments, depending on their display resolution and measuring characteristics.

5. CONCLUSIONS

The system presented in this paper allowed INMETRO to extend and improve its measurement capability to perform calibration of vibration transducers and measuring instruments at low frequencies. Due to the higher force rating and larger load table of the vibration exciter used in this new system, the vibration laboratory can currently calibrate accelerometers and acceleration measuring sets from 1 Hz to 160 Hz and data loggers and integrated measuring instruments from 1 Hz up to 100 Hz. Some of these instruments integrate vibration transducers, memory, battery, display and even a printer, usually being considerably large and massive.

Fully automated comparison calibrations of transducers and instruments with analog output can be carried out against a reference accelerometer or a laser vibrometer. Calibration results of several types of transducers were presented. The system has already been applied to the calibration of servo-accelerometers, piezoelectric, piezoresistive, and variable capacitance accelerometers and also to the evaluation of some MEMs-based accelerometers.

The capability of achieving expanded uncertainties of the order of 0.5 % for low frequency comparison calibrations of accelerometers far exceeds the requirements of most of the laboratory customers.

The frequency range covered by the system complies with the requirements stated in the technical protocol [3] of the next low-frequency primary acceleration comparison that will be carried out within the Interamerican Metrology System (SIM). Therefore, the system may also be applied for verification of primary calibration results obtained by the low frequency primary calibration system at INMETRO. This will help achieving a high level of confidence and allow the quality assurance of the results reported by INMETRO.

REFERENCES

[1] ISO 16063-21, Methods for the calibration of vibration and shock transducers – Part 21: Vibration calibration by comparison to a reference transducer.

[2] ISO/IEC Guide 98-3:2008, Uncertainty of Measurement – part 3: Guide to the Expression of Uncertainty in Measurement (GUM:1995).

[3] G. Silva-Pineda, “Technical Protocol of the Interlaboratory comparison on acceleration at low frequencies, 2 Hz to 160 Hz, CENAM, January 2007.