REFERENCE VIBRATION CALIBRATION EQUIPMENT AT LNE: INFLUENCE OF METHODS AND EXCITERS

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Abstract – The traceability to the acceleration measurements for the industry is done in France by the LNE. This traceability to the national standards is necessary for the industries that have processes where knowledge of the parameters related to the acceleration is essential in terms of quality and safety, such as nuclear, space, automotive or military fields.

The reference accelerometers calibrations for the industry and other laboratories are performed at the LNE's site located in Trappes since 2006 by the absolute method using a Michelson interferometer. However, the equipment used, presented in [1], was of old design and a first step of the upgrade is presented in [2].

This article presents the end of the qualification, including the comparison of methods 1&2 versus method 3 described in standards 16063-1 and -11 [3]. It presents the comparison results of two different design exciters: one in beryllium also an air bearing guide and one with a pierced aluminum moving element with a mechanical guide.

Metrological approval was based on the consistency achieved between the calibration results for given accelerometers obtained using the new bench and those obtained using the original bench.

A comparison with a national primary vibration calibration laboratory was performed and presented.

Keywords : Accelerometer - Vibration - Calibration

1. INTRODUCTION

The medium and high frequency bench used before for primary national references uses the method 1, referred to as the *fringe counting method*, and method 2, referred to as *minimum point method* described in standards 16063-1 and -11 [3]. A first step of the bench upgrade was presented in [2] comprising the laser interferometer and the acquisition and analysis system associated with a new low frequency exciter.

This paper describes the continuation of the upgrade. It includes the qualification of:
- A B&K Pulse 5309 data acquisition and analysis system

- A medium and high frequency Endevco 2911 electrodynamic shaker with air bearings.

Two accelerometers, a single-ended (SE) Endevco 2270M8 and a back-to-back (BB) Endevco 2270, were specified during the bench approval qualification following its transfer [1] and first step of the upgrade [2]. They are used to qualify the new elements of the bench described in the following paragraphs.

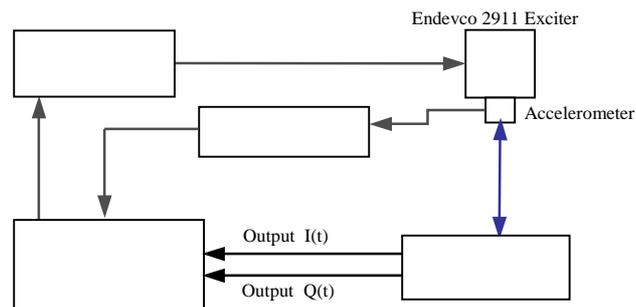The final bench is presented on figure 1.

Fig. 1. Schematic diagram of the calibration bench after upgrade

The uncertainty in determining the sensitivity of an accelerometer or an accelerometric chain becomes in relative value (k=2) on the final configuration:

Low frequency exciter (cf. [2]):
± 0.30% from 0,5 to 160 Hz

Medium and high frequency shaker:
± 0.30% from 10 Hz to 5 kHz
± 0.60% from 5 to 7 kHz
± 1.0% from 7 to 10 kHz.

Those uncertainties have been estimated according to the determination uncertainty method described in standard 16063-1 and -11 [3].

As a conclusion, a comparison with other national primary vibration calibration laboratories was performed and presented.

2. COMPARISON OF METHODS 1&2 VERSUS METHOD 3

2.1. Presentation of the comparison

The methods used with the previous system were 1. fringe counting method and 2. the zero detection of the Bessel function. They are implemented using a voltmeter, a digital filter, and a frequencymeter counter.

The system sourced is a Bruel and Kjaer Pulse 5309 analyzer that uses Fourier transform to implement method 3 in accordance with the standard ISO 16063-11 [3]. Therefore, the comparison takes into account the change in method and analysis system.

The comparison was carried out using the single ended accelerometer and back to back one described in the introduction. In order to compare only the methods, without taking into account errors while operating, the accelerometer has not been unmounted during the calibration.

2.2. Presentation of method 3

This method is applicable for the 0,5 - 10 000 Hz frequency range, without criteria on the displacement.

The output signals of the laser interferometer are defined as:

$$I = I_0 \cos\left(\frac{4\pi}{\lambda} x\right) \text{ and } Q = Q_0 \sin\left(\frac{4\pi}{\lambda} x\right) = Q_0 \cos\left(\frac{4\pi}{\lambda}\left(x + \frac{\lambda}{8}\right)\right).$$

With x defined as the displacement measured by the accelerometer and λ as the laser wavelength.

Both signals are thus spatially phase-shifted of a λ/8 displacement, regardless of the shape of this displacement.

The displacement seen from the laser is therefore:

$$x_L = \frac{\lambda}{4\pi} \arctan\left(\frac{Q}{I}\right) [n\pi].$$

The amplitude of the displacement x_0 of the accelerometer is equal to x_{L0}, the amplitude of the signal x_L.

This amplitude may be obtained by sinusoidal approximation from the sampled x_L signal, or by a Fourier transform of that signal.

The Pulse system by Bruel and Kjaer uses the Fourier transform to obtain the signal amplitude. A more precise description of how this system works is given in [4].

2.3. Comparison results

The following graphs present the difference between calibration with methods 1 & 2 versus method 3 on a same mechanical configuration. The thick lines correspond to the uncertainties of the bench in its original configuration.
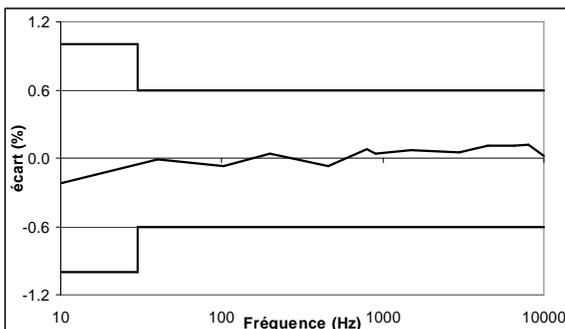

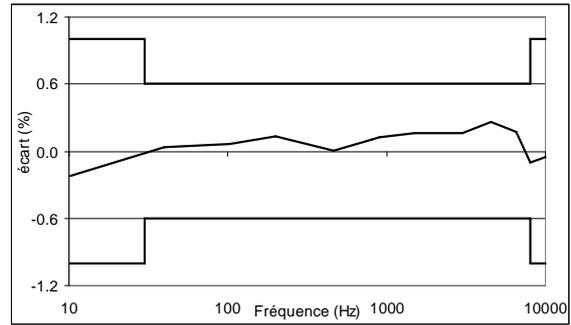Fig. 3. Difference between calibrations of a BB accelerometer in M1&2 versus M3

Fig. 4. Difference between calibrations of a SE accelerometer in M1&2 versus M3

The deviations observed in figures 3 and 4 for the two sensors between the two methods are much smaller than the uncertainty and allow method 3 to be equivalent to methods 1&2 for medium and high frequency calibrations.

2.4. Pulse qualification

Qualification of a digital system cannot be performed as that of an analog one.

Pulse 5309 is composed of a front end and a PC with software.

Pulse is used to:
- Measure the output of the accelerometer and the laser
- Generate the sine wave to the exciter
- Calculate the mean when several points are measured for a same calibration

So, Pulse is calibrated as an analog instrument for:
- Sine generation
- Input voltage measurement
- Phase difference between the laser channels

In order to be more accurate, Pulse 5309 does not use raw voltage measurement. A specific database frequency and range-dependant corrections are used. This database is created through a voltage comparison to a standard voltmeter.

The software is verified by data set validation. The tool Mathcad is used to generate the 3 input files: accelerometer and the two laser outputs at a defined sensitivity and vibration frequency.

The software then processes these files and the given sensitivity is compared to the generated one.

The database is validated by a manual operation. A voltmeter standard is used to determine the accuracy error of the input voltage measurement of the pulse for a few points. Mathcad is then used to evidence the corrections on the same frequency points over the same range of tension. The database is validated by comparing its corrections with the accuracy error observed in regard to the uncertainty.

The limitation of the method is due to fringe counting speed. The fringe frequency f_f is defined by $f_f=v/d$ with v the speed of the accelerometer and d the displacement required by the sequence of two fringes. f is defined as the vibration frequency. The maximal acceleration of the accelerometer is then limited to $a = \pi f \lambda \dfrac{f_e}{2.56}$ (m/s²) with f_e being the sampling frequency.

3. CHANGE OF THE VIBRATION EXCITER

3.1. Presentation of the exciters

The original exciter was a PM 75 with an aluminum moving element and a mechanical linear bearing. The new exciter is an Endevco 2911 with air bearings coupled to a BK2719 amplifier. Its specifications are:
- 45N force rated
- Frequency range 10 – 10 000 Hz
- Maximum transverse level of 5%
- Maximum displacement of 10 mm

Qualification started with verification of the transverses accelerations levels of the exciter, then by comparing calibration results with the original configuration.

Fig. 5. Photo of the new exciter and its insulated table

3.2. Installation of the new exciter

The exciter was installed on the seismic block of the previous shaker. An interface was developed by the supplier to adapt the previous mounting plate to the new exciter. As the old exciter was used in horizontal position and the new one in vertical position, a new insulated table equipped with a rotating system was developed for the laser.

The verification of the vibration level of the interferometer fixed on the new insulated table was performed (lower than 0,05% of the generated level).

3.3. Determination of transverse acceleration levels

The transverse acceleration levels were measured as part of the qualification approval of the shaker. The thick curve corresponds to the supplier's technical specifications (i.e 5%). The generated acceleration is measured with the internal accelerometer 2270M18 of the exciter.
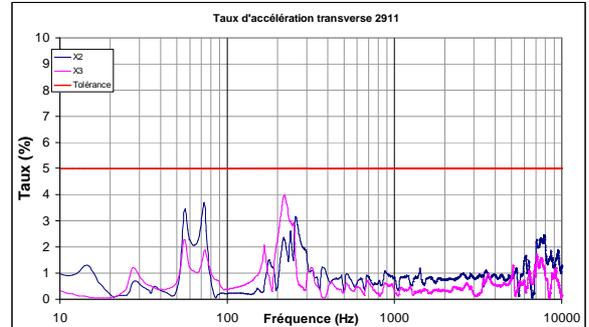

Fig. 6. Transverse levels

The measured levels are lower than the specifications. The limit can be used in the uncertainty budget.

3.4. Comparison before/after the change of exciter

The deviations between the two calibrations of each accelerometer have to be compared to the calibration uncertainties to measure their importance. The thick lines correspond to the combination of the uncertainties of the two configurations in k=2.
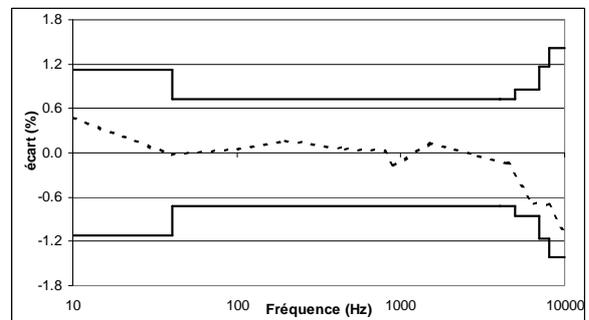

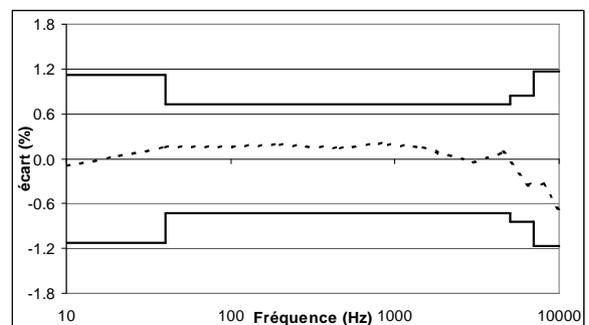Fig.7. Comparison on the 2270M8

Fig.8. Comparison on the 2270

The deviations observed between the calibrations carried out in the two configurations are lower than the combined uncertainties of the benches, i.e. not significant. These results therefore confirm the validation of the vibration reference bench following the change in acquisition and analysis. However, the observed differences in high frequency (> 7 kHz) are repetable and could be due to the change of shaker design.

4. BILATERAL COMPARISON

A bilateral comparison with PTB was carried out over the frequency range 10 Hz to 10 kHz. The LNE and PTB use method 3. Figures 10 and 11 show the relative deviations in sensitivity in relation to a given nominal value for the two accelerometers as a function of the frequency. Bars represent the uncertainties of each laboratory as a function of the frequency
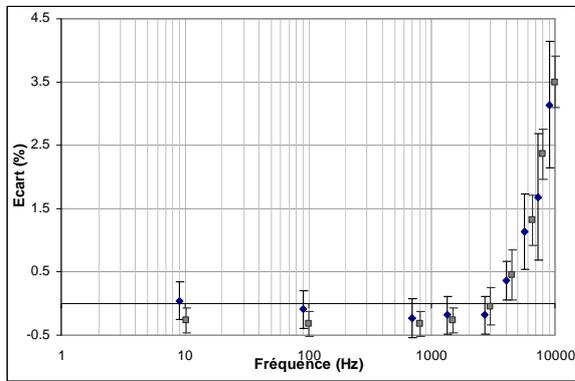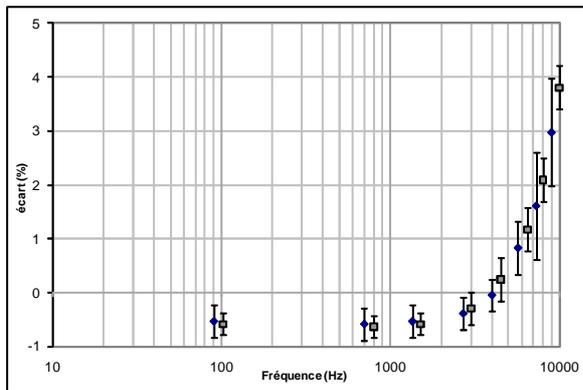

Fig.10. Bilateral comparison on the 2270

Fig.11. Bilateral comparison on the 2270M8

The observed deviations are lower than the uncertainties. This comparison allows to confirm the uncertainties estimation.

If we take into account the comparison in low frequency presented in [2], the uncertainties of the new LNE benches mentioned in the introduction are validated from 0.5 Hz to 10 kHz.

5. CONCLUSION

The vibration calibration reference equipment is now fully upgraded and operational. The uncertainties are improved. The new bench fully reached its goal.

Thanks to this upgrade of the vibration benches, the LNE and the French metrology play an important role in international accelerometric activities.

ACKNOWLEDGMENTS

The authors want to thank Jean-Noël Durocher, in charge of the acoustic laboratory at LNE for his expertise in signal processing.

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