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# UPGRADE OF THE MEDIUM AND HIGH FREQUENCY VIBRATION CALIBRATION REFERENCE EQUIPMENT AND EXTENSION TO LOW FREQUENCIES

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**Abstract** – The national accelerometry references in France are provided by the LNE. Such traceability to national standards is essential for industrial organisations using processes in which an understanding of acceleration related parameters is of primary importance in terms of quality and safety. These fields include the armaments, nuclear, aerospace and automotive industries.

The calibration of reference accelerometers for industries and other laboratories has been carried out on the LNE site at Trappes since 2006, using an absolute method involving a Michelson laser interferometer in accordance with standard ISO 16063 [1]. The bench used, which is described in article [2] is however of an old design and an upgrading program has been drawn up and carried out.

This article describes the upgrading of this bench. The characteristics of the components undergoing modifications are described. These are the laser interferometer, the shaker and the measurement system and data processing system. In order to cover requirements for traceability chains for vibration frequencies below 10 Hz, an additional specific shaker for low frequencies has been sourced.

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.

**Keywords:** accelerometer - vibration - calibration

## 1. INTRODUCTION

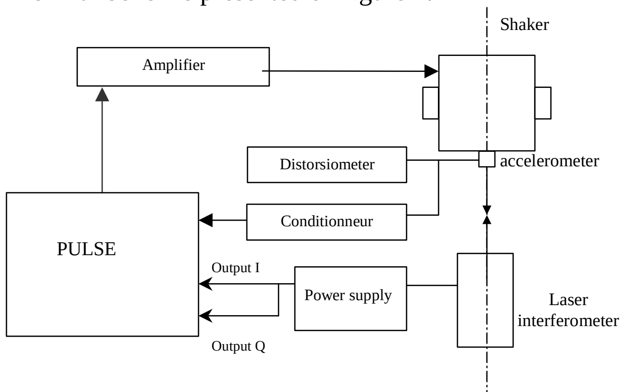
The medium and high frequency bench today used for primary national references uses the method 1, referred to as the fringe counting method, and 2 referred to as minimum point method described in standards 16063-1 and -11 [1]. All the bench components are original and date from 1974 except for the data post-processing software, which was transcribed onto a spreadsheet during the transfer of the bench from CEA CESTA in 2006 [2]. There is an increasing risk of failure and repairs are not always possible. LNE therefore decided to update the bench with the aim of:

- ensuring equipment reliability;
- reducing calibration times;
- reducing uncertainty of acceleration measurements and of the sensitivity of the accelerometer.

The update of the following three parts was initiated:

- the laser interferometer;
- the acquisition and analysis system;
- the medium and high frequency shaker.

The final bench is presented on figure 1.




$$A = X_o\,(2\,\pi\,f\,)^2$$

$$X_0 = \frac{\lambda}{4\pi} Arc\tan\left(\frac{I}{Q}\right)[n\pi]$$

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

The items that were acquired are:

- A Mach Zehnder heterodyne interferometer with dual outputs in phase quadrature. Its approval qualification is described in chapter 2.
- A Pulse 5309 data acquisition and analysis system using method 3 by sine approximation involving Fourier transform over the entire frequency range.
  It is undergoing qualification on the medium and high frequency bench and will be the subject of a special publication. It is in place for the time being and is described in this article on the low frequency shaker.
- A medium and high frequency Endevco 2911 electrodynamic shaker with air bearings. Qualification of this shaker is underway and will be described in a future article.

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In addition an APS 500 low frequency shaker providing excitation from 0.8 to 160 Hz with application of methods 1 and 3. Its approval qualification is described in chapter 3.

Since the equipment involves new technologies, and in order to separate possible sources of deviation and to ensure continuity of metrology, the qualification of new equipments was carried out on a component by component basis. Since the most sensitive was the laser, we started the update program with this one. Qualification of the low-frequency shaker was carried out with the two methods, 1 by fringe counting and 3 by sinusoidal approximation.

## 2. CHANGE OF THE LASER INTERFEROMETER

The original interferometer was a fragmented Michelson interferometer in which all components could be adjusted (lens, polariser etc.) and which offered a single output. The new laser interferometer allows method 3 using sinusoidal approximation to be used [1].

Fig. 2. New laser interferometer photography.

The major steps in qualification were as follows:

- Measurement of the vibration level of the interferometer, fixed on an insulated table. The interferometer's own movement is liable to disturb measurements of the accelerometer's movement;
- The metrological traceability for the laser wavelength;
- Comparison of the results of calibration of the three accelerometers obtained using the new interferometer with that of the original.

The final uncertainty of the acceleration and of the sensitivity remain unchanged, since the uncertainty associated with the laser interferometer is not an influential parameter in the uncertainty budget.

### *2.1. Measurement of vibration level*

Standard 16063-11 [1] specifies a maximum residual vibration level on the interferometer of 0.1%. The levels measured in the directions which are longitudinal and transverse to the vibration during a calibration were measured as less than 0.05% over the frequency range 10-10 000 Hz.

### *2.2. Wavelength traceability*

The laser source for the Mach-Zehnder interferometer is an unstabilized laser whose wavelength and relative standard deviation are specified in the article ''Advice from the CCL on the use of unstabilized lasers as standards of wavelength'' published by the working group on Unstabilized Lasers of the Consultative Committee for Length. The values specified and used in the calculations are:

$\lambda$= 632,990 8 nm in vacuum

relative standard uncertainty = $1{,}5 \cdot 10^{-6}$

### *2.3. Comparison before/after the change of laser*

The three sensors specified during the bench approval qualification following its transfer [2] were used for metrological monitoring of the bench. They were also used to qualify new components of the medium and high frequency bench. They were two single ended sensors type, one Endevco 2270M8 and a Bruel & Kjaer 8305-001. The third sensor was an Endevco 2270 or back to back (BB) type. These three sensors are recognised for their metrological stability and are used in many national laboratories. The 8305-001 sensor was used as an accelerometer and as an accelerometric chain with the Bruel & Kjaer 2525 charge amplifier.

Two different operators carried out calibrations in order to validate their qualification on the new equipment and at two different periods in order to qualify the short term drift also.

Figure 3 shows the relative deviations between the two configurations for each sensor and at each calibration frequency point.

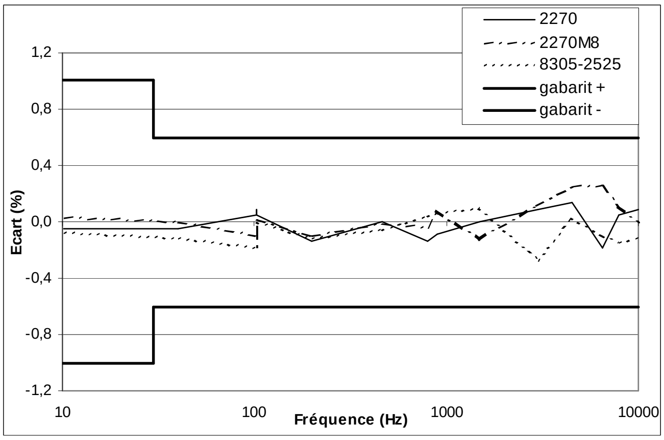


Fig. 3. Deviations between calibrations carried out on the sensors before and after the change of laser.

The deviations observed between the calibrations carried out using the two laser interferometers are less than the uncertainties for the bench, i.e. not significant. These results therefore confirm the validation of the accelerometry reference bench following the change of laser interferometer.

## 3. EXTENSION OF LOW FREQUENCY CALIBRATION CAPABILITIES

This extension at low frequencies is to meet the growing demand from French industry, in particular in the field of transport. It also allows demands relating to the field of health to be met, where the frequency ranges may fall to 0.8 Hz.

The low frequency shaker selected for the primary vibration calibration bench is an APS 500 which covers the frequency range 0.8 – 160 Hz. It offers displacements of 152 mm and a maximum acceleration of 50 m/s$^2$. It allows calibrations to be carried out for piezoelectric accelerometers of the type used in medium and high frequencies, accelerometers of the seismic type or of Q-flex quartz technology.

Qualification started with verification of the transverses acceleration levels of the of the shaker, then by comparing the low frequency and medium and high frequency shakers over their common range.

### *3.1. Installation of the new low frequency shaker*

The shaker was installed in the same laboratory as the medium and high frequency bench, an area whose temperature is regulated at 23°C ± 1°C and whose relative humidity is regulated at 55% ± 10%.

#### *Seismic block*

A granite block weighting over a tonne was provided. It was placed on a tarred mat of the same type as that used for the medium and high frequency shaker. An interface plate was built for fixing the shaker and sealed on the block using eleven M20 screws bolted in an epoxy sealant consisting of two components with enhanced mechanical strength characteristics. The height of the mass was determined so that alignment of the accelerometers to be calibrated could be carried out with the laser placed on the insulated table.

Fig. 4. APS 500 exciter photography.

#### *Determination of transverse acceleration levels*

The transverse acceleration levels were measured as part of the qualification approval of the shaker. Two series of measurements were made corresponding to the two main operating configurations : with a sensor for the very low frequencies QA 700, with a weight of 280g, and with the cube on which piezoelectric accelerometers are to be mounted. Figures 5 and 6 show the transverse levels measured in two directions that are orthogonal to each other. The curves in red correspond to the supplier's technical specifications.

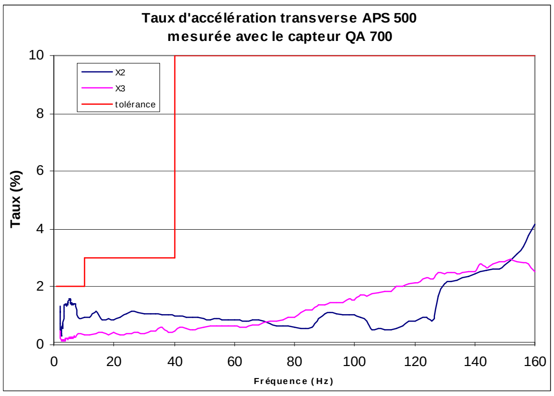


Fig. 5. Transverse levels measured on the Q Flex sensor.

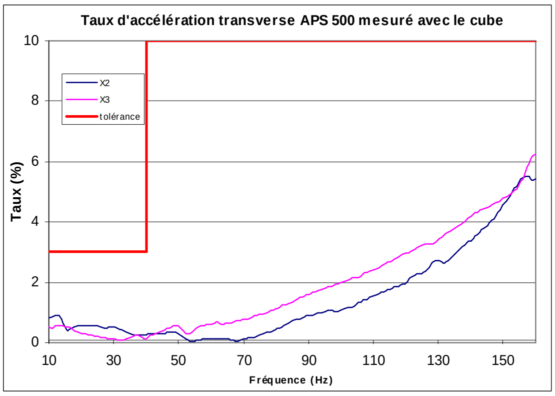


Fig. 6. Transverse levels measured on the cube.

The measured levels are lower than the technical specifications given by the supplier over the entire frequency range. This meant that the APS 500 could be qualified as regards this point.

#### *Comparison of low frequency and medium and high frequency shakers*

The three accelerometers were calibrated using the fringe counting method for the low frequency shaker and the medium and high frequency shaker.
The back to back sensor was calibrated in the same configuration on both shakers.
The single ended sensors were fitted onto the low frequency shaker on a cube where the laser pointing surface is not the same as for the medium and high frequency shaker. The

8305 sensor was calibrated as an accelerometric chain with the Bruel & Kjaer 2525 conditioner.

Figure 7 shows the relative deviations in sensitivity between the calibrations made using the two shakers as a function of the frequency. The continuous thick lines correspond to the lower and upper uncertainties for the medium and high frequency bench.

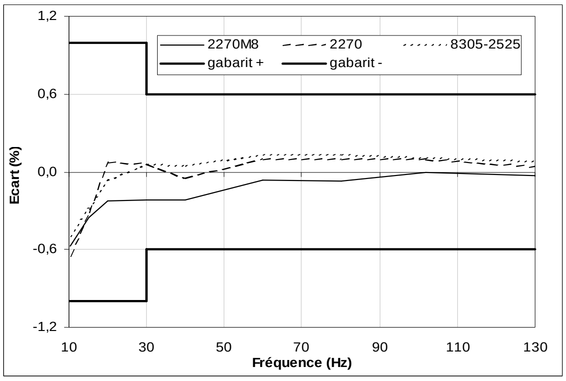


Fig. 7. Comparison of the 2 shakers for the 3 sensors.

Beyond 15 Hz the deviations observed are much smaller than the calibration uncertainties of the bench for the three sensors, single ended and back to back, i.e. they are not significant. The excitation frequency 10.2 Hz shows a systematic deviation of the order of 0.6% for an uncertainty of 1%. It corresponds to the lower limit for the medium and high frequency shaker where the signal exhibits harmonic distortion which explains this difference. The deviations observed also allow mounting of single ended sensors onto the cube to be validated.

### *3.2. Implementation of method 3*

The system sourced, is a Bruel & Kjaer Pulse analyser, which uses Fourier transform to implement method 3 in accordance with the standard ISO 16063-11 [1,3].

Qualification of the Pulse system is carried out through comparison with method 1 using fringe counting on both types of sensor technology, piezoelectric and quartz Q-Flex, on the low frequency shaker over the common range for the two methods, 10-100 Hz.

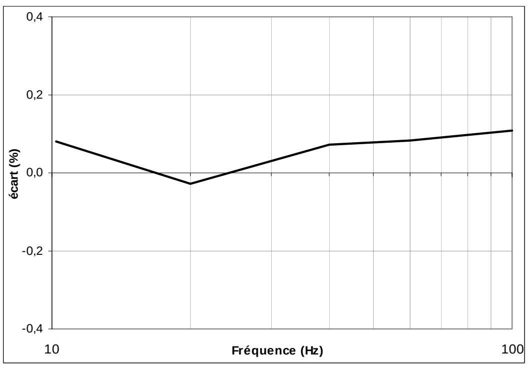


Fig. 8. Calibration of the Q-Flex sensor using methods 1 and 3.

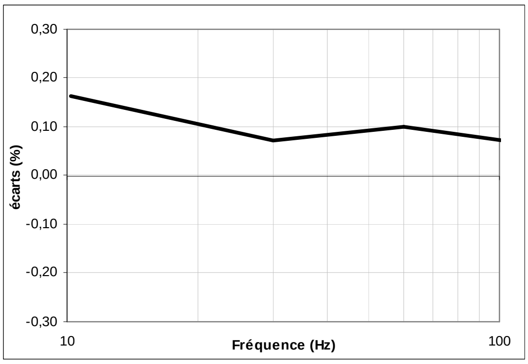


Fig. 9. Calibration of the 2270 sensor using methods 1 and 3.

The uncertainties estimated, apart from effects associated with the shaker (transverse, distortion) are of the order of 0.3% irrespective of the method.

The deviations observed on figures 8 and 9 for the two sensors between the two methods are smaller than the uncertainty and allow method 3 to be validated for low frequency calibrations.

### *3.3. Bilateral comparison*

A bilateral comparison with PTB was carried out over the frequency range 0.7 Hz to 60 Hz. LNE used method 3 using Fourier transform and PTB used method 3 using sinusoidal approximation.

Figure 10 shows the relative deviations in sensitivity in relation to a given nominal value for the two calibrations as a function of the frequency.

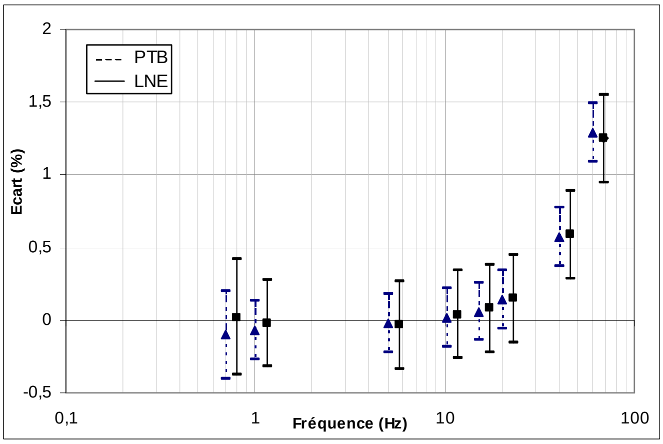


Fig. 10. Comparison between the LNE bench and the PTB bench for the Q-Flex sensor.

The observed deviations between the two calibrations are less than the uncertainties, represented by the vertical bars on the previous figure (of the order of 0.3%). They are not significant. This means that the metrological capabilities of the low frequency bench can be validated.

## 4. CONCLUSION

The most critical technical feature of the original configuration, the laser, was quickly qualified and placed in service in order to ensure the LNE's mission to provide national references.

The low frequency bench was first of all qualified by comparison with the medium and high frequency bench over the common range, a qualification which used two methods, method 1 using the original system and method 3 using the Pulse system. It was finally qualified by means of a bilateral comparison using a Q-flex technology sensor at very low frequency.

LNE is therefore able to offer industrial organizations traceability chains over an extended frequency range at low frequencies.

Qualification of the acquisition and analysis system on the medium and high frequency bench and of the new shaker obtained for this bench are still to be carried out. This will offer improved levels of uncertainties compared to those that are offered today.

This upgrade of the vibration benches will allow LNE and French metrology to play a important role in accelerometry international activities.

## ACKNOWLEDGMENTS

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