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TRANSFER OF THE FRENCH ACCELEROMETRY REFERENCE LABORATORY FROM CEA-CESTA TO LNE

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Abstract: LNE has taken over the function of accelerometry reference laboratory following the decision of the CEA-CESTA to give up this activity. This article presents the principal stages in the transfer of the reference for medium and high frequency vibrations.

Key words: accelerometry, vibration.

1. INTRODUCTION

The national accelerometry references are being restructured after the decision taken by CEA CESTA in 2005 to stop being the reference laboratory in this domain, a task it had fulfilled since 1974. LNE has taken over this function and installed a new laboratory dedicated to this activity on its Trappes site.

The primary national references of CEA-CESTA were made up of three equipments :

- an absolute for medium and high frequency vibrations,
- two other for shock (medium and high level).

In the course of the year 2005, the medium and high-frequency vibration equipment as well as the laser velocimeter pick up of the shock equipment were transferred to LNE. CEA-CESTA is keeping the actual shock equipments (without velocimeter) for its own comparative calibration needs.

The transferred equipment makes use of the absolute calibration method for medium and high frequency vibrations (laser interferometer). In France, this station serves as reference for calibrating the accelerometers used by calibration laboratories for comparison measurements.

After an overview of the main characteristics of the transferred equipment, the following topics are discussed in this article:

- facilities (site, foundation, computers) and removal,
- testing,
- comparison results,
- upgrading and future extensions.

2. PRESENTATION OF THE TRANSFERRED EQUIPMENT

The primary accelerometry equipment in sinus vibration mode with medium and high frequencies (fig.1) consists of the following basic components :

- a seismic block,
- a vibrator,
- a Michelson interferometer with helium-neon laser,
- a frequencemeter/counter and a voltmeter.

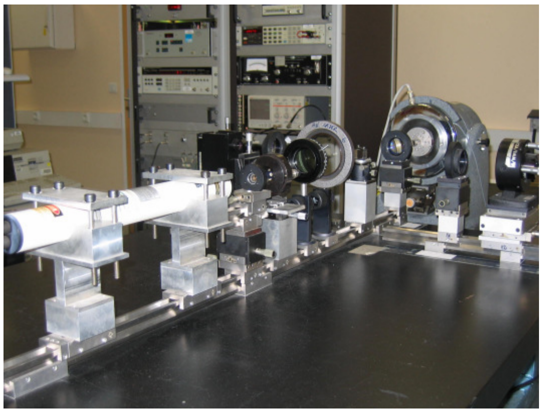
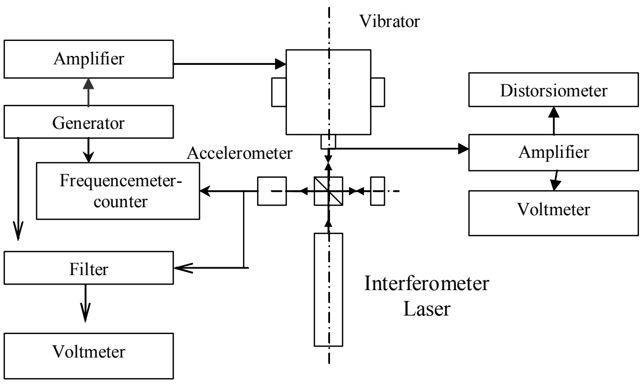


Fig. 1. Accelerometry equipment for medium and high frequency vibrations

The following diagram (Fig. 2) gives a simplified overview of the operation of such a system :



$A = X_o (2 \pi f)^2$	
$X_o = N \lambda / 8$ $N = f_f / f$	$X_o = x_n \lambda / (4 \pi)$

Fig. 2. Principle of the accelerometry equipment

The methods used by the station have already been described [1] and are subject to an international standard [2], which is summarized in the following.

2.1. *Accelerometry through interferometry*

The accelerometer fixed to the vibrator is subjected to a sinusoidal oscillation of frequency f and amplitude X_o. By successive derivations the amplitude A of the applied sinusoidal acceleration equals $X_o (2 \pi f)^2$.

The displacement amplitude is measured by a Michelson interferometer whose mobile mirror is attached to the accelerometer. The displacement of the accelerometer required for the successive appearance of two interference fringes corresponds to half the length of the laser wave ($\lambda/2$).

For a linear time displacement of the accelerometer, the signal of the Michelson interferometer is sinusoidal in function of the time, the necessary displacement for the succession of two maximum signals being one half of a laser wavelength.

A graphical representation of this phenomenon is given in Fig.3 for a linear mirror displacement as a function of time and in Fig.4 for a sinusoidal displacement as a function of time.

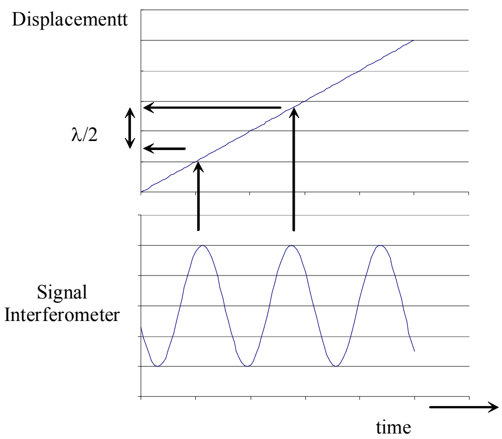


Fig. 3. Signal for linear displacement

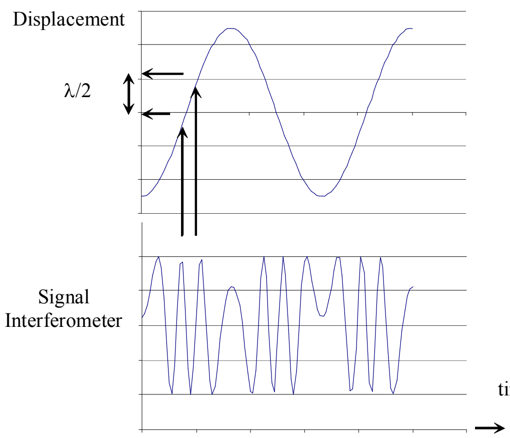


Fig. 4. Signal for sinusoidal displacement

2.2. *Fringe-counting method*

If N fringes are counted for an accelerometer moving period, i.e., for 4 X_o move, then the move corresponds to $N \lambda / 2$, and we get: $X_o = N \lambda / 8$.

On the same period, the counter determines the number of n_f fringes from the interferometer signal and the number of n_d moving periods from the generator signal Their quotient allows calculating N the number of fringes for a period: $N = n_f / n_d$.

Dividing the numerator and denominator by the counting period does not change the equality and allows us to express the number of fringes for an N moving period in terms of the f moving frequency and of an f_f equivalent frequency of fringes. $N = f_f / f$.

For very small moving amplitudes, which is what notably occurs when frequencies are high, the uncertainty due to the count can play a primary role in relative terms. The following method is then used.

2.3. *Minimum point method*

When X(t) move is a sine function of frequency f ($X(t) = X_o \cos(\omega t)$, pulsation $\omega = 2 \pi f$), the signal at the output of detector I(t) is frequency modulated sinusoidal signal where the cycle is 1/ f. (Fig. 4), which is written :

$I(t) = M \{1 + N \cos[(4\pi/\lambda)(d_o - X_o \cos(\omega t)]\}$

Where M and N are coefficients dependent on the intensity and contrast of fringes, and d_0 represents the difference of the optical pathway between the two resting beams.

One demonstrates mathematically that such a signal shows a spectrum of pulsation rays regularly spaced ω, 2ω, 3ω…

$I(t) = M \{1 + M_1 \cos(\omega t) + M_2 \cos(2\omega t) + M_3 \cos(3\omega t) \ldots\}$

The amplitude of each of these spectral components varies based on the peak amplitude of displacement X_0. For example, if we consider coefficient M_1, which is the standardized peak amplitude of pulsation component ω, we have:

$M_1 = W \cos(4\pi d_o/\lambda) J_1(4\pi X_o/\lambda)$, where W is dependent on the contrast.

This coefficient M_1 oscillates based on peak displacement X_0 and it cancels out for certain particular values of this one, which cancels the first order Bessel function $J_1(x)$.

If we filter the output signal of the detector by allowing the ω component to pass through, it will then be sufficient to increase the displacement amplitude until a null signal is obtained at the output of the filter corresponding to the first zero of function $J_1(x)$, then the second one, etc…

For this particular values, the amplitude of peak displacement X_0 may be known very precisely and it corresponds to :

	x_1	x_2	x_3	…
$4\pi X_o/\lambda$	3.8317	7.01559	10.17346	…

The successive values of x_n are given in [2].

2.4. Field

This equipment allows the application of the fringe counting method and the zero research methods. On the other hand, this equipment does not allow the application of the most recent method that requires the installation of a laser interferometer with quadrature output.

The amplitude limits of the field depend on the application possibilities of the presented methods, the technical characteristics of the exciter and the mass that charges its moving part.

Before its transfer, this equipment was accredited by Cofrac (French accreditation committee). The calibration uncertainly (k=2) was equal to ± 0.6 % of the sensitivity of the calibrated instrument (accelerometer or accelerometric chain). The sensitivity is defined in relation to the electrical output of the instrument by applied acceleration. The latter is determined by counting fringes ranging from 10 Hz to 900 Hz and by search of $J_1(z)$ zeros from 800 Hz to 10 kHz.

3. ARRANGEMENT AND MOVE

3.1. Premises

In order to accept the new equipment, a 45 square meter laboratory was rearranged from three contiguous offices. This new laboratory is located on the ground floor of the Louis Lumière Building at the LNE's Trappes site. A rearrangement was then required for the main work projects, as follows:

- Demolition of partition walls between offices, building of a double door on the hallway, installation of the existing false ceiling and raising it to a height of 3 meters, elimination of existing ventilation convection units on the ceiling;
- Recoating and painting of walls and doors built, floor recoating, plumbing work - compressed air – electrical work;
- Building of laboratory ventilation and air-conditioning with such conditions as:
  . Temperature: 23 °C ± 1 °C
  . Relative humidity: 55 % ± 10 %

A station connected to a probe installed in the central area allows monitoring for proper compliance with these ambient conditions. A verification of spatial homogeneity s performed for a period of one week.

The floor allows for a distributed load of up to 350 kg/m^2. In order to verify the vibration characteristics of the slab, measurements were taken. These measurements show a weak vibration level of the floor of the new laboratory.

3.2. Seismic block

The seismic block of CEA-CESTA, installed in a mini-trench, was not transferred. A granite block weighing over a ton (1200 kg) was provided. It was placed on a concrete mat (base) of the type used under the LNE mass comparator blocks. An interface plate for securing the exciter was built and sealed on the block with 12 M 20 screws bolted in an epoxy sealant consisting of two components with enhanced mechanical strength properties.

Fig. 5. . Installation of the exciter interface plate on the new 1200 kg block

In the new laboratory, this seismic block which was not installed inside a trench, a frame supporting the laser interferometer table was built for achieving a compatible height.

3.3. Data Processing

At CEA-CESTA the bench was controlled by an obsolete generation computer. An unrecoverable breakdown of this computer has shown evidence of the fast retaking of the activity. One of the solutions contemplated was the operational commissioning of a new bench where certain components had been already provided. However, the qualification of this new system also entailed a significant of the activity.

To correct the situation, a spreadsheet (Excel) was developed. It allows to assist and to make possible a manual use of the transferred equipment. For purposes of setting parameters and their easy management, a specific tab was created consisting of all the measurement parameters of the methods and procedures implemented. It involves a mini database of measurement parameters. The sorter then consists of 4 other main tabs that are linked to the database tab:

- "Program": It sets the calibration program in relation to the domain based on the method, amplitude and frequency.

- "Control": It tests the proper operation of the power of the bench.
- "Count": It determines the target voltage values of the generator, then from the measurements, the calculation of the acceleration amplitude and the sensitivity of the accelerometric chain. In the case of calibration of one single accelerometer, its sensitivity is determined from the amplifier gain. The latter is interpolated from the frequency to be achieved and from the stated gain range, all of it using the database table.
- "Zeros": Functions identical to the previous tab but by applying the zero research method.

The comments are linked to each cell consisting of a formula for describing it. The "notice" tabs give the detail of the functions and the formulas applied in each of the main tabs.

Concurrently, specific data automation was installed for editing the calibration certificates with automated determination of the derivation of the instrument. This second data automation is independent of the data automation of the bench control so as to remain updated after a bench change.

3.4. Moving the Office

Fig. 6. Arrival of Equipment before Installation at LNE.

The new LNE Team assisted by the former manager in charge of the CEA accelerometry laboratory performed disassembly and Packing of the Bench at CEA-CESTA. Each instrument was individually packed and placed in a transport crate. The 5 pallets that were built, the frames of the two emptied cabinets and the support table of the interferometer were transported without breaking any load (Fig. 6).

The personnel of the new accelerometry laboratory performed the unpacking, wiring and adjustment of the equipment also with the assistance of the former accelerometry manager. Tests for proper operation showed satisfactory performance of the equipment (Fig. 7) after the bench was reassembled.

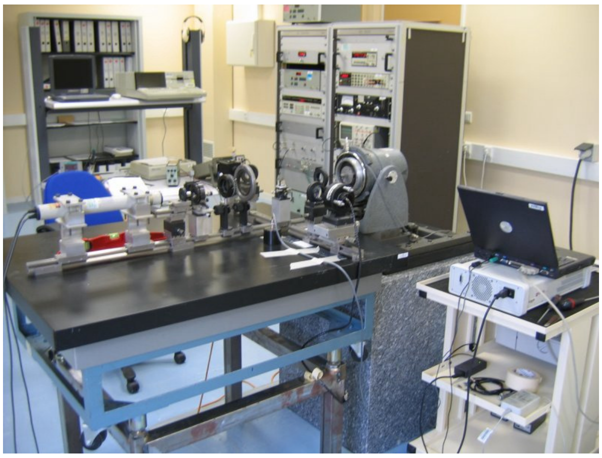


Fig. 7. View of the Installation at LNE after Reassembly.

4. QUALIFICATION

The main stages of the qualification carried out after the transfer were:

- Measurements of the vibration levels of the support table of the laser interferometer for different operating levels of the exciter. The movement of the interferometer itself is indeed of a nature to cause the moving measurement of the accelerometer to fail.

- Measurements of the crosswise movement rate of the moving part of the exciter. This crosswise movement disturbs the axial moving rate by the parallelism default created. On the other hand, based on the transverse sensitivity of the standardized instrument, an uncertainty component, as a function of the crosswise movement rate, is taken into account.

- Calibration of the measuring equipment. Each time, the calibration program applied by the previous laboratory was optimised relative to the usage domain and with the necessary and sufficient uncertainties. The main calibrated equipment are:
  . The laser interferometer,
  . The voltmeter,
  . The frequency meter/counter,
  . The amplifier.

The analysis of the results allowed for a new determination of uncertainties connected to the use of the bench.

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

± 1.0% of 10 to 30 Hz
± 0.60% of 30 to 10,000 Hz.

The degradation retained for the weak frequencies does not seem to originate in the transfer but rather in a degradation of performance levels originating in the exciter, already confirmed at CEA-CESTA (crosswise movement and distortion).

5. COMPARISONS

In order to verify the metrological continuity of the bench after its transfer, witness accelerometers were calibrated at CEA-CESTA before the move. These same accelerometers were again calibrated at LNE.

The following sections of this chapter present:

- The equipment used for the comparisons,
- The program of comparisons,
- The results,
- The analysis of deviations.

5.1. The accelerometers

So that the conclusions will not depend on the accelerometer and amplifier used, an accelerometer and a reference accelerometric chain (accelerometer and amplifier) were defined and supplied. With the reference accelerometer supplied by CEA with the bench, the three witness instruments allow a sufficient redundancy.

. Endevco Accelerometer, Type 2270
Specialized for acceleration measurements transmitted on top of the accelerometer. This type of transducer is used as a reference for comparison standards. This transducer was used by CEA for several years as a way to check measurement stability of the bench.

. Endevco Accelerometer, Type 2270M8
Specialized for acceleration measurement applied to its base. It was obtained by LNE at the time of taking charge of accelerometric activity. The bench configuration for the standards "at the base" is different from the configuration for standards "at the top". The use of both types of accelerometer will allow verifying the characteristics for both configurations of the bench.

. B&K Accelerometer Type 8305-001
This accelerometer is again specialized for an acceleration measurement applied at the base. It was also obtained by LNE at the time of taking charge of the accelerometric activity. The measurement redundancy thus established will allow showing that the results do not depend on the transducer used.

5.2. The Amplifiers

The amplifier allows a conversion of the electric power output signal of the accelerometer compatible with the bench voltmeter.

. B&K amplifier, Type 2626
This is the amplifier traditionally associated with the bench in the case of one single accelerometer presented for standardization. This amplifier was associated with both Endevco accelerometers.

. B&K amplifier, Type 2525
This is a new generation amplifier. Also obtained for the occasion, this new measurement redundancy will allow attributing any deviations to one of the amplifiers or to the other components of the bench. It was associated with the B&K accelerometer.

5.3. The Achieved calibrations

For each of the three transducers, a calibration program was defined to cover the bench operation domain. The frequency and the applied sinusoidal acceleration amplitude define each calibration point of a program. The retained program is given below:

Frequency (Hz)	10	40	102	102	102	200	460	800
Amplitude ($m.s^{-2}$)	5	10	50	100	200	60	400	40

Frequency (Hz)	900	1500	3000	4500	6500	8000	10000
Amplitude ($m.s^{-2}$)	50	45	125	155	320	490	760

The calibration of one of the accelerometers is also obtained by B&K on its own bench at 160 Hz with an amplitude of 50 $m.s^{-2}$. In order to take advantage of the results, the following program was added for the B&K accelerometer :

Frequency (Hz)	102	102	160	160
Amplitude ($m.s^{-2}$)	20	200	50	300

The calibrations at CEA-CESTA were repeated with the replacement of the operator to validate the qualification of the new parties involved and for two different periods so as to quantify the drift on the short term.

The standardizations were first performed at CEA-CESTA, by Mr. Christian Barreau, former manager in charge of the Cofrac-accredited standardization centre, in binomials with Philippe Averlant, manager in charge of the LNE accelerometry laboratory. Two standardizations were performed in the two bench configurations (base and top).

The second calibration was then repeated without CEA's help. The deviations obtained allow confirming the skill of the new operator. Two supplementary calibrations were also performed by the latter with a replacement of accelerometer and then a replacement of amplifier.

With a few interval periods and always at CEA-CESTA, these five calibrations were repeated by Mr. Christian Barreau and by Mr. Cédric de Waubert, accelerometry technician at LNE. Again, the deviations allow confirming the skill of the operator and the measurement stability of the bench on the short term.

After the transfer of the bench from CEA-CESTA (Bordeaux) and LNE (Trappes), the five standardizations were again repeated to confirm the preservation of the measurement characteristics of the bench after it was relocated.

Table 1 below summarizes the calibrations performed, listing the place and date; the operators; the methods and the code used throughout the document.

Table 1 – Development of the Comparisons

place	date	Operators	Transducer	Réf
DK	24/04/05	B&K	B&K 8305-001	K
CEA	7/06/05	C. Barreau (CEA) et P. Averlant (LNE)	Endevco 2270	A
	8/06/05		Endevco 2270M8	B
	8/06/05	P. Averlant (LNE)	Endevco 2270M8	C
	9/06/05		B&K 8305-001/2525	D
	9/06/05		B&K 8305-001	E
CEA	5/07/05	C. Barreau (CEA) et C. de Waubert (LNE)	Endevco 2270	F
	6/07/05		Endevco 2270M8	G
	6/07/05	C. de Waubert (LNE)	Endevco 2270M8	H
	7/07/05		B&K 8305-001/2525	I
	7/07/05		B&K 8305-001	J
LNE	10/02/06	C. de Waubert (LNE)	Endevco 2270	G010303/4
	07/02/06		Endevco 2270M8	G010303/1
	09/02/05		B&K 8305-001/2525	G010303/3
	09/02/06		B&K 8305-001	G010303/2

5.3. Presentation of Results

The following graphs (Fig. 8 to 11) show the results obtained for each of the accelerometers and for the accelerometric chain. The reference of the calibrations is the one defined in Table 1. Each time, the curve in a thick straight continuous line corresponds to the calibration after the transfer (at LNE). The graphs represent the relative sensitivity deviations relative to the nominal value and based on frequency. For a given graph, the deviations between the curves represent the calibration deviations.

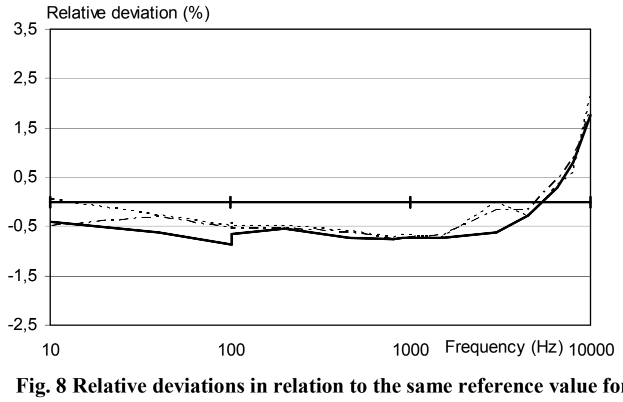


Fig. 8 Relative deviations in relation to the same reference value for Endevco 2270 (Calibrations A - F and G010303/4)

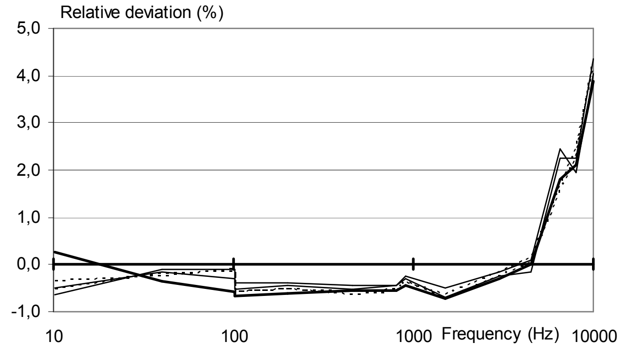


Fig. 9. Relative deviations in relation to the same reference value for Endevco 2270M8 (Calibrations B-C – G-H and G010303/1)

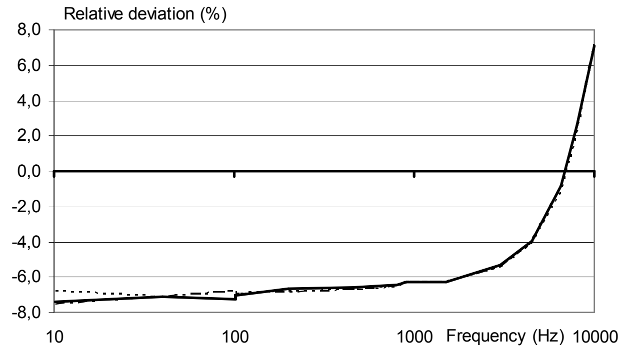


Fig. 10. Relative deviations in relation to the same reference value for B&K 8305-001/2525 (Calibrations D – I- and G010303/3)

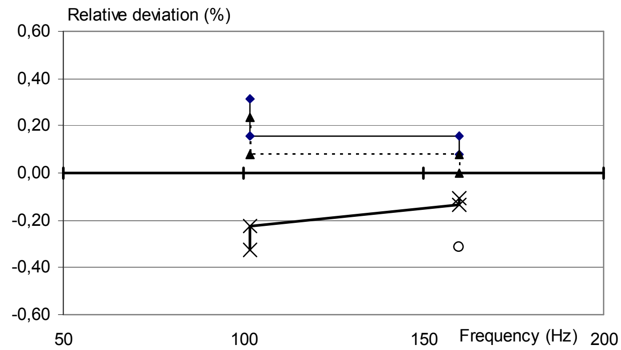


Fig. 11. Relative deviations in relation to the same reference value for B&K 8305-001 (Calibrations K – E - J and G010303/2)

5.4. Deviations Obtained

The deviations between the different previous curves represent the calibrations deviations. To judge their importance, they are to be compared to calibration uncertainties.

In the following graphs (Figs. 12 to 15), each calibration point is inserted in terms of its deviation from the mean value of the obtained results. The thick continuous lines represent the new uncertainty of the bench more or less two standard-deviation.

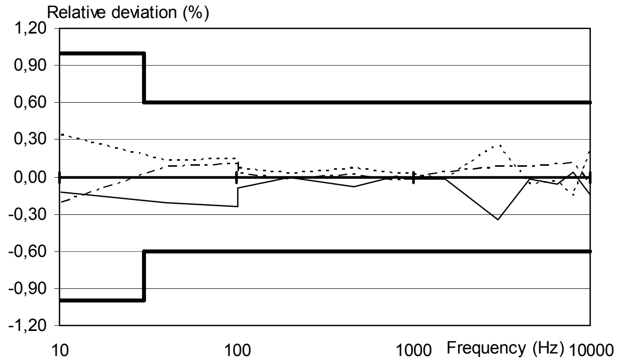


Fig. 12. Relative Deviations between Calibrations for Endevco 2270 (Calibrations A - F and G010303/4)

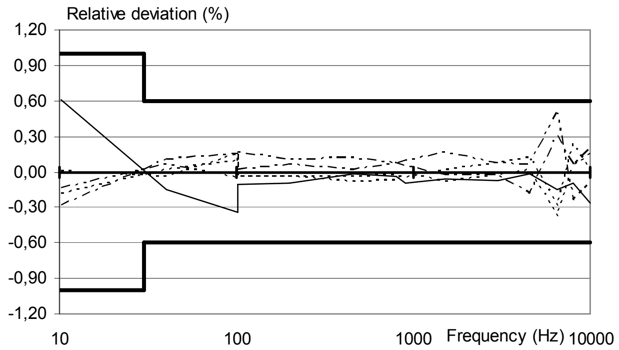


Fig. 13. Relative Deviations between Calibrations for Endevco 2270M8 (Calibrations B-C – G-H and G010303/1)

5.5. Analysis

The previous graphs (Figs. 12 to 15) show that the obtained deviations are not significant with regard to the vibration bench calibration uncertainty.

Let us remember that the calibrations compared before and after the transfer of the bench were obtained with a change in the comparison transducer and a replacement of the operators. The calibration result of a foreign laboratory was even taken into account.

These results allow supporting the continuity of accelerometry references after the transfer and are intended to confirm reliance on retained estimating of uncertainties.

6. LEVEL SETTING

The transferred accelerometry bench has been operating for more than 15 years on a technology whose design and its main measurement philosophy elements are sometimes more than 20 years old. The maintenance of this type of equipment is not possible and in case of a breakdown, major modifications must be provided. In addition, new technology and techniques have been developed. A new standardization method has been regularized [2]. It cannot be applied to support the present bench.

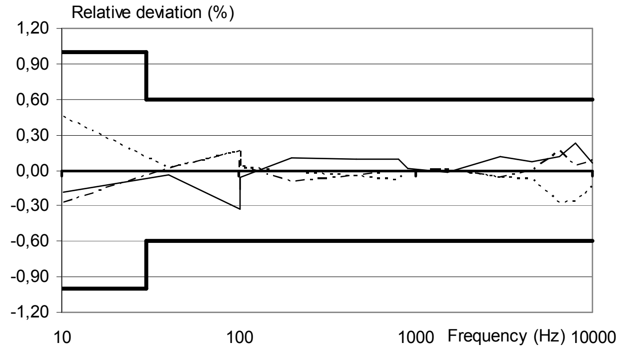


Fig. 14. Relative Deviations between Calibrations for B&K 8305-001/2525 (Calibrations D – I- and G010303/3)

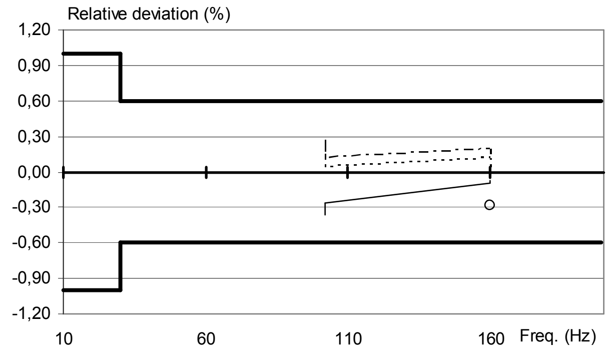


Fig. 15. Relative Deviations between Calibrations for B&K 8305-001 (Calibrations K – E - J and G010303/2)

Setting to the level of this average bench and high frequency is therefore necessary. A new laser portion and the measurement system, processing and editing have already been provided. Their measurement qualification, on the one hand, and setting to the vibrator level and the power amplifier, on the other hand. After this level setting, an international comparison must be made.

A supplementary objective is envisioned. In France, presently there is no reference equipment to cover the primary calibration requirements for vibration frequencies below 10 Hz.

The laser and the medium and high frequency measurement system will have the characteristic of being usable for low frequency calibrations. It is envisioned that the preceding acquisitions will be completed by the supply of an exciter and a specific block for low frequency.

Thus, the final configuration contemplated is a medium and high frequency exciter; another exciter for low frequency; one single laser and finally a common measurement, processing and editing system. . The common installation of the equipment and methods allows for optimising the system as it is extended to low frequencies

The old transferred bench may be discarded. The move will have been useful by favouring the exchange of skills and facilitating the comparison between the old system and the new system for the continuity of the measurement references. On the other hand, this move will have allowed a faster resumption of the activity. In fact, the new system based on a digital analyser, still poses measurement-calibration problems that will have to be solved.

7. CONCLUSION

The transfer of accelerometry references from CEA-CESTA to LNE was achieved by moving the absolute sinusoidal vibration method/medium and high frequency reference equipment.

The care provided during this move, in providing techniques and procedures of this new area for LNE and the importance afforded to the confirmation of the metrological stability of this reference intended to demonstrate the skills of the team in integrating the activity of a new measurement field and performing the respective calibrations with one of the highest measurement capabilities.

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Mr. Cédric de Waubert (LNE) also participated actively in the relocation. Finally, Jean-Noël Durocher, in charge of the accoustic laboratory at LNE, provided his expertise in the processing of signals.

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