48º CONGRESO ESPAÑOL DE ACÚSTICA
ENCUENTRO IBÉRICO DE ACÚSTICA
EUROPEAN SYMPOSIUM ON UNDERWATER ACOUSTICS APPLICATIONS
EUROPEAN SYMPOSIUM ON SUSTAINABLE BUILDING ACOUSTICS

INSTRUMENTATION INHERENT NOISE CONSIDERATIONS IN BUILDING ACOUSTICS VIBRATION VELOCITY

PACS: 43.55.Rg

San Millán-Castillo, Roberto[1]; Morgado Reyes, Eduardo[1]; Goya Esteban, Rebeca[1]; Figuera Pozuelo, Carlos[1]

[1] E.T.S.I. Telecomunicación – Universidad Rey Juan Carlos, Camino del Molino, s/n - 28943 Fuenlabrada (Madrid, Spain). roberto.sanmillan@urjc.es

Key words: accelerometer, vibration, insulation, airborne sound, transmission.

ABSTRACT.
To get more sustainable building acoustics design and realisations, vibration velocity level is an interesting airborne sound insulation estimator, facing classical sound pressure level-based methods. However, the right sensors and data acquisition systems employment must be the proper one for the application. Instrumentation inherent noise is critical when dealing with high insulation ratings. Testing of limit minimum measurement levels is suggested and analysed. Results show arranged typical set-ups performance, and a use proposal is recommended.

RESUMEN.
De cara a un diseño y ejecuciones más sostenibles en acústica de la edificación, el nivel de velocidad de vibración es un estimador interesante del aislamiento acústico a ruido aéreo, frente a los métodos clásicos basados en niveles de presión sonora. Sin embargo, el uso de sensores y cadena de medida debe ser adecuado a su aplicación. El ruido inherente de la instrumentación es crítico trabajando con aislamientos elevados. Se proponen y analizan unas pruebas para acotar niveles mínimos de medida. Los resultados muestran el comportamiento de configuraciones tipo adaptadas, y se sugieren pautas de uso.

INTRODUCTION

Airborne sound insulation between rooms is determined by procedures included in international standards [1]. Field insulation certification of a separating partition and its comparison with legal limits is the main goal [2]. When trying to perform a sustainable and efficient design which increases sound insulation, data from standardized tests might be incomplete. Unless testing environment works as sound transmission suite, unusual in real cases, flanking transmissions are likely to contribute to receiving levels along with the separating partition [3,4].

One important variable which can determine lateral transmissions is vibration velocity level (L_v) [5]. L_v is a parameter tied to radiated sound power from partitions and its acquisition is simple [6,7]. There are instrumentation solutions supported on general purpose one-axis accelerometers, whose design can be improved regarding the needs in building acoustics testing [8]. A moderate resource investment can provide us with room wall vibrational responses.

In general, sound insulation is better in high frequency range, fact underlined regarding multiple layer partition design, and flanking paths [7]. Then, vibration signal levels can reach very low values which can interfere with noise, even more when using a vibration probe [8]. In low frequency range, inherent noise usually rises to relevant levels as it happens with sensors [9,10]. So, it is imperative to know background noise in this data collection procedure. Besides vibration signal from other sources, inherent noise of the equipment is also involved. Piezoelectric sensor inherent noise can be estimated by its thermo-electric and thermo-mechanic noises [9]. Some of the required data is not always available in manufacturers technical specifications, they are hardly to find out, or difficult to check in a regular engineering work. Usual available data is noise spectrum density at certain frequencies (10Hz, 100Hz, y1kHz and/or broadband), but it is uncommon to have a detailed information for all frequencies [10,11], or for a real measurement set-up with all parts interacting with each other in certain circumstances (analyser, cables, connectors and sensors).

This paper shows results of some testing proposals aimed to measure inherent noise of a whole measurement system devoted to vibration signal collection in building acoustics. Experiments are carried out on different features piezoelectric accelerometers and several mounting techniques. Testing are willing to be operational, and reasonable in a general engineering environment; not a laboratory one. Operational use proposal are suggested with regard to the testing environment

PROBLEM STATEMENT

In building acoustics, vibration signal levels could be very low. Flanking elements are not airborne straight excited and background signal levels must be considered in the measurement. The problem states this way: there is a possible contribution of instrumentation to background signal, and it can interfere with vibration signal which is generated by an acoustic source excitation. A measurement system consists of several elements which is not described in terms of noise as a whole, and far from a real testing environment [12]. So, inherent noise in every measurement system could increase. This noise must be known to be able to damp it in signal level estimation. The issues to deal with are the following ones:

- Assessment and analysis of interference of inherent noise of a measurement system with vibration signal in a building acoustics environment.
- Proper and efficient quantification of inherent noise of a measurement system in a true testing case and in the right frequency range.
- Recommendations suggestion on field inherent noise estimation of instrumentation by simple, quick and affordable procedures, depending on tests to be performed.
- Further research lines suggestion to improve and broaden data gathered.

EXPERIMENTS

Tests were performed in Rey Juan Carlos University facilities (Madrid, Spain). Experiments were carried out in a soundproof chamber (CEA) in the Acoustics Laboratory to avoid not desired and difficult to identify airborne and structure borne signals, mainly in low frequency range. The "quieter" moments are chosen, discarding occasional events.

Two one axis piezoelectric accelerometers CCLD™ are employed, whose global specifications are: general purpose design, low sensitivity to environmental factors, several mounting techniques availability, lightweight as 8.6g, and professional and precision use. The following technical accelerometers features should be remarked [11]:

- Type 4533-B-004, from B&K. Voltage sensitivity: ~50mV/g. Frequency range of use (Amplitude):0.2-12.8kHz. Resonance frequency: 43kHz. Amplitude range: +/-163dB. Wide band Inherent noise: ~63dB.
- Type 4533-B-002, from B&K. Voltage sensitivity: ~500mV/g. Frequency range of use (Amplitude):0.2-12.8kHz. Resonance frequency: 40kHz. Amplitude range: +/-143dB. Wide band Inherent noise: ~59dB.
- Low noise coaxial cable 10-32UNF, and BNC adaptor, length 1.2m].
- Frequency analyser, type Soundbook, from Sinus.

In all tests, the whole measurement system is analysed with one-third octave band resolution. An exponential average is applied over a time measurement of 15s. The variable studied is acceleration level to obtain a direct value, and not an integrated one as velocity, so direct comparison might be done against manufacturer´s sensors specifications or other research papers in this field [9,10,11]. The different performed experiments are described and justified as follows, see *Figure 1*. All of them use both 50mV/g and 500mV/g sensors:

- ***BN_OnRubber***, background noise. The sensor rests on an antivibration elastomer pad in the CEA. This measurement goal is to record the background vibrational signal of the whole measuring system, in the least environmentally biased circumstances. It is the closest test to the ones performed in a proper calibration laboratory, and it is supposed to show the minimum inherent noise provided by the measurement system. Therefore, *BN_OnRubber* test is considered as the "Gold Standard", or reference value.
- ***BN_OnAir***, background noise in the air. The sensor is supported by hand in the air vertically, trying not to move it at all. This test would be an alternative to obtain background noise when a proper surface to let the sensor rest is not available.
- ***BN_Mov***, background noise with movements. This test is very similar to *BN_OnAir*, but performing a slight movement with the hand holding the sensor, up and down around 10cm. It tries to show the effect of an exaggerated movement in a test carried out by an expert, but not so far from a beginner; or in a situation when a forced position can cause extra movement (e.g. a measurement on the ceiling, or on a difficult access partition area)
- ***BN__OnRubber_XXBrass***, background noise with probe. In this test some brass probe of different lengths are attached to the accelerometers (XX means 6.5mm or 25mm), and measurements are performed in different probe orientations (Vertical or lateral). The goal of this measurement is the research of the effect of probe attaching to the sensor when it comes to inherent noise. Probes rest on an elastomer, simulating testing on a wall, but with no vibrations.

RESULTS AND DISCUSSION

EXPERIMENT 1: FIRST HYPOTHESIS AND BN_OnRubber, BACKGROUND NOISE

The most advantageous situation regarding background noise is shown first, *BN_OnRubber*, see *Figure 2*. It is important to verify whether first hypothesis is right, and inherent noise values can interfere with vibration signal collected in real testing on a airborne excited partition. Inherent noise is represented as a vibration velocity level (L_v), referenced 10^{-9}m/s. The rest of signals are part of an airborne sound insulation test (R´w = 48dB, an average value in building acoustics):

separating and a flanking element velocity levels. Regarding the separating element, inherent measurement system noise figures hardly interfere: there is at least a 12.5dB difference in low frequency range, and its correction is possible (i.e. more than 6dB). Flanking element case is different and even its velocity level signal goes 10dB below the inherent noise of the least sensitive accelerometer; then there is no chance to correct it. In a general scope, more unfavourable situations are possible: higher insulation values which means lower L_v; and lower sensitivity sensors whose inherent noise uses to be higher as well. So, the first hypothesis is confirmed.

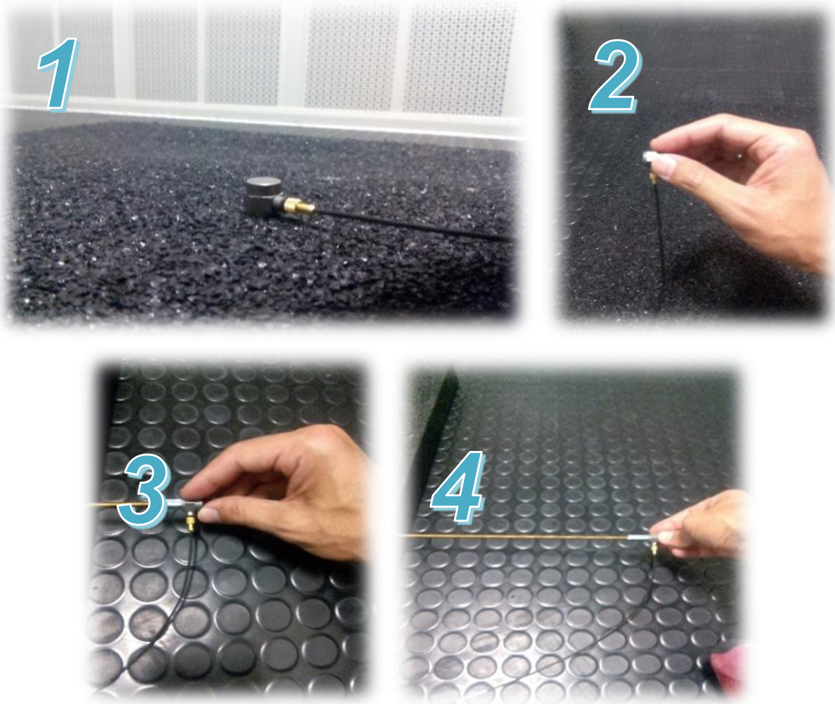

Figura 1. Example photographs on some postitions: 1) BN_OnRubber, 2) BN_OnAir, 3) BN_OnRubber_6.5Brass_Lateral, 4) BN_OnRubber_255Brass_Lateral

EXPERIMENT 2: BN_OnRubber, BACKGROUND NOISE BN_OnAir, BN ON THE AIR
BN_OnRubber and *BN_OnAir* experiment effects are studied now, see *Figure 3*. *BN_OnRubber* is the reference experiment for all the rest, and comparisons regard to it. From this point to the end of the paper, figures represent vibration acceleration levels (L_a), referenced to 10^{-6}m/s^2, more adequate for sensor features comparisons. *BN_OnRubber* let us see sensor sensitivity crucial influence when measuring the same very low levels; the higher the sensitivity, the higher the sensor resolution. Noise figure also differs from sensors specifications because of the rest of the system noise interference in that right situation. At very low frequencies, the 500mV/g sensor detects even very low level vibration. From there, the spectrum is very close to a white noise one, typical of thermo-electrical circuitry noise.

Moreover, *Figure* 3 shows how the fact of holding the sensor in the air increases inherent noise regarding the reference. This change is focused on low frequencies where levels are up to 25dB higher in the most sensible accelerometer. The effect is very similar for both sensors, considering, linearity in most sensors (+/-1/3%), and a movement that is random. This effect is linked to the hand movement since it disappears in the static experiment. The 500mV/g remains more influenced in the frequency range (up to 800Hz-1kHz bands, against 200Hz band). However, once those frequency bands are over, the new inherent noise agrees with the gold standard.

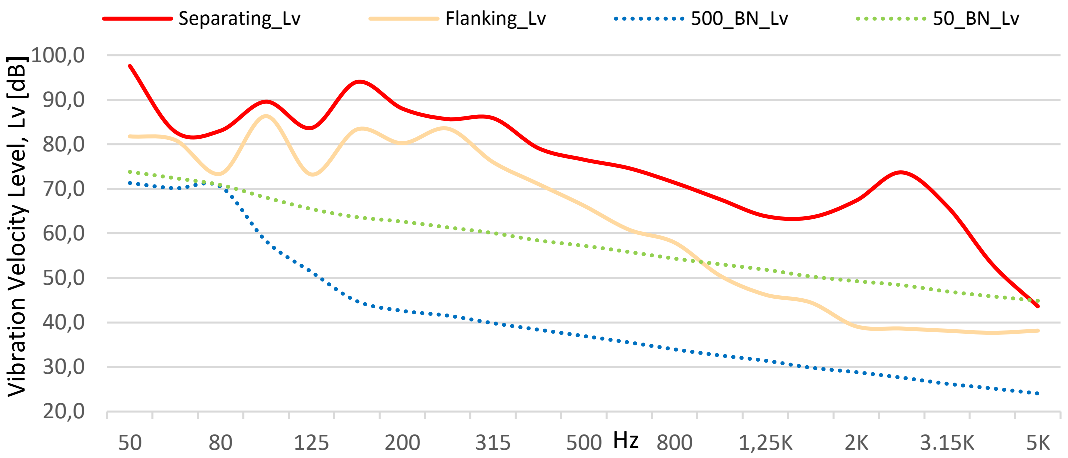

Figure 2. Separating element L_v and flanking element L_v comparison versus measurement system inherent noise L_v with 50mV/g and 500mV/g sensors performing BN_OnRubber experiment.

EXPERIMENT 3: BN_Mov, BACKGROUND NOISE WITH SENSOR MOVEMENT

The impact of a looser accelerometer support that includes some movement is now presented in *Figure 4*. A stronger movement make inherent noise figures worse than just on the air: sensor responses are quite worse broadband, keeping the worst in the low frequency range, and again the most sensible accelerometer is much more affected. However, the 50mV/g sensor increases much more noise level in this experiment. These tests lead to the inconvenience of movements over vibration measurements, with a clear and random deterioration in a signal broadband.

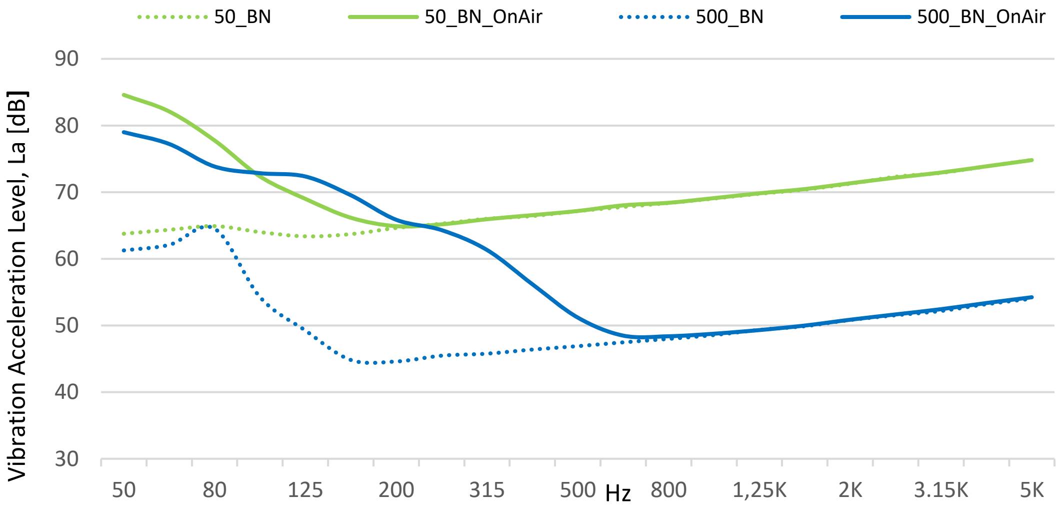

Figure 3. BN_OnAir experiment L_a and BN_OnRubber (50_BN and 500_BN) experiment L_a comparison, with 50mV/g and 500mV/g sensors.

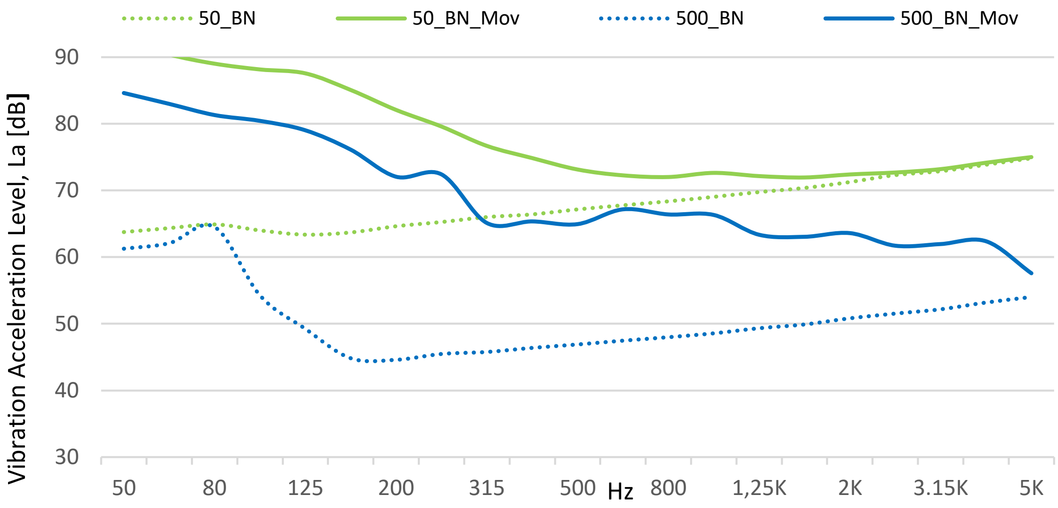

Figure 4. BN_Mov experiment L_a and BN_OnRubber (50_BN and 500_BN) experiment L_a comparison with 50mV/g and 500mV/g sensors.

EXPERIMENTS 4&5: BN_OnRubber_(Lateral)_XX_Brass, BN WITH PROBE
Attaching a probe to accelerometers to collect vibration data brings some certain movements when holding the probe because of a more unstable support. *Figure 5* shows measurements with a 6.5mm length brass probe in a vertical and lateral orientation. It can be verified that different probe orientation barely changes the results, although once again there is a disagreement with the reference measurement. An inherent noise increasing can be scrutinized on the least sensitive sensor comparing with *BN_OnAir*; On the other hand, 500mV/g accelerometer remains the same *BN_OnAir* levels. When it comes to movement, features remain or are improved since support can generate more stability on grasping the accelerometer probe.

The 25mm brass probe analysis comes out some changes with respect to the shortest probe, see *Figure 6*. Firstly, a degeneration in the *Lateral* response in both sensors is confirmed, unlike with the former probe. It can be explained because the lateral support is more unsteady that the vertical one. The new length causes more movement than a shorter one, due to a more forced measurement position. Nevertheless, a very remarkable phenomenon is the improved low frequency response in a vertical position regarding the 6.5m probe, with both sensors. It is likely that a weight gain is the main reason to obtain a better sensor response, so the probe support become firmer.

Concerning gold standard inherent noise measurements, the rest of the experiments show a worse response mostly in low frequencies. As far as 21dB difference with 50mV/g sensor, and as far as 25dB with 500mV/g sensor. Inherent noise has a diverse spectrum depending the experiment performed, but with similar trends: in low frequency range is more changeable although it looks like an A/f noise; in high frequency range, it follows a white noise pattern, shifted in amplitude depending on the accelerometer sensitivity.

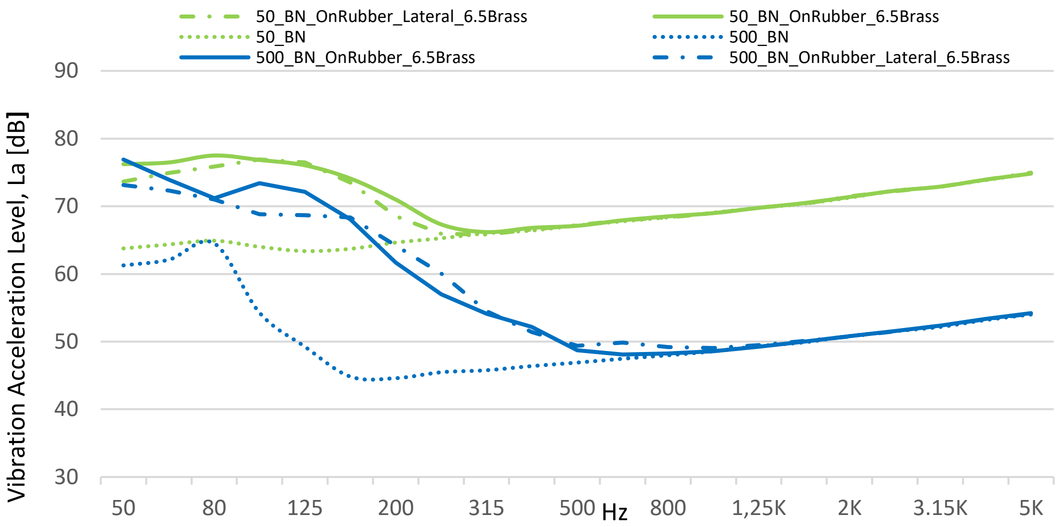

Figure 5. BN_OnRubber_6.5Brass L_a, BN_OnRubber_6.5Brass_Lateral and BN_OnRubber (50_BN and 500_BN) experiment L_a comparison with 50mV/g and 500mV/g sensors.

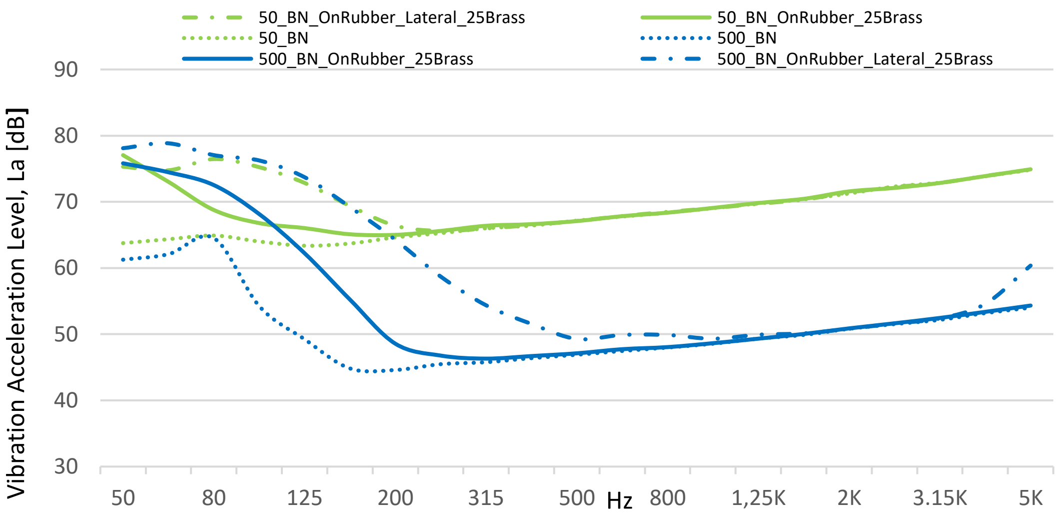

Figure 6. BN_OnRubber_25Brass L_a, BN_OnRubber_25Brass_Lateral and BN_OnRubber (50_BN and 500_BN) experiment L_a comparison with 50mV/g and 500mV/g sensors.

CONCLUSIONS

An experimental point of view of inherent noise of a professional precision measurement system has been provided, along with several simple noise characterization procedures depending on real environment and available resources. So, a sustainable and useful equipment inherent noise assessment is presented. Agreements and disagreements among them have been analysed depending on mounting techniques and sensors involved in tests. The relevance on estimating equipment inherent noise has been confirmed since interference with signals collected in vibrational building acoustics testing can happen. Signal distortion is verified over an average airborne sound insulation test sample, so a deterioration is expected with higher insulation.

Inherent noise values rise concerning the experiments are divergent, operational use recommendation are as follows:

- A stable support is critical since hand movements add noise to system inherent noise. As far as 26dB of increased level should be borne in mind when correcting vibration signal coming from separating, and mostly, flanking room partitions.
- High frequency range is less sensitive to hand measurement movements. So, this fact is very helpful when estimating insulation leakage (e.g. critical/coincidence frequency).
- High frequency range has a white noise structure caused by thermo-electrical noise from sensors and circuitry, and hardly influenced by sensor sensitivity which limit measurement range resolution.
- Low frequency range is strongly dependant on mounting techniques and supporting movements.

Results are interesting from a sustainable operational point of view, and encourage to carry on with further research:

- Experimental and statistical nature of this study suggests sample enlargement. Ongoing research works on more sensors with different features testing, and alternative procedures.
- Equipment Inherent noise statistical modelling is suggested by means of general an easy access sensor features. So, an efficient resource use let one knows the right signal to noise ratio when measuring vibration velocity levels in building acoustics.

REFERENCES

[1] ISO 16283-1:2014 Acoustics-Field measurement of sound insulation in buildings and of building elements-Part1: Airborne sound insulation. International Organization for Standardization; 2014.
[2] Ministerio de Fomento, Gobierno de España. Código Técnico de la edificación (CTE). Documento básico HR, Protección frente al ruido (DB-HR); 2009.
[3] Aniorte Pérez, José Antonio y Domingo Bets, Salvador. “Método matricial para la ingeniería de aislamiento acústico”. 41º Spanish Congress on Acoustics, Tecniacústica León; 2010.
[4] Rosao, V. et Carreira, A. “Use of vibration measurements to determine the most suitable locations to improve sound insulation in buildings”. The 21st Congress on Sound and Vibration (ICSV), Beijing/China; 2014.
[5] ISO 10848-Acoustics–Laboratory measurement of flanking transmission of airborne and impact sound between adjoining rooms-(parts 1-3). International Organization for Standardization; 2006-2007.
[6] Cremer, L., Heckl, M., Petersson, Björn A.T. Structure-Borne Sound; 2005.
[7] Hopkins, C. Sound insulation. Elsevier/Butterworth-Heinemann; 2007.
[8] San Millán-Castillo, Roberto; Domingo Bets, Salvador; Pavón García, Ignacio. “Evolución de una sonda de vibraciones para simplificar la evaluación de transmisión sonora por flancos entre recintos”. 46º Spanish Congress on Acoustics, Tecniacústica Valencia; 2015.
[9] Levinzon, Felix A. "Fundamental noise limit of piezoelectric accelerometer." *IEEE Sensors Journal* 4.1 (2004): 108-111.
[10] Mohd-Yasin, Faisal, et al. "Low frequency noise measurement and analysis of capacitive micro-accelerometers." *Microelectronic engineering* 84.5 (2007): 1788-1791.
[11] Brüel&Kjaer Product Data. CCLD accelerometers. Type 4533-B-002 and 4533-B-004.
[12] Fernandez Comesana, Daniel, Fan Yang, and Emiel Tus. "Influence of background noise on non-contact vibration measurements using particle velocity sensors." *INTER-NOISE and NOISE-CON Congress and Conference Proceedings*. Vol. 249. No. 6. Institute of Noise Control Engineering, 2014.