

Influence of Installation Errors On the Output Data of the Piezoelectric Vibrations Transducers

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Abstract. The paper examines an influence of installation errors of the piezoelectric vibrations transducers on the output data. PCB Piezotronics piezoelectric accelerometers were used to perform calibrations by comparison. The measurements were performed with TMS 9155 Calibration Workstation version 5.4.0 at frequency in the range of 5Hz – 2000Hz. Accelerometers were fixed on the calibration station in a so-called back-to-back configuration in accordance with the applicable international standard - ISO 16063-21: Methods for the calibration of vibration and shock transducers – Part 21: Vibration calibration by comparison to a reference transducer. The first accelerometer was calibrated by suitable methods with traceability to a primary reference transducer. Each subsequent calibration was performed when changing one setting in relation to the original calibration. The alterations were related to negligence and failures in relation to the above-mentioned standards and operating guidelines – e.g. the sensor was not tightened or appropriate substance was not placed. Also, there was modified the method of connection which was in the standards requirements. Different kind of wax, light oil, grease and other assembly methods were used. The aim of the study was to verify the significance of standards requirements and to estimate of their validity. The authors also wanted to highlight the most significant calibration errors. Moreover, relation between various appropriate methods of the connection was demonstrated.

1. Introduction

Calibration, which is a test of the quality and compatibility of testing equipment, must meet more stringent requirements than the testing itself. The error appearing during calibration of the apparatus and during the tests using this apparatus is duplicated. It does not work in other direction. The error of testing will not affect the quality of calibration.

Therefore, the ISO 16063-21: Methods for the calibration of vibration and shock transducers – Part 21: Vibration calibration by comparison to a reference transducer [1] precisely defines the conditions that must be met during calibration of vibration sensors. It exactly defines system standards, environmental conditions and, above all, acceptable measurement uncertainty errors. It does not allow for arbitrary interpretation of the way of calibration of vibration sensors. An ISO-compliant sensor in various countries, not just in the country in which was calibrated, can be easily used.

According to the standard ISO 16063-21, automated system of The Modal Shop, INC, in many laboratories around the world is used. Despite the fact that it complies with the applicable standards, the reliability of the equipment without a thorough knowledge of the ISO standard and related standards would be a far-reaching neglect. It could generate many errors. For this reason, the computerization of



many areas of life does not absolve us from the obligation to know the fundamental laws of physics and to observe the established norms and standards (e.g. [1-5]).

The aim of the study was to verify the significance of standards requirements and to estimate of their validity. The authors wanted to highlight the most significant calibration errors. Moreover, a relation between various appropriate methods of the connection was demonstrated, which could be used also in laboratory and in situ conditions. Another information about mounting the sensors can be found in [6-8].

2. Background information

The paper deals with an influence of installation errors of the piezoelectric vibrations transducers on the output data. PCB Piezotronics piezoelectric accelerometers were used to perform calibrations by comparison. The measurements were performed with TMS 9155 Calibration Workstation version 5.4.0 at frequency in the range of 5Hz – 2000Hz. The sensor and the shaker are presented in Figure 1.



Figure 1. PCB sensor Model: 393B12 [9] and Air Bearing Shaker Simplifies Accelerometer Calibration – component of TMS 9155 Calibration Station [10]

The measurements were conducted under standard laboratory conditions. The environmental conditions were maintained. The room temperature was 24°C and the relative humidity did not exceed 75 % max.

Accelerometers were fixed on the calibration station in a so-called back-to-back configuration in accordance with the applicable international standard - ISO 16063-21. Figure 1 shows a diagram of the sensor calibration. Results obtained from the sensor under test (SUT) are compared with the results from reference transducer (REF). The reference transducer has a traceable calibration with corresponding uncertainty documented. It was not calibrated by primary means, but it was validated through interlaboratory comparison. The Air Bearing Shaker generates vibrations. The system captures time domain data from SUT and REF transducers, implements Discrete Fourier Transform (DFT), and works out the magnitude and phase.

During the experiment, the first accelerometer was calibrated by suitable methods. Each subsequent calibration was performed when changing one setting in relation to the original calibration. The alterations were related to negligence and failures in relation to the standards and operating guidelines. Term ‘a reference calibration’ means that the calibration is carried out in accordance with all regulatory requirements. Appropriate fixing screws fasten the sensors to each other. Grease is used at the sensor contact. Protection of the cable is so as not to affect the measurement results. Tightening of the sensor is full. The calibration is marked as A. Change one or more settings relative to calibration A refers to other calibrations. The description and indications of subsequent calibrations are shown in Table 1. Some of the mounting techniques are presented in Figure 3. By grease, we understand Dow Corning 4

Electrical Insulating Compound. The wax stands for PCB Model 080A109 Petro Wax. PCB's pad is PCB Model 080A12 and screw means PCB Model 081B20.

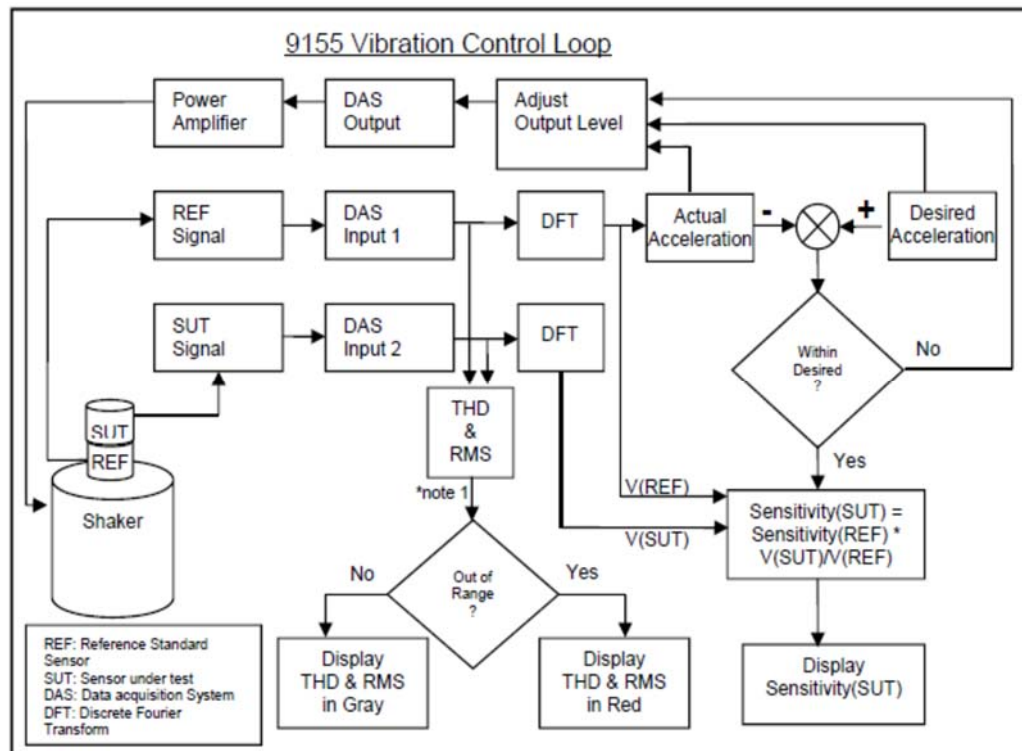


Figure 2. Schematic arrangement of Vibration Control Loop [11]

Table 1. Mounting methods

Sign	Description of the calibrations
A	Calibration is appropriate. It's a reference calibration
B	The calibration is without any substance between the sensors
C	The sensor is not tightened in 100% (tighten by hand)
D	The sensor is not tightened (a quarter turn from tightening)
E	The cable is not secured (this may affect the load on the sensor)
F	The calibration is with a disruption - a hair between the sensors
G	The grease is replaced by wax.
H	At the sensor contact are PCB's pad, ModalShop's pad and a wax
I	At the sensor contact are ModalShop's pad and a grease
J	At the sensor contact is only a grease (without screws)
K	At the sensor contact are an aluminium pad and a grease
L	At the sensor contact are ModalShop's pad and a wax
M	The sensor is not tightened (one and a half turn from tightening)
N	At the sensor contact is only a wax (without screws)

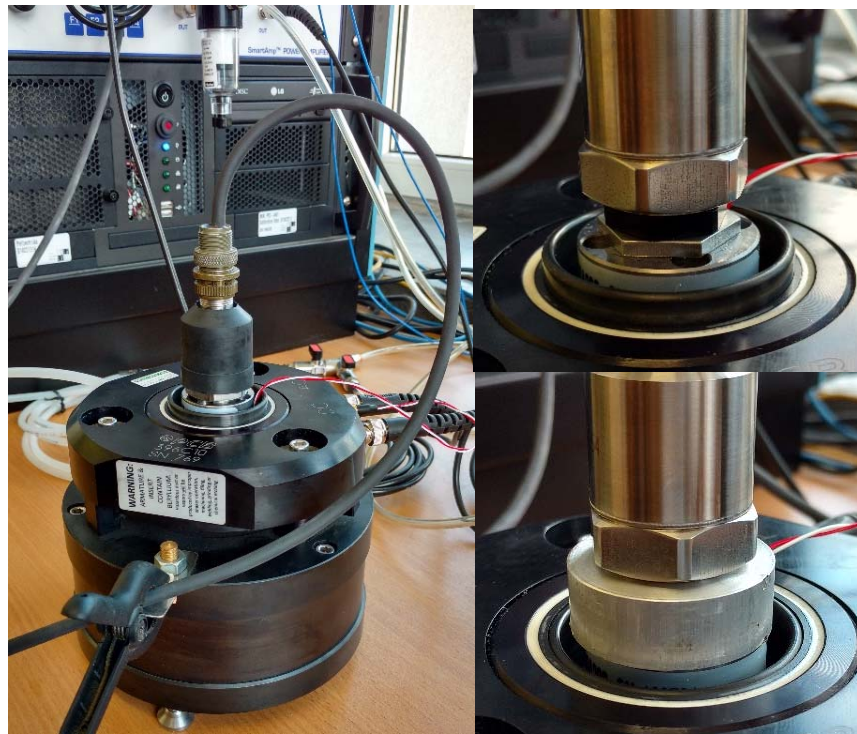


Figure 3. Mounting methods: left site – calibration A, right site – upper –H, lower -K

3. Results and discussions

In this case, calibration begins with the appointment of the sensitivity at the frequency of 100 Hz. For a tested sensor, it should be 10 mV/g ($\pm 10\%$). Sensitivity determined at this frequency is assigned to the sensitivity of the sensor. Sensitivity designated for other frequencies is compared to that sensitivity, and its deviation is calculated. Calibrations M and N were rejected by the system. Measurements with a very poorly tightened sensor and using only wax without a fixing screw do not give the opportunity to determine the sensitivity clearly. Figure 4 shows the distribution of deviation for measurements (A-L). The biggest differences correspond to B and H cases, where the calibration was carried out without any substance between the sensors and with too many connecting elements.

Nevertheless, in order to check the exact indications, the percentages of the data are excluded. Figure 5 shows the absolute sensitivity values for each calibration [mV/g]. Here the deviation from the sensitivity indices for 100 Hz can be seen. Type B shows the greatest difference in comparison to reference calibration, as well. For the whole frequency range, the H and L calibrations also show big differences. This indicates that the use of a set of ModalShop's pad and wax is not a recommended solution.

For all measurements, the results obtained were compared with the limits declared by the sensor manufacturer. Percentage deviation from sensitivity should not exceed 5 % for frequencies up to 1000Hz and 10 % above that frequency. The results are shown in Figure 6. Only calibration H is not meeting the requirements. The other calibrations with smaller or larger reserves were within the limits. For this reason, an assembly error might not be detected at first glance. A ranking of the connections was created. Each measurement was represented by its worst percentage deviation value. The summary was made for the whole frequency band. In the case of vibration effects on buildings, only frequencies up to 100 Hz are harmful (according to standard [12]). Therefore, the calibrations are ranked according to the indications in this frequency range. The data is shown in the Table 2. For the entire frequency range, the

calibration that has been identified as the benchmark has better substitutes. But in the case of installation on buildings it is the best option. In both cases, option B and H are ones of the worst options.

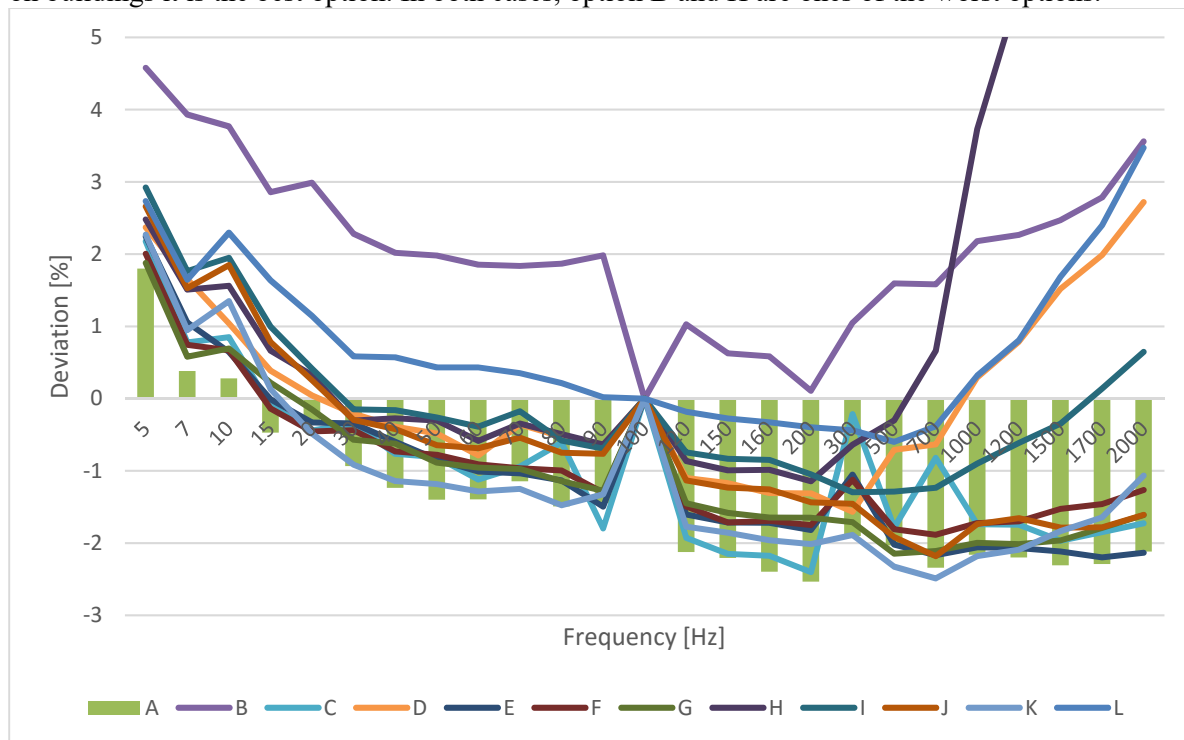


Figure 4. Percentage deviation from sensitivity

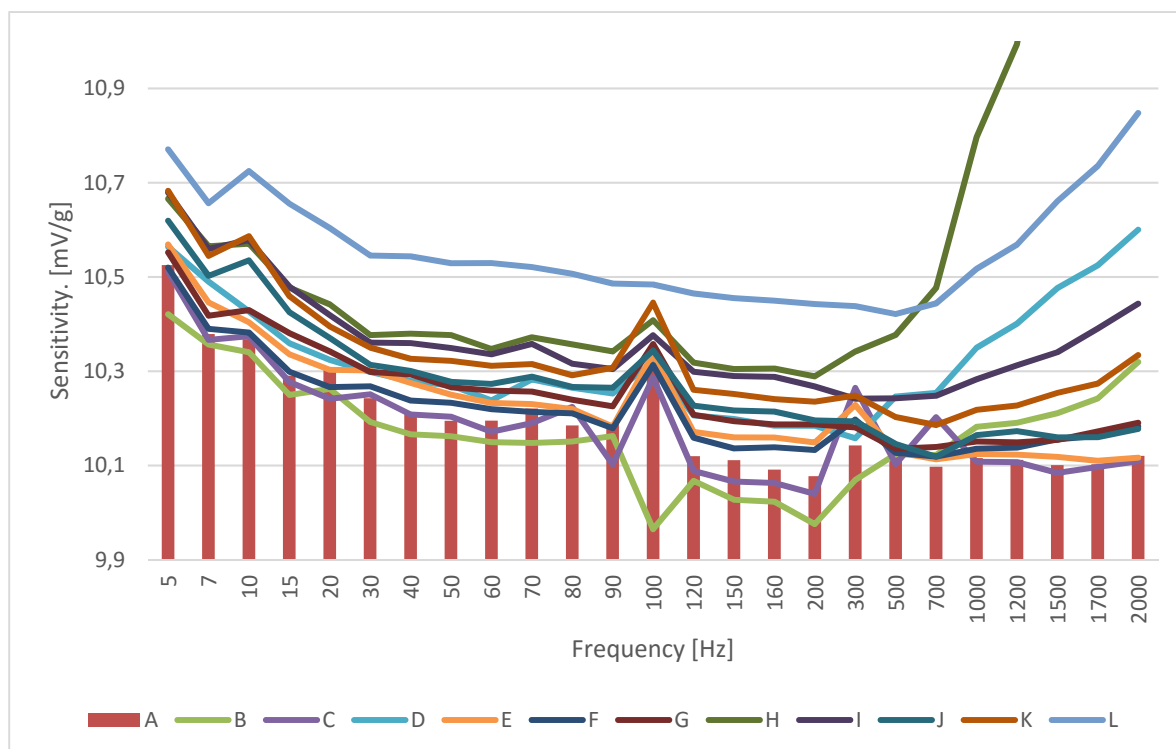


Figure 5. Absolute deviation from sensitivity

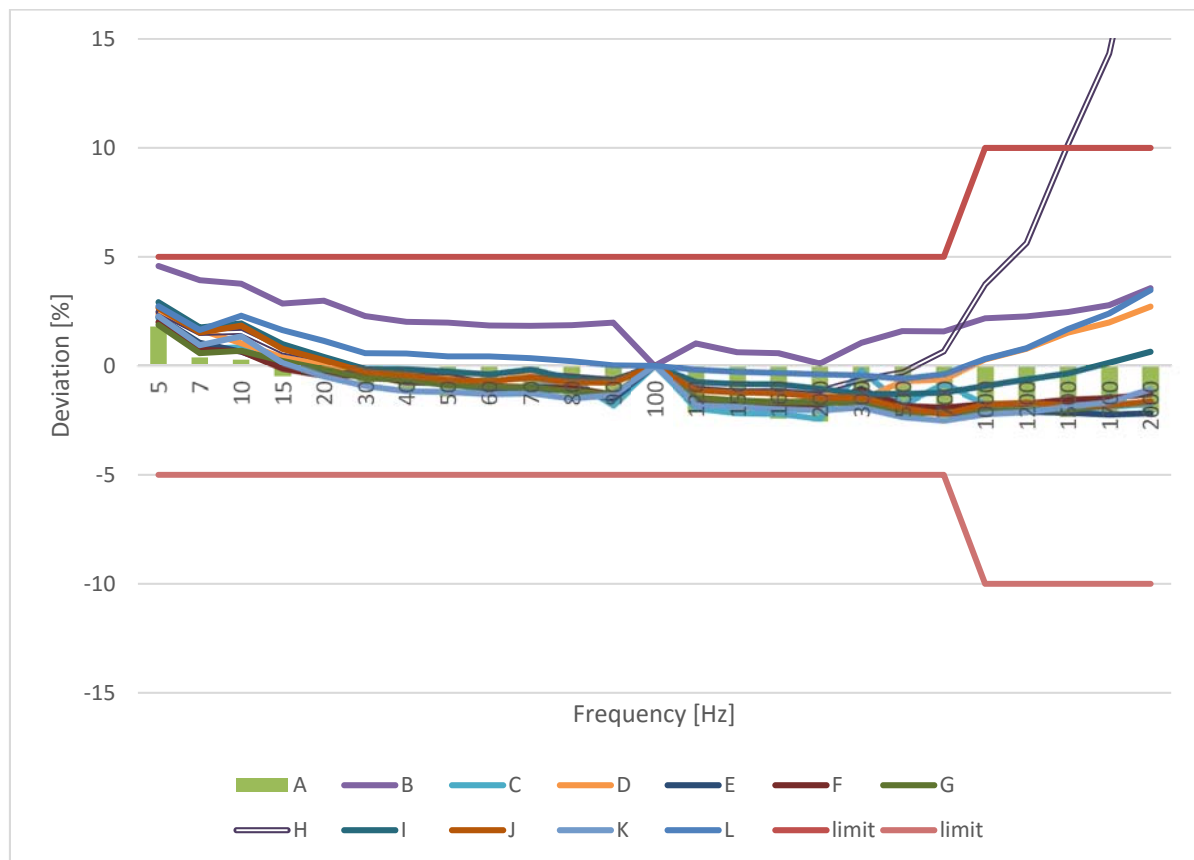


Figure 6. Percentage deviation from sensitivity with its limits

Table 2. Ranking of the best calibration settings

Frequency (5-2000Hz)		Frequency (5-100Hz)	
Sign	Deviation [%]	Sign	Deviation [%]
F	2.00	A	1.80
G	2.15	G	1.88
E	2.24	F	2.00
C	2.40	C	2.18
K	2.49	E	2.24
A	2.53	K	2.27
J	2.66	D	2.37
D	2.72	H	2.48
I	2.92	J	2.66
L	3.47	L	2.73
B	4.58	I	2.92
H	22.89	B	4.58
M	-	M	-
N	-	N	-

When calibrating to 100 Hz also the examples I and L are very bad (ModalShop's pad plus wax and ModalShop's pad plus grease). It follows that the ModalShop's pad is not a recommended solution for low frequencies. Options F, G, E, C, and K are good in both cases. Thick aluminium pad or substitute grease with wax is an acceptable change. The disturbance caused by the placement of the hair did not appear in these frequencies. In addition, insecure cable caused no interference.

In addition, it was compared the differences in the sensitivity obtained at 100 Hz. Absolute sensitivity values were compared to the sensitivity for case A. The data are summarized in Table 3. This statement does not show drastic differences compared with the previous ones. However, the case K turns out to be not a good solution. The aluminium pad significantly affects sensor sensitivity, but is uniform throughout the entire band. Therefore, this option was not detected in previous reports.

Table 3. Ranking of the deviation from sensitivity at frequency 100 Hz

Sign	Deviation from sensitivity (100Hz)
A	0.00%
E	-0.02%
J	0.05%
G	0.18%
D	-0.19%
F	-0.25%
I	0.36%
C	-0.51%
H	0.67%
K	1.03%
L	1.40%
B	-3.62%
M	-
N	-

The research was carried out for the frequency range 5 Hz-2000 Hz. However, interest in ultra-low frequencies (0.5Hz-5Hz) seems interesting. The question remains open for further work. Therefore, the ultra-low frequencies will be the aim of future research.

4. Conclusions

Based on the analysis of calibration data, we can draw the following conclusions:

- What is obvious, frequent control of equipment by calibrating the sensors is an indispensable part of the measurements. Moreover, the method of attachment of sensors should be checked. Because even a perfectly functioning but poorly mounted sensor does not meet the requirements. In addition, it causes interference in the results.
- The worst case was the absence of any substance on the surface contact and the use of too many fasteners. The main conclusion of the work is that it is better to replace some type of fixation than to not apply any or apply several at a time.
- A hair between the sensors did not significantly affect the calibration result in the test frequencies. However, this does not mean that for higher frequencies the situation will be the

same. Therefore, any unwanted elements at the sensor contact with the surface to be examined should be considered.

- Unprotected cable also did not negatively affect the measurement. Particularly unprotected cable did not interfere with measurement. However, one must be aware of situations in which the cable in any way significantly pulls the sensor in one side (especially when three components of vibrations are measured simultaneously) or is very tight. The investigation did not verify this case because of the fear of system damage.
- It is important to adapt the assembly system to interesting frequencies. The fact that fixing is appropriate for some extent, it does not mean it will be good for another range. In addition, better way of mounting can be found depending on the frequency to be tested.

Acknowledgment

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