

TRACEABLE CALIBRATION OF VIBRATION SENSORS IN A WIDE FREQUENCY AND TEMPERATURE RANGE

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Abstract: This paper describes how to calibrate accelerometers in a temperature range from -55°C to +100°C. Compared earlier solutions the suggested approach is able to cover the wide frequency range 10 Hz to 10 kHz and the temperature range -55°C to 100°C while the calibration is still traceable.

Keywords: ISO 16063-11, ISO 16063-21, accelerometer calibration, determination of temperature coefficient.

1. INTRODUCTION

ISO 16063-21 defines the allowed temperature for an accelerometer calibration to be in the range 23°C ± 3°C. For many purposes, this may be sufficient but there are also other use cases where the temperature is outside this temperature range. Thus, the determination of a temperature coefficient that describes the change of the transducer sensitivity depending on the temperature is important. For many reasons it is not a trivial task to calibrate an accelerometer under different temperature conditions.



Figure 1 Accelerometer calibration system with shaker placed outside the temperature chamber and back-to-back reference transducer

- The vibration exciter has to be placed outside the temperature chamber because it cannot be exposed to very high or low temperatures (see Figure 1).
- The vibration exciter has to be protected from the temperatures inside the chamber by a thermal barrier on top of the shaker table (see white ceramic disk underneath the back-to-back sensor in Figure 1).
- A reference accelerometer inside the shaker table (and thus outside the temperature chamber) is no good solution because the thermal barrier can

provoke mechanical problems like relative movement between shaker table and DUT or increased cross motion.

- A back-to-back (BtB) reference accelerometer inside the temperature chamber is the better solution to allow a direct coupling between reference sensor and DUT
- Thus the temperature coefficient of the BtB reference accelerometer has to be determined in the temperature and frequency range of the calibration system.

A conclusion of the items above is, if no primary calibration system for the calibration of the BtB accelerometer in the operation ranges of the thermal secondary calibration system is available, we simply do not have a traceable reference accelerometer.

This paper will show how a BtB accelerometer for such a calibration system can be calibrated traceable by means of a combination of primary and secondary calibrations under these conditions and will give an outlook how this may be improved with a single primary calibration in the future.

2. DETERMINATION OF THE TEMPERATURE COEFFICIENT

2.1 Calibration process

The whole calibration process is shown in Figure 2.

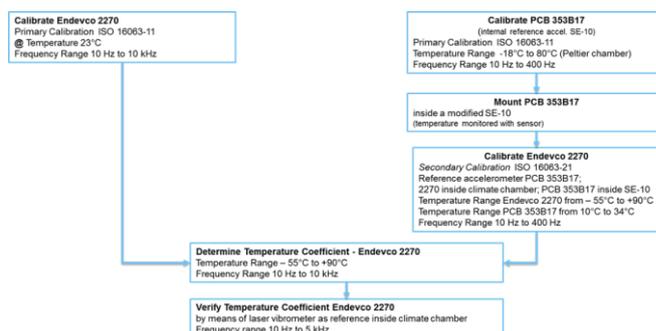


Figure 2 Flow chart of the calibration process

The primary calibration according to ISO 16063-11 of the Endevco 2270 BtB accelerometer at room temperature was the main basic calibration of the reference accelerometer. All further measurements had the goal to determine the deviation of the sensitivity values from this initial calibration due to the influence of temperature changes. Two assumptions were made in the calibration process according to Figure 2

1. The temperature characteristics of this particular accelerometer will not change over time
2. The temperature coefficient of this particular reference accelerometer is independent of the frequency

The first assumption simply says that the reference accelerometer including the temperature response must be stable over time.

The second assumption is necessary because due to the mechanical issues, the transfer calibration from the internal reference accelerometer to the BtB accelerometer is only possible in a very limited frequency range. Thus under this assumption we can use the temperature coefficient that we have determined at one frequency or a limited frequency range, for the whole frequency range. However, the last process step in *Figure 2* tries to verify this assumption.

2.2 Why is a transfer calibration necessary?

The primary calibration setup that was available in the laboratory of the authors for calibration under different temperature conditions had a very limited temperature and frequency range. It was based on a Peltier device that could cool or heat a small chamber with a window for the laser beam. This Peltier chamber was mounted at a long stroke shaker that is part of a primary calibration system according to ISO 16063-11 (see *Figure 3*). This add-on device had the following limits

- Temperature range about -10°C to 80°C (heating and cooling by Peltier element)
- Frequency range 0.2 Hz to 400 Hz or less (due to size and mechanical properties)

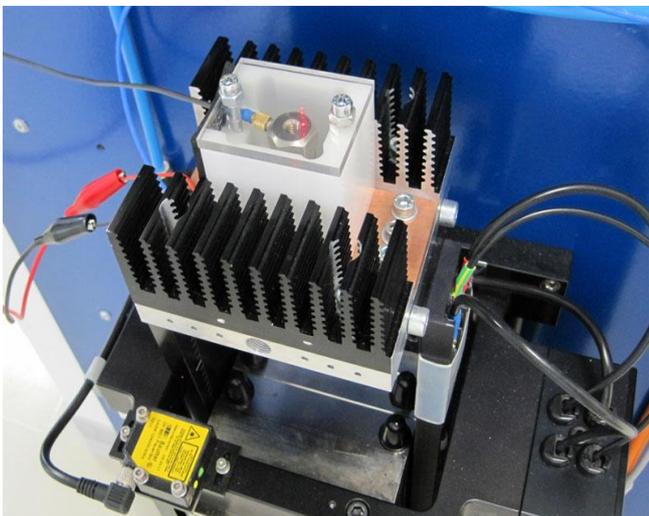


Figure 3 Peltier chamber

According to the first assumption the temperature coefficient of a reference transducer determined at one frequency can be used over the whole frequency range. Thus, the limited frequency range was no problem.

But the limited temperature did not allow to determine the temperature coefficient of the BtB reference accelerometer directly with this setup. The workaround that was used to overcome this issue was the transfer calibration from the internal reference accelerometer inside the shaker

table to the BtB accelerometer. Inside the shaker the temperature variation could be limited by means of the thermal barrier and an additional fan from $+10^{\circ}\text{C}$ to $+35^{\circ}\text{C}$ while the temperature inside the climate chamber was changed from -55°C to $+100^{\circ}\text{C}$. So the internal reference accelerometer was calibrated in a first step in the Peltier chamber, then mounted inside the shaker together with a RTD. In a second step the shaker was mounted underneath the thermal chamber and the internal reference sensor was used to calibrate the BtB sensor inside the temperature chamber. By means of the RTD the sensitivity of the internal reference sensor was corrected with the thermal coefficient determined in the Peltier chamber and thus the temperature coefficient of the BtB accelerometer was determined in the wider temperature range -55°C to $+100^{\circ}\text{C}$.

2.3 Traceability

Looking at the process diagram in *Figure 2* the calibration of the BtB accelerometer was based on a primary calibration that was traceable to PTB. On the other hand also the primary calibration of the internal reference accelerometer can be regarded as traceable because the same traceable calibration system was used. But due to the Peltier chamber the measurement uncertainty was higher for this setup. Finally, the temperature coefficient of the BtB accelerometer was determined by the transfer calibration from the internal reference accelerometer to the BtB reference accelerometer. This process step did not break the traceability chain and thus the whole calibration of the BtB accelerometer with the temperature coefficient can be assumed a traceable calibration.

3. RESULTS

3.1 Primary calibration of the internal reference accelerometer

Before the internal reference accelerometer was mounted inside the shaker table, it was calibrated by means of the Peltier chamber in the temperature range 0°C to 60°C in a frequency range 3 Hz to 400 Hz according to ISO 16063-11. The results showed that above 125 Hz the mechanical issues of the Peltier chamber were not acceptable (see *Figure 4*). So only measurement values from 3 Hz to 125 Hz were used to determine the temperature coefficient by averaging the measured sensitivity values from each frequency point. As can also be seen in *Figure 4* the sensitivity deviation in the important temperature range $+10^{\circ}\text{C}$ to $+40^{\circ}\text{C}$ can be described by a linear function with one single temperature coefficient.

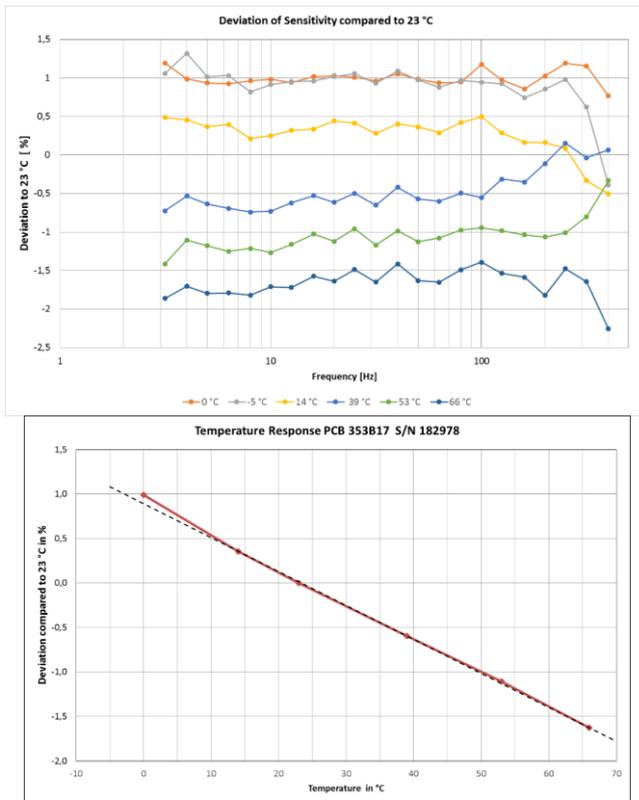


Figure 4 Temperature response of the internal reference accelerometer determined with the Peltier chamber

3.2 Transfer calibration

The next step was to transfer the now well-known properties of the internal accelerometer in the limited temperature range 0°C to 60°C to the BtB accelerometer in the wider temperature range -55°C to 100°C inside the climate chamber by means of a transfer calibration. The results can be found in **Figure 5**.

It turned out that in the frequency range between 10 Hz and 1 kHz the measured deviation of the sensitivity compared to the sensitivity at room temperature was very constant. Below 10 Hz the sensitivity of the BtB accelerometer combined with the limited stroke of the shaker lead to higher deviations that were not related to the temperature response. Thus the frequency range of the system was limited to 10 Hz at the low frequency end.

At higher frequencies mechanical issues due to the ceramics thermal barrier and the properties of the BtB accelerometer lead to higher deviations. Both findings were proved later by means of an additional measurement with a laser vibrometer. However, since reliable primary calibration results of the internal reference accelerometer were only available in the limited frequency range of 10 Hz to 125 Hz, only calibration results in this frequency range were used for the evaluation of the temperature coefficient of the BtB reference accelerometer. The measured temperature response of this sensor was even better than described by the data sheet (see **Figure 5**).

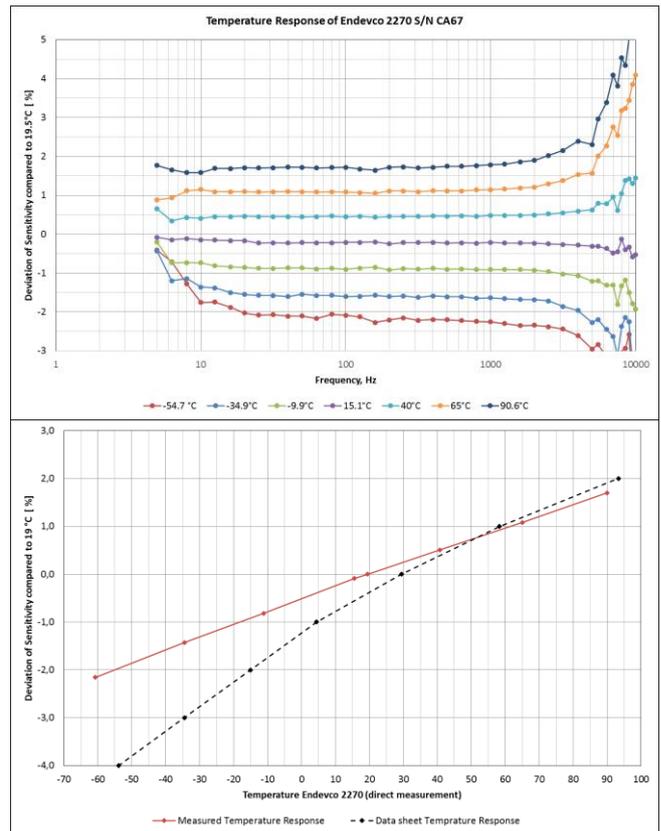


Figure 5 Temperature response of the BtB accelerometer determined by the transfer calibration

3.2 Verification of the results by means of a laser vibrometer measurement

As already written above the determination of the temperature coefficient of the BtB accelerometer could only be performed in a very limited frequency range compared to the wide range in which the system shall be used. So an additional measurement setup was chosen to verify that the temperature coefficient is really independent from the frequency in the working range of the calibration system. For this purpose a laser vibrometer was mounted on a tripod and positioned close to the cable inlet on the left side of the climate chamber. The laser beam was directed through a small hole in the insulation foam via a mirror above the BtB accelerometer on the surface of this reference accelerometer (see **Figure 6**). The laser vibrometer output was used as reference sensor for a further calibration of the back-to-back sensor inside the climate chamber.

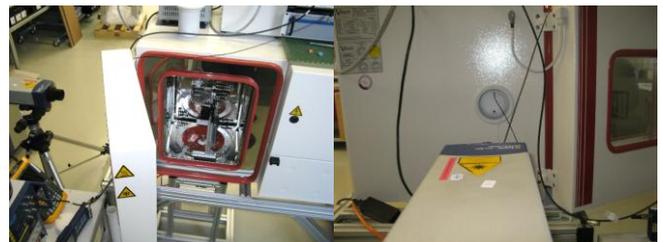


Figure 6 Verification measurements by means of a laser vibrometer as reference

Some results of these measurements can be found in **Figure 7** below. The light blue graph shows the result from the earlier transfer calibration using the accelerometer inside the shaker as reference. From the frequency response of the BtB accelerometer determined with a primary calibration at room temperature this curve should be flat up to at least 5 kHz. But as stated earlier mechanical issues caused by the thermal barrier already lead to higher deviations above 1 kHz.

With the laser vibrometer measurements, the deviation value of the transfer calibration at 1 kHz could be well reproduced. But in contrast to the transfer calibration the deviation stayed stable up to 4 kHz. Since we measured with the laser beam directly on the surface of the BtB accelerometer, we got rid of any mechanical issues between shaker and back-to-back accelerometer. Above 4 kHz we ran into new mechanical issues related to the vibration of the mirror that was used to direct the laser beam on the accelerometer. This mirror was mounted at an aluminum framework support that was loosely standing inside the climate chamber. So this setup could not avoid vibration modes of the mirror above 4 kHz.

However, with this measurement at least up to 4 kHz it could be proved that the temperature coefficient of the BtB accelerometer is independent from frequency. Furthermore, we did not find any serious indication for a frequency dependency above 4 kHz up to 10 kHz.

Thus a much better measurement uncertainty as with the method described above can be expected.

The current schedule is to setup such a system in the first half of 2017. Until then the authors will also have to evaluate the measurement uncertainty of the system we described in this paper because this will be a first step in order to determine the uncertainty of the future primary system.

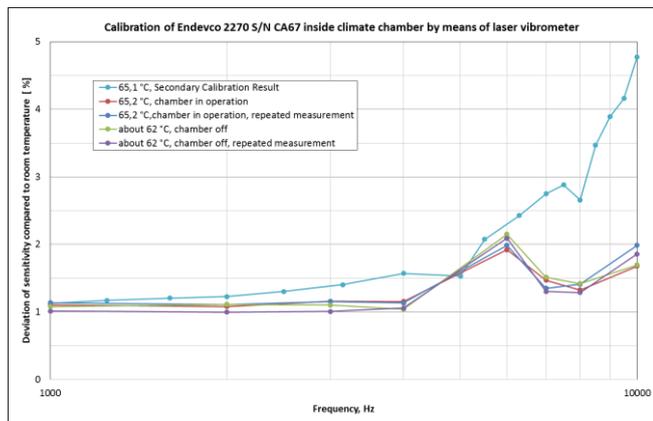


Figure 7 Results from the verification measurements compared to the transfer calibration (light blue curve)

4. OUTLOOK

In principle, the verification measurements with the laser vibrometer described in the last section were already a first step towards a direct primary calibration of the BtB accelerometer inside the temperature chamber. The on-the-fly setup we had to choose for these measurements did not allow to cover the frequency range above 4 kHz. So the next step will be to design a new calibration system with a temperature chamber that has an additional port on the top of the chamber. This will allow to direct the beam of the reference laser vibrometer directly on the BtB accelerometer or any other DUT inside the chamber. In this way reference BtB accelerometers can be calibrated with a method according to ISO 16063-11 inside the temperature chamber.