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CALIBRATION OF VIBRATION REFERENCE TRANSDUCERS WITH PRIMARY AND SECONDARY METHODS. PROPOSALS FOR HANDLING THE DEPENDANCE OF HIGH FREQUENCY RESPONSE ON MOUNTING PARAMETERS.

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Abstract − Dissemination of vibration sensitivity values to the broader vibration community has been dominated over several decades by the calibrations performed at NMIs using primary vibration calibration by laser interferometry using the methods described in the ISO 5347-1 (latest edition1993) replaced by 16063-11 in 1999.

In most cases this method is applied to reference transducers, either single-ended or meant for back-to-back calibration.

In recent years there has been a push towards very low uncertainties and frequencies above 5 kHz. About 5 years ago it became evident that although the calibration at the NMIs with similar equipment could be reproduced with high confidence it is questionable if these results and uncertainties can be disseminated with sufficient confidence to the users of the reference transducers.

It has been demonstrated that the results depend on the actual mounting conditions described by the mechanical impedance of the structure which calls for recommendations for increased uncertainties and/or correction factors and methods for use of the results.

Calibration of reference transducers have in some countries been performed by using transfer standards to calibrate back-to back references for the users and naturally the results obtained and the stated uncertainties are questionable in the light of the newest discoveries.

Examples and some proposed solutions to these challenges including uncertainty calculations will be presented.

Keywords: vibration, calibration, interferometry, dissemination.

1. INTRODUCTION

A general request for a secondary calibration of reference standard back-to-back accelerometers at low uncertainties in Brüel & Kjær service center, Denmark, lead to a process of implementing what is called a reference grade service.

The reference grade service concerns Brüel & Kjær type 8305, Endevco type 2270 and similar back-to-back types.

At time of implementation and as of yet, there were no commonly accepted solution for calibration of transfer standard accelerometers without a dependency on the dynamic properties of the surface it is mounted on or a common mounting technique to avoid this problem. Thus the task had to be solved on a secondary level, involving preparation of a model for a correction, fitting the use of transfer standards calibrated on Beryllium armature to the basis of approval of the reference grade service using calibration data obtained by use of SPEKTRA SE-9 (ceramic armature).

Criteria of success was En-values < 0,6 @ uncertainties < 0,6% against primary calibration data of type 8305.

A PTB-calibrated transfer std. type 2270M8 was used as reference.

In order to implement and verify implementation of “*Direct comparison special correction*” and compensate for the systematic deviation between a transfer standard accelerometer calibrated on SPEKTRA type SE-09 ceramic armature and a Beryllium armature, the following considerations and exercises were made:

As laboratory transfer standards are preferably calibrated on the same armature material and the laboratory transfer standard history obtained on beryllium traditionally used, it was desired to not only adapt initial direct comparison correction to beryllium calibrated transfer standards but when doing so considering discussions, observations and technical papers on the subject of primary calibration of transfer standards being dependent on dynamic properties of armature materials – namely beryllium types i.e. Endevco type 2901/2911, Bouche type 1000, PCB type K394B31 and Ceramic types (ceramic being less definite in properties as it is a composite material) i.e. SPEKTRA type SE-09, TIRA S514-C/S540-C.

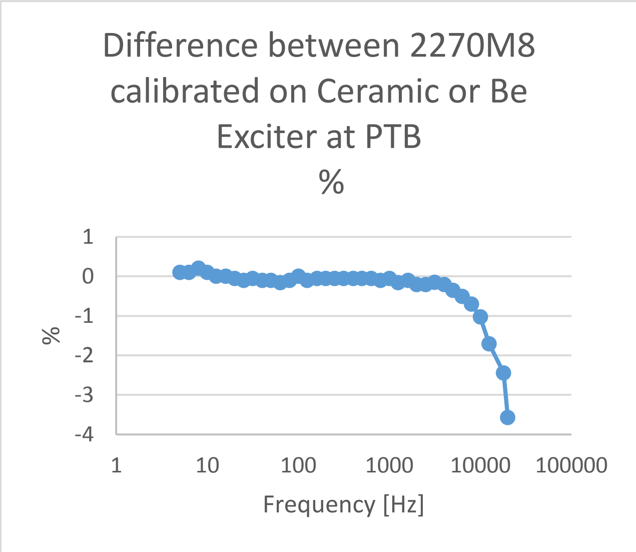

Figure 1. Difference in sensitivity of transfer standard calibrated on different types of armatures.

The unit used demonstrated the influence of the calibration conditions. Figure 1 shows the difference between two PTB calibrations on Ceramic and Be exciter armatures (PTB-17037-2011 ceramic and PTB-17141-2013 Be).

2. THEORY

The problem has in a different context been described in [1] and [2]. The model of a transfer standard was defined as shown in Figure 1. The mathematical description for the frequency response of such a system with the reference plane being the top of the armature (where the motion is measured by interferometry) is given in [2] equation (4)

$$S_{qa}^{ISO} = [S_0\omega_{1H}^2(i\omega\delta_{2B} + \omega_{2B}^2)]\big[\big((\omega_{2B}^2 + \eta\omega_{1H}^2) + i\omega(\delta_{2B} + \eta\delta_{1H}) - \omega^2\big)(\omega_{1H}^2 + i\omega\delta_{1H} - \omega^2) - \eta(i\omega\delta_{1H} + \omega_{1H}^2)^2\big]^{-1}$$

where S_0 is the low frequency sensitivity of the accelerometer and

$$\omega_{1H} = \sqrt{\frac{k_1}{m_H}}$$

$$\omega_{2B} = \sqrt{\frac{k_2}{m_B}}$$

$$\delta_{1H} = d_1/m_H$$

$$\delta_{2B} = d_2/m_B$$

$$\eta = m_H/m_B$$

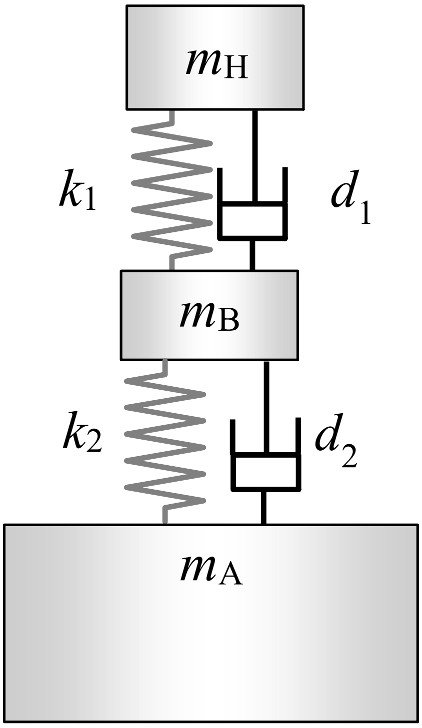

Figure 2. Model of single ended accelerometer mounted on a shaker armature. Seismic mass m_H, base mass m_B, armature mass m_A connected by springs with small damping.

The model frequencies do however have the drawback that they cannot be seen or measured directly, but has to be extracted using advanced modelling techniques.

For the purpose of making corrections at frequencies less than half the ω_{1H} frequency and much smaller than the ω_{2B} the damping can be ignored. Furthermore a fourth order term can be ignored and that leads to the simple expression

$$S_{qa}^{ISO} = [S_0]\big[1 - (\omega/\omega_{App})^2\big)\big]^{-1}$$

which is the well-known simplified expression for the response of an accelerometer except that the ω_{App} is what could be called the apparent resonance frequency.

This indicates that a simple correction formula can be used to enable us to use the results on single ended transfer standards calibrated by laser interferometry on advanced exciters to calibrate back-to-back reference standard accelerometers if the proper parameters can be determined.

The correction can then be described by the simple formula:

$$S_d(f) = S_r(f)\frac{1 - \left(\frac{f}{f_1}\right)^2}{1 - \left(\frac{f}{f_2}\right)^2}$$

where $S_d(f)$ is the sensitivity of the back-to-back accelerometer to be calibrated using the transfer standard with the calibrated values $S_r(f)$.

The two “correction” frequencies f_1 *and* f_2 can be seen as the apparent resonance frequencies during the two different mounting conditions. They were determined empirically, but detailed modelling might be possible to use for this purpose.

3. METHOD OF VERIFICATION

The final verification of the direct comparison special correction was done by following exercises:

1. Average of 3 direct comparison measurements of a known PTB-calibrated type 8305 - 2270m8 reference using PTB - *calibration data obtained by use of Bouche 1000* vibration exciter - Direct comparison special correction ***not enabled***
2. Average of 3 direct comparison measurements of a known PTB-calibrated type 8305 - 2270m8 reference using PTB - *calibration data obtained by use of Spectra type SE-09* vibration exciter - Direct comparison special correction ***not enabled*** (initially approved)
3. Average of 3 direct comparison measurements of a known PTB-calibrated type 8305 - 2270m8 reference using PTB - *calibration data obtained by use of Bouche 1000* vibration exciter - Direct comparison special correction ***enabled***

4. RESULTS

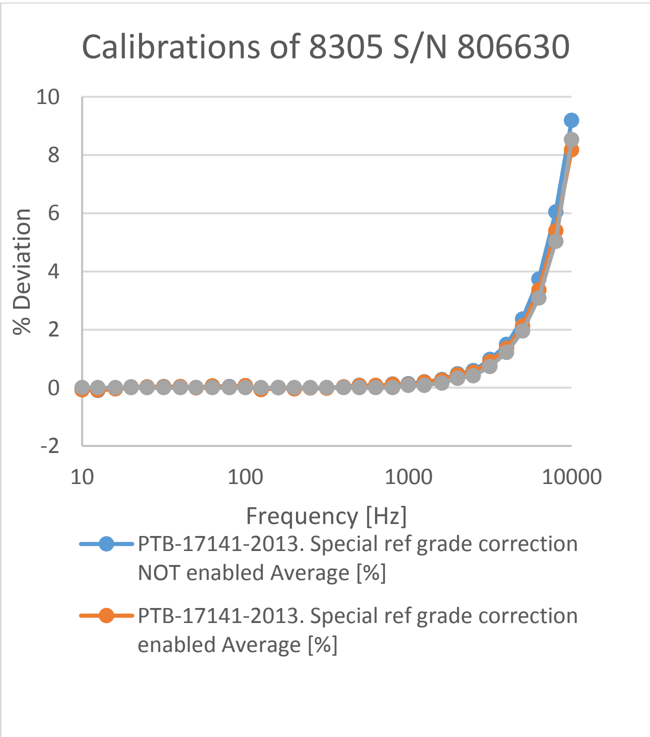

Figure 3. Calibration results for a 8305, with special correction, without special correction and primary calibration results from PTB.

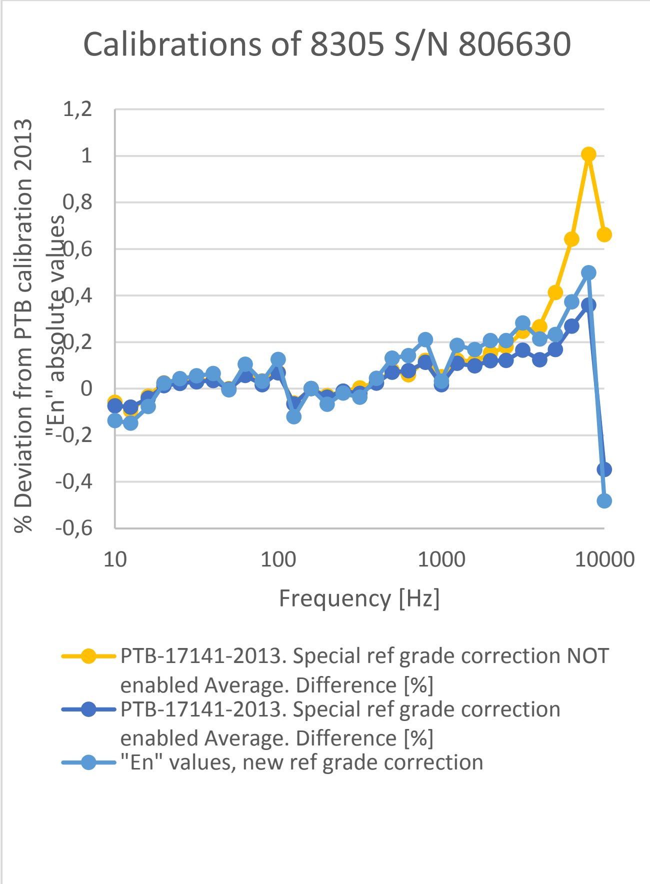

Figure 4. Calibration results for a 8305, with special correction, without special correction and primary calibration results from PTB showing the differences only and with E_n values added.

For comparison as the DUT type 8305 was last calibrated at PTB 2007 (calibrated on Bouche type 1000 vibration exciter) during first part of exercise, calibration results merely had focus on relative frequency response to avoid misinterpretation of result due to drift of transducer.

E_n-values based on relative responses against PTB was found to be < 0,5 based on 2007 PTB-calibration where Bouche type 1000 was used, as with initial reference grade service approval process. The results are shown in Figure 3 and 4.

The DUT was then sent for calibration at PTB (using Spectra type SE-09 unlike 2007) and exercise was repeated including sensitivity. Fortunately DUT shows little sign of drift improving basis for final evaluation. Low frequency differences were in the order of 0,04 to 0,08% and this was also the case for the values obtained by comparison which means that the E_n values will be practically identically to the “E_n” values given here.

E_n-values based on relative responses against PTB was found to be < 0,6 based on 2014 PTB-calibration where Spectra type SE-09 was used, see Figure 5.

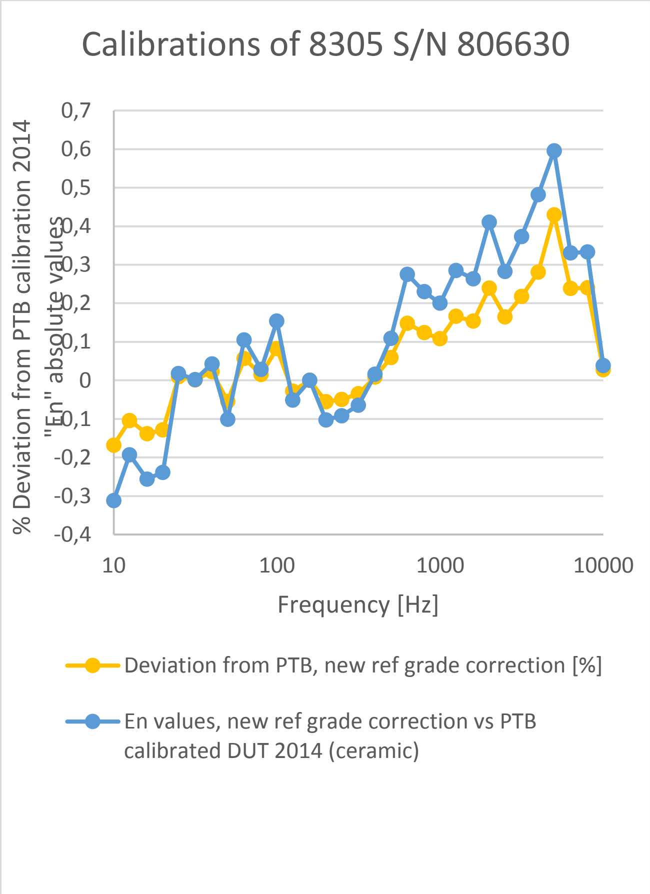

Figure 5. Calibration results for the 8305, with special correction compared to primary calibration results from PTB who used the ceramic exciter. The differences and E_n values are shown.

5. CONCLUSION

The performed measurements verifies not only the reference grade special correction implementation in type 3629 accelerometer calibration system but also verifies that it corresponds well to DUT having been calibrated on both Spectra type SE-09 vibration exciter as well as Bouche type 1000 vibration exciter with Beryllium armature.

A generally accepted solution to these phenomena would definitely be preferred making full comparability between back-to-back reference transducer calibrations possible and no additional correction needed.

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