IMEKO 22nd TC3, 12th TC5 and 3rd TC22 International Conferences
3 to 5 February, 2014, Cape Town, Republic of South Africa

0 Hz AND LOW FREQUENCY CALIBRATION OF LOW FREQUENCY REFERENCE ACCELEROMETERS

Torben R. Licht [1] *and Sven Erik Salboel* [2]

[1]DPLA and Brüel & Kjaer S&V, Naerum, Denmark, trlicht@bksv.com
[2]DPLA and Brüel & Kjaer S&V, Naerum, Denmark, sesalbol@bksv.com

Abstract – During the last decade more and more interest has been found in making low frequency vibration measurements. One area that has driven this is the earthquake studies, but here accuracy is not a focus point. However when we start to look at large structures like wind turbines, large aircrafts with 60 to 80 m wingspan, bridges and 400 to 500 m towers the accuracy becomes vital. These large structures have vibration modes in the range 0.3 to 1 Hz.

The method for Primary vibration calibration by laser interferometry using quadrature outputs described in ISO 16063-11 [1] can be extended down to 0.1 Hz today thus giving the foundation for accurate measurements in the low frequency (LF) range.

It is however desirable to link these results that are obtained at very low vibration levels and frequencies to measurements at 0 Hz with constant acceleration of about 9.8 m/s^2.

This method is basically described in ISO 5347-5 [2] (to be revised as ISO16063-16) but a detailed description of uncertainty budgets is not given.

Recently the Danish Primary Laboratory of Acoustics (DPLA) participated in the first international comparison covering the LF range of vibration, and in that context we decided to make a 0 Hz calibration with relatively simple means but exploiting the fact that the local Gravity today can be determined by an uncertainty of about 10^{-8} .

By using a transfer technique and without utilising the full potential we could make an uncertainty budget with an expanded uncertainty of about 0.04% on a servo-accelerometer calibration, where one of the main contributions turned out to be thermal drift.

The experience we got during this calibration and the uncertainty budget created will be presented.

Keywords: vibration, calibration, gravity, interferometry.

1. INTRODUCTION

ISO 5347-5:1993 Methods for the calibration of vibration and shock pick-ups- Part 5: *Calibration by Earth's gravitation* describes the general method of turning the static responding transducer 180 degrees in the local gravitational field.

It requires a platform aligned within ± 0.5º from vertical and a voltage measurement better than ± 0.01% of reading.

In ISO 5347-5:1993 a limit of attainable uncertainty of 0.1% is given. This value is probably not going to be changed for the revision ISO16063-16, which is at the FDIS (Final Draft International Standard) stage and will replace the old standard.

When DPLA recently participated in the European Comparison EURAMET.AUV.V-S1, Primary calibration of accelerometers at low frequencies, covering 0.1 to 200 Hz and permitting to include 0 Hz, it was decided to implement a gravitational calibration system. This was seen as a good way of verifying the flat response of a static acceleration responding accelerometer.

2. INSTRUMENTATION

First of all, a stable, angle adjustable measurement platform was needed. This was implemented using a granite block, some standard micrometre screw gauge parts and an aluminium base plate.

Secondly, a reliable instrument for ensuring that the plate is horizontal was needed and therefore an inclinometer was added. A dual axis digital inclinometer with a graphical display, a 0.01º resolution and 0.05º accuracy was chosen.

Finally, a high precision DC voltmeter (hp3458A) available in the laboratory was used to measure the accelerometer output.

The schematic of the setup is shown in Figure 1.

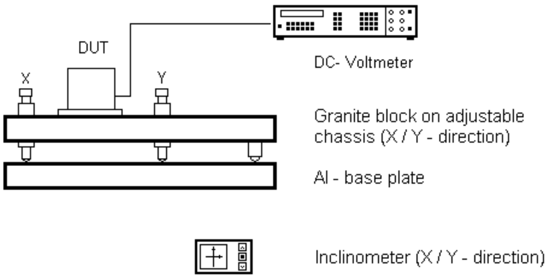

Figure 1. Basic setup

3. PROCEDURE

3.1 Zero calibration of the angle indicator

The angle indicator zero-points can be set with high accuracy by taking the average value between 2 measurement directions, the second after turning the indicator 180° in plane. The average is found automatically by the instrument.

3.2 Calibration of the accelerometer by Earth's gravitation.

The surface of the granite block is adjusted to horizontal by use of the precision adjusters mounted on the frame for the granite block and the angle from horizontal is measured by the inclinometer (better than ± 0,1°).

The accelerometer is placed on the granite block (on an adapter if needed) with the reference end pointing towards the Earth center (0° - direction).

The output voltage is measured, V_{Oi} (0 deg)

Then the accelerometer is placed on the granite block (on an adapter if needed) with the reference end pointing away from the Earth center (180° - direction). The output voltage is measured, V_{Oi} (180 deg). The measurements are repeated 3 times.

The static sensitivity can then be calculated by

$$S_V = \frac{\sum_{i=1}^{3}\left[\frac{V_{Oi}(0\,\mathrm{deg}) - V_{Oi}(180\,\mathrm{deg})}{2}\right]}{g_{DPLA}} \quad \left[\frac{V}{ms^{-2}}\right]$$

3.3 Determination of the phase (0deg) for the sensitivity, S_V:

The sign for the output voltage is positive when the positive direction for the acceleration is directed from the surface of the mirror or the reference end and towards the Earth centre.

4. CALIBRATION OF REFERENCE ACCELEROMETER

Instead of relying on formulas for the Earth's gravitation and local position and height (uncertainty approximately 0.2% at 95% coverage) it was decided to use a transfer technique, as the Danish Technical University nearby has a space institute that is involved in such measurements [3] and therefore has a location where Earth's gravitation is known with high accuracy.

The Reference Accelerometer (Sundstrand 2895) was calibrated at the reference Earth's gravitation point in the basement at DTU-Space.

The geographical coordinates of the reference Earth's gravitation point at DTU are:

Latitude: N 55°47' 0.06"
Longitude: E 12°30' 59.76"

The calibration information for the reference point (at floor level) is split into 3 parts:

1) The time independent Earth's gravitation (the influence from the mass and rotation of the earth, where 1 µGal = 10 nms^{-2}):

   g = 981545988.80 µGal
   Uncertainty: 20 µGal (2σ value)

2) The height-correction (dependent on the actual height above the reference Earth's gravitation point at floor-level, where the calibration is performed).
The height correction is calculated by use of the gradient value for the reference Earth's gravitation point given by DTU-Space:

The gradient at floor level = -2.861 µGal/cm

The height correction is calculated for a position approx. 29 cm above the floor with a ± 4 cm variation from nominal height between the positions for calibration at 0° and a 180° rotation of the accelerometer during the calibration.

3) The tide-correction (date and time dependent influence from sun and moon). The tide-correction is calculated by a DTU-software using data for a synthetic calibration, which was performed with the same date and time as the accelerometer calibration.

The calibration of the accelerometer is performed in 10 sets of measurements for 0° and 180° position.

5. DETERMINATION OF EARTH'S GRAVITATION ON THE GRANITE BLOCK AT DPLA.

The Earth's gravitation on the granite block in DPLA is measured by comparison by means of the accelerometer calibrated at DTU-Space.

The procedure described in 3.2 is used, but instead of calculating the accelerometer sensitivity, the Earth's gravitation value which fits the accelerometer sensitivity found at DTU is determined and can then be used for future calibrations at DPLA. 10 sets of measurements were performed. The time of the day was the same as at DTU the day before.

6. RESULTS

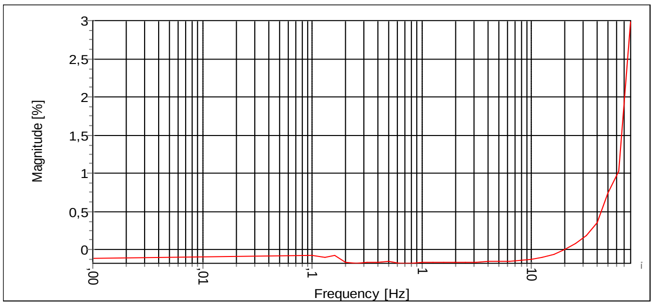

Figure 2. Magnitude Frequency response of servo-accelerometer

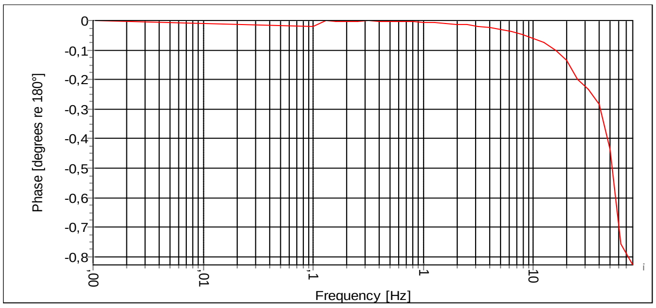

Figure 3. Phase Frequency response of servo-accelerometer

A set of results on a servo-accelerometer Honeywell QA 700 are shown in the graphs Figure 2 and Figure 3. The calibration results by Earth's gravitation are inserted at the lowest frequency on the graphs (which is not 0 but 0.001 Hz on the logarithmic scale). The phase value can just be 0 or 180 degrees.

The magnitude values from 0 to 16 Hz are all within ±0.05%.

7. UNCERTAINTIES

The calculation of the uncertainties is given in Table 1 and Table 2.

Table 1 Earth's gravitation at DTU-Space for the used platform.

Uncertainty	Type of Value	Distri-bution		Unit
Actual Gravity value w/corrections	2σ	Normal	20	μGal
	Relative 2σ	Normal	0.0204	ppm
Height Corr. ± 4 cm on the 29 cm distance from floor. Gradient - 2,861 μGal/cm	Bounds	Rectan-gular	11.444	μGal
	Relative 1σ	Normal	0.0067	ppm
	Relative 2σ	Normal	0.0135	ppm
Total for calculation of gravity during calibration of Sundstrand 2895	**Relative 2σ**	**Normal**	**0.0244**	**ppm**

The total relative expanded uncertainty given here in ppm translates into a relative expanded uncertainty of 0.00000224%.

During the calibration some drift and change in temperature of the unit was observed. Naturally the output is also at a high level (corresponding to 1 g or nearly 5 V all the time which is not the case during the calibration by sinusoidal excitation in horizontal direction where the maximum level is about 2 mg at 0.1 Hz. The temperature coefficient was found to be approx. 155 ppm/K. This corresponds well to the specified <200 ppm/K given by the manufacturer.

Table 2. Calibration of servo-accelerometer by means of Earth's gravitation in DPLA on granite block by use of Sundstrand 2895 calibrated by Earth's gravitation at DTU-Space.

Uncertainty	**Type of Value**	**Distribu-tion**		**Unit**
Uncertainty of Earth's gravitation determined at DPLA	Relative 2σ	Normal	112.5	ppm
Error in angle	Relative 2σ	Normal	0.07	ppm
Std. dev. on measurements (t=2.353)	Relative 2σ	Normal	1.605	ppm
hp 3458A voltage measurements	Relative 2σ	Normal	7.6	ppm
Influence of Temp. ± 2 °C	Relative 2σ	Normal	357	ppm
Total	**Relative 2σ**	**Normal**	**374**	**ppm**

The total relative expanded uncertainty given here in ppm translates into a relative expanded uncertainty of 0.0374%.

8. CONCLUSION

It has been demonstrated that calibration by Earth's gravitation is well suited to complete low frequency dynamic calibration without a large investment in special equipment.

This gives an uncertainty well below the attainable values for dynamic measurements and the tests performed showed a perfect fit to these values.

It also showed that the main contribution to the uncertainty is the thermal influence on the accelerometer sensitivity. If this can be avoided the uncertainty could be reduced by a factor of 2 or 3.

Further investigations will be performed to obtain improvements, but for the comparison to dynamic measurements this is not crucial.

9. REFERENCES

[1] ISO 16063-11 Methods for the calibration of vibration and shock pick-ups - Part 11: Primary vibration calibration by laser interferometry

[2] ISO 5347-5:1993 Methods for the calibration of vibration and shock pick-ups - Part 5: Calibration by Earth's gravitation (under revision as ISO16063-16)

[3] Gravity measurements in Denmark in 2005. Survey and processing report by G. Strykowski1, L. Timmen3, O. Gitlein3, R. Forsberg1, B. Madsen2 and C. J. Andersen1
1 Geodynamic Department, Danish National Space Center
2 Geodetic Department, Danish National Space Center
3 Institut für Erdmessung, University of Hannover