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Methods for the calibration of vibration and shock transducers —

Part 42:
Calibration of seismometers with high accuracy using acceleration of gravity

Méthodes pour l'étalonnage des transducteurs de vibrations et de chocs —

Partie 42: Étalonnage des diomomètres de haute exactitude utilisant l'accélération due à la pesanteur

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 16063-42 was prepared by Technical Committee ISO/TC 108, *Mechanical vibration, shock and condition monitoring*, Subcommittee SC 3, *Use and calibration of vibration and shock measuring instruments*.

ISO 16063 consists of the following parts, under the general title *Methods for the calibration of vibration and shock transducers*:

— *Part 1: Basic concepts*

— *Part 11: Primary vibration calibration by laser interferometry*

— *Part 12: Primary vibration calibration by the reciprocity method*

— *Part 13: Primary shock calibration using laser interferometry*

— *Part 15: Primary angular vibration calibration by laser interferometry*

— *Part 21: Vibration calibration by comparison to a reference transducer*

— *Part 22: Shock calibration by comparison to a reference transducer*

— *Part 31: Testing of transverse vibration sensitivity*

— *Part 41: Calibration of laser vibrometers*

The following parts are under preparation:

— *Part 16: Calibration by Earth's graviation*

— *Part 32: Resonance testing – Testing the frequency and the phase response of accelerometers by means of its excitation*

Methods for the calibration of vibration and shock transducers — Part 42: Calibration of seismometers with high accuracy using acceleration of gravity

1 Scope

This International Standard prescribes the instrumentation and procedure to be used for the accurate calibration of seismometer sensitivity using local gravitational acceleration (local Earth's gravitation; local value for the acceleration due to the Earth's gravity) as a reference value.

This International Standard should generally apply to a servo-type accelerometer with/without a velocity output, as which usually has a mass position output, in the category of a wide-band seismometer with a bandwidth from 0,003 Hz to 100 Hz.

The method described in this International Standard enables the users to obtain static sensitivity for the seismometers up to 10^{-5} m/s^2 (which corresponds to 1 mGal and approximately 1 ppm of the gravitational acceleration).

The combined and expanded (k=2) uncertainty of applied acceleration achieved by these methods is 10^{-6} m/s^2 (0,1 mGal). When the absolute gravimeter described in this document is used, the uncertainty of applied acceleration can be suppressed to 5 x 10^{-8} m/s^2 (5 µGal). The relative uncertainty of calibration, excluding the uncertainty due to the device under test (DUT), is 0,5 %.

The intended end-usage of the seismometer to be applied in this standard is as follows.

a) Measurement and observation for the earth science including geophysics usage;

b) Measurement and observation for the disaster prevention, such as detecting the precursor of a land slide;

c) Diagnosis for the soundness of a building structure and foundation soil in the civil engineering;

d) Observation for nuclear-test detection.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 5347-5:1993, *Methods for the calibration of vibration and shock pick-ups – Part 5: Calibration by Earth's gravitation*

ISO/IEC Guide 98-3, *Uncertainty of measurement – Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)* [1)]

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1) ISO/IEC Guide 98-3 is published as a reissue of the Guide to the expression of uncertainty in measurement (GUM), 1995.

International Gravity Standardization Network-1971 (IGSN-71) (Morelli, 1974) Morelli, Carlo, ed., 1974, The International Gravity Standardization Net 1971: International Association of Geodesy Special Publication No. 4, 194p.

3 Traceability of measurement

The traceability of measurement in this method is shown in Annex A and Annex B.

4 Determination of local gravity

4.1 Method using gravitational acceleration standardization network

Correct the latitude and altitude of the point at which measurements are to be conducted on the basis of the reference position, where is a geographically nearest point to the intended point, and the point to determine the local gravitational acceleration according to (IGSN-71).

The uncertainty of the thus-obtained local gravitational acceleration is approximately 10^{-5} m/s^2 (1 mGal). Here, this is only applied to the case without any geometrical anomaly.

Geological survey institutes or meteorology institutes in each country may provide measured values of higher precision than those on IGSN-71. If available, those values can be used.

Because an altitude difference of 1 m corresponds to a difference of approximately 3×10^{-6} m/s^2 (0,3 mGal), the uncertainty of altitude should be less than 2 m.

NOTE 1 An effect of 1 degree at a latitude of around 45 degree corresponds to approximately 1×10^{-6} m/s^2 (0,1 mGal).

NOTE 2 An effect of a longitude of around 45 degrees is mainly dependent on geoid and altitude. The local gravity map includes the values of the geoid and altitude components.

4.2 Method using gravitational acceleration standardization network and relative gravimeter

At the reference point, where the local gravitational acceleration has already been known from the IGSN-71, determine the absolute local gravitational acceleration using the relative gravimeter. No correction of latitude and altitude is required. The uncertainty value (10^{-5} m/s^2 (1 mGal)) of the relative gravimeter is defined by a production company in manual.

Geological survey institutes or meteorology institutes in each country may provide measured values of higher precision than those of IGSN-71. If available, those values can be used.

4.3 Method using absolute gravimeter

Determine the absolute local gravitational acceleration using a free-fall absolute gravimeter (FG-5 or other apparatus). The uncertainty of the thus-obtained local gravitational acceleration is approximately 5×10^{-8} m/s^2 (5 µGal).

5 Requirements for apparatus and environmental conditions

5.1 Calibration environment

As reference atmosphere conditions, the atmospheric pressure is 100 kPa, the relative humidity is 50 %, and the temperature is 23 ^{o}C. The temperature and atmospheric pressure shall be measured.

5.2 Base and vibration environment (seismic block for calibration apparatus)

The calibration apparatus shall be placed on a sufficiently heavy base, the edges shall be separated from the building in order to prevent effect from the motion of ground to measured data.

5.3 Voltage-measuring instrumentation

The relative measurement uncertainty of the voltmeter, with which the output voltage from the seismometer is measured, shall be 0,1 % or smaller.

5.4 Tunable low-pass filter

a) Cut-off frequency: This shall be selected among 10 Hz, 30 Hz and 60 Hz. The normal cut-off frequency is 30 Hz.

b) Attenuation rate (filter slopes): This shall be 24 dB per octave or higher.

5.5 Power supply

The power supply shall have a sufficient stability and noise in comparison with the scale factor, by which the sensitivity of the seismometer (voltmeter) is affected.

5.6 Tilt table

The resolution shall be 0,05 degrees or smaller and the uncertainty should be less than 0,03 degrees. The tilt table should have sufficient rigidity to support the mass of the seismometer, and also sufficiently small backrush and should have enough linearity.

6 Method

6.1 Calibration principle

Figure 2 shows the principle of the calibration apparatus.

A tilt table is placed on a platform. The platform shall be rigidly connected to the base described in 5.2, namely, the seismic block for the calibration apparatus, and be kept horizontally to the vertical axis. The angular deviation from the horizontal plane shall be smaller than 0,03 degrees. The effect of the force component due to the deviation from the horizontal plane is approximately 10^{-7}. The deviation from the horizontal plane shall be confirmed by a tilt meter, which has sufficient resolution.

The vertical and horizontal components of acceleration applied to the seismometers on the tilt table, $a_{\theta v}$ or $a_{\theta h}$, are given as

$$a_{\theta v} = \cos\theta \cdot g \tag{1}$$

$$a_{\theta h} = \sin\theta \cdot g \tag{2}$$

where θ is the tilt angle from the horizontal plane obtained by placing the tilt table and g that is the gravity.

Here, output signal of the seismometer is given by (Equation 2)

$$E = Sa_{\theta v} + B \quad \text{or} \quad E = Sa_{\theta h} + B \tag{3}$$

where

S : Sensitivity of the seismometer (V/m/s^2)

$a_{\theta v}$ or $a_{\theta h}$: Induced acceleration to the sensitive axis of the accelerometer (m/s^2)

B : Bias component of the output (V)

E : Output voltage of the seismometer (V)

When θv or θh are changed from $\theta 1$ to θn , each output signal of the seismometer for n times measurement is given as

$$E_1 = Sa_{\theta 1} + B$$

$$E_2 = Sa_{\theta 2} + B$$

….

$$E_n = Sa_{\theta n} + B \tag{3}$$

Sensitivity of the seismometer S and bias component of the output B is given as follows

$$S = \frac{n\sum_{i=1}^{n} a_{\theta i}E_i - \sum_{i=1}^{n} a_{\theta i}\sum_{i=1}^{n} E_i}{n\sum_{i=1}^{n}(a_{\theta i})^2 - \left(\sum_{i=1}^{n} a_{\theta i}\right)^2} \tag{4}$$

$$B = \frac{\sum_{i=1}^{n} a_{\theta i}{}^2\sum_{i=1}^{n} E_i - \sum_{i=1}^{n} a_{\theta i}E_i\sum_{i=1}^{n} a_{\theta i}}{n\sum_{i=1}^{n}(a_{\theta i})^2 - \left(\sum_{i=1}^{n} E_i\right)^2} \tag{5}$$

6.2 Calibration procedure

The seismometer is placed on the tilt table as which the sensitive axis is aligned with the vertical axis. The deviation of the angle between sensitive axis and vertical axis shall be smaller than 0,03 degrees. After these settings are precisely adjusted, the seismometer shall be accommodated to the environment temperature.

A seismometer generally has the angular alignment error of its enclosure, which is called case alignment, to their sensitivity axes. When calibrating the seismometer, as mentioned above, the axis for inputting acceleration should be fit to the sensitivity axis of the seismometer. Otherwise, the uncertainty of the case alignment error should be included into the tilt angular uncertainty of the tilt table.

The vertical or horizontal components of acceleration, $a_{\theta v0}$, $a_{\theta h0}$, applied to the seismometer on the tilt table under the initial tilt angle is given as

$a_{\theta v0} = \cos\theta_0 \cdot g$ or $a_{\theta h0} = \sin\theta_0 \cdot g$

The outputs are measured necessary number of times at the interval of a sampling frequency.

This should be recorded as V_0 under applied accelerations $a_{\theta v0}$ or $a_{\theta h0}$.

Then, the tilt angle is changed to θ_1. The vertical or horizontal components of accelerations, $a_{\theta v1}$ or $a_{\theta h1}$ are given as

$a_{\theta v1} = \cos\theta_1 \cdot g$ or $a_{\theta h0} = \sin\theta_{01} \cdot g$

After setting the angle of the tilt table, the measurement shall be started. The outputs are measured with the necessary number of times at the interval of a sampling frequency.

7 Expression of results

Items of calibration results to be described are listed below:

— Sensitivity: The sensitivity S is given as described in 6.2 and the unit is $V/(m/s^2)$.

— Uncertainty: This indicates the value relative to the described sensitivity. Specify the coefficient of expansion.

— Applied acceleration: The unit is m/s^2.

— Method of setting local gravitational acceleration and its estimated uncertainty: Refer to comment on Clause 4.

— Environment: Changes in a temperature and an atmospheric pressure during a measurement period.

— Measurement method: Methods using a horizontal platform and using an additional tilt table.

— Setting of the filter.

— Number of measurements.