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Methods for the calibration of vibration and shock pick-ups —

Part 8:
Primary calibration by dual centrifuge

Méthodes pour l'étalonnage de capteurs de vibrations et de chocs —
Partie 8: Étalonnage primaire par centrifugeur double

Reference number
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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.

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.

International Standard ISO 5347-8 was prepared by Technical Committee ISO/TC 108, *Mechanical vibration and shock*, Sub-Committee SC 3, *Use and calibration of vibration and shock measuring instruments*.

ISO 5347 consists of the following parts, under the general title *Methods for the calibration of vibration and shock pick-ups*:

- *Part 0: Basic concepts*
- *Part 1: Primary vibration calibration by laser interferometry*
- *Part 2: Primary shock calibration by light cutting*
- *Part 3: Secondary vibration calibration*
- *Part 4: Secondary shock calibration*
- *Part 5: Calibration by Earth's gravitation*
- *Part 6: Primary vibration calibration at low frequencies*
- *Part 7: Primary calibration by centrifuge*
- *Part 8: Primary calibration by dual centrifuge*

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- *Part 9: Secondary vibration calibration by comparison of phase angles*
- *Part 10: Primary calibration by high-impact shocks*
- *Part 11: Testing of transverse vibration sensitivity*
- *Part 12: Testing of transverse shock sensitivity*
- *Part 13: Testing of base strain sensitivity*
- *Part 14: Resonance frequency testing of undamped accelerometers on a steel block*
- *Part 15: Testing of acoustic sensitivity*
- *Part 16: Testing of mounting torque sensitivity*
- *Part 17: Testing of fixed temperature sensitivity*
- *Part 18: Testing of transient temperature sensitivity*
- *Part 19: Testing of magnetic field sensitivity*
- *Part 20: Primary vibration calibration by the reciprocity method*

Annex A forms an integral part of this part of ISO 5347.

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Methods for the calibration of vibration and shock pick-ups —

Part 8:
Primary calibration by dual centrifuge

1 Scope

ISO 5347 comprises a series of documents dealing with methods for the calibration of vibration and shock pick-ups.

This part of ISO 5347 lays down detailed specifications for the instrumentation and procedure to be used for primary calibration of accelerometers using centrifuge calibration. It applies to all types of rectilinear accelerometers, primary standards and working pick-ups.

This part of ISO 5347 is applicable for a frequency range from 0,7 Hz to 10 Hz and a dynamic range from 10 m/s^2 to 100 m/s^2.

The limits of uncertainty applicable are ± 2 % of reading.

2 Apparatus

2.1 Equipment capable of maintaining room temperature at 23 °C ± 3 °C.

2.2 Balanced table, rotating about a vertical axis with uniform angular speed. A smaller table rotating with independent and uniform angular speed in the reverse direction shall be mounted eccentrically and perpendicularly on the table.

The tables shall be levelled within ± 0,5°.

The angular speed of the larger table shall be uniform within ± 0,1 %. The angular speed of the smaller table shall be uniform within ± 1 %.

The distance between the centres of rotation of the two tables shall be measured with an uncertainty of less than ± 0,1 %.

The centre of the pick-up mass element shall be located at the centre of rotation of the smaller table with an uncertainty of less than ± 0,1 % of the distance between the axes of rotation of the two tables.

2.3 Instrumentation for measuring rotational frequency, with an uncertainty of maximum ± 0,1 % of reading.

2.4 Voltage instrumentation for measuring true r.m.s. accelerometer output, with an uncertainty of maximum ± 0,1 % of reading.

The r.m.s. value shall be multiplied by a factor of $\sqrt{2}$ to obtain (single) amplitude used in the formulae.

3 Preferred amplitudes and frequencies

The following amplitudes, in metres per second squared, shall be used:

10; 20; 50; 100.

The following frequencies, in hertz, shall be used:

0,7; 1; 2; 5; 10.

The reference acceleration shall be 100 m/s^2 (second choice: 50 m/s^2) and the frequency shall be 5 Hz (second choice: 1 Hz).

4 Method

4.1 Test procedure

Rotate the larger table at different frequencies determined by calculation of the calibration acceleration, a, in metres per second squared, from the standard levels using the following formula:

$$a = 4\pi^2 n^2 r + k$$

Set the smaller table to the calibration frequency.

Determine the calibration factor at the reference frequency and reference acceleration. Then determine the sensitivity at the other frequencies and accelerations. The results shall be given as a percentage deviation from the calibration factor.

4.2 Expression of results

The sensitivity, S, in volts per (metre per second squared) [V/(m/s^2)], related to the (single) amplitude for every frequency is given by the following formula:

$$S = \frac{V}{4\pi^2 n^2 r + k}$$

where

n is the rotational frequency of the larger table, in hertz;

r is the radius of rotation, in metres;

k is a correction factor given by the formula below.

At the lowest acceleration level and the highest frequencies or when the tolerance between the centre of rotation of the smaller table and the centre of the pick-up mass element cannot be kept within the limits given above, the correction factor k shall be used. The value of k is given by the following formula:

$$k = 4\pi^2 e_\mathrm{d}(n - n_x)^2$$

where

n is the rotational frequency of the larger table, in hertz;

e_d is the positional error between the centre of the pick-up mass element and the centre of rotation of the smaller table, in metres;

n_x is the calibration rotational frequency, which is equal to the rotational frequency of the smaller table, in hertz.

When the calibration results are reported, the total uncertainty of the calibration and the corresponding confidence level, calculated in accordance with annex A, shall also be reported.

A confidence level of 95 % shall be used.

Annex A
(normative)

Calculation of uncertainty

A.1 Calculation of total uncertainty

The total uncertainty of the calibration for a specified confidence level (for the purposes of this part of ISO 5347, CL = 95 %), X_{95}, shall be calculated from the following formula:

$$X_{95} = \pm \sqrt{X_r^2 + X_s^2}$$

where

X_r is the random uncertainty;

X_s is the systematic uncertainty.

The random uncertainty for the specified confidence level, $X_{r(95)}$, is calculated from the following formula:

$$X_{r(95)} = \pm\, t \left[\frac{e_{r1}^2 + e_{r2}^2 + e_{r3}^2 + \ldots + e_{rn}^2}{n(n-1)} \right]^{1/2}$$

where

e_{r1}, e_{r2}, etc. are the deviations from the arithmetic mean of single measurements in the series;

n is the number of measurements;

t is the value from Student's distribution for the specified confidence level and the number of measurements.

The systematic errors shall, first of all, be eliminated or corrected. The remaining uncertainty, $X_{s(95)}$, shall be taken into account by using the following formula:

$$X_{s(95)} = \frac{K}{\sqrt{3}} \times e_S$$

where

K equals 2,0 for the 95 % confidence level;

e_S is the absolute uncertainty for the calibration factor, at calibrated levels and frequencies, expressed in volts per (metre per second squared) (see A.2).

A.2 Calculation of the absolute uncertainty for the calibration factor, e_S, at calibrated levels and frequencies

The absolute uncertainty for the calibration factor, e_S, expressed in volts per (metre per second squared), at calibrated levels and frequencies is calculated by the law of the combination of errors from the following formula:

$$\frac{e_S}{S} = \pm \left\{ \left(\frac{e_V}{V} \right)^2 + \left[\frac{9{,}8(1 - \cos \alpha)}{a} \right]^2 + \left(\frac{2e_n}{n} \right)^2 + \left(\frac{2e_{\Delta n}}{n_x} \right)^2 + \left(\frac{e_r}{r} \right)^2 + \left(\frac{a_{\mathrm{H}}}{a} \right)^2 + \left(\frac{k}{a} \right)^2 + \left(\frac{e_P}{P} \right)^2 + \left(\frac{2e_{n_x}}{n_x} \right)^2 + \left(\frac{2e_{\Delta n_x}}{n_x} \right)^2 \right\}^{1/2}$$

where

S is the calibration factor, in volts per (metre per second squared) (see 4.2);

V is the accelerometer output, in volts;

e_V is the absolute uncertainty for the accelerometer output, in volts;

α is the table levelling error, in degrees;

a is the calibration acceleration, in metres per second squared (see 4.1);

n is the rotational frequency of the larger table, in hertz;

e_n is the absolute uncertainty for the rotational frequency of the larger table, in hertz;

$e_{\Delta n}$ is the absolute uncertainty for the rotational frequency constancy of the larger table, in hertz;

n_x is the calibration rotational frequency, which is equal to the rotational frequency of the smaller table, in hertz;

e_{n_x} is the absolute uncertainty for the rotational frequency of the smaller table, in hertz;

$e_{\Delta n_x}$ is the absolute uncertainty for the rotational frequency constancy of the smaller table, in hertz;

r is the radius of rotation to the centre of the accelerometer mass element, in metres;

e_r is the uncertainty in the radius of rotation, in metres;

a_{H} is the acceleration amplitude caused by hum and noise, in metres per second squared;

k is the correction factor for the induced acceleration of the smaller table, calculated in accordance with 4.2, in metres per second squared;

P is the voltage supply to the accelerometer;

e_P is the uncertainty in voltage supply to the accelerometer.

A.3 Calculation of the total absolute uncertainty for the calibration factor, e_{S_1}, over the complete frequency and amplitude range

The absolute uncertainty for the calibration factor, e_S, calculated in accordance with A.2, is only valid for the calibrated levels and frequencies. The total absolute uncertainty for the calibration factor, e_{S_1}, in volts per (metre per second squared), over the complete frequency and amplitude range is calculated from the following formula:

$$\frac{e_{S_1}}{S} = \pm \left[\left(\frac{e_S}{S} \right)^2 + \left(\frac{L_{\mathrm{fA}}}{100} \right)^2 + \left(\frac{L_{\mathrm{fP}}}{100} \right)^2 + \left(\frac{L_{\mathrm{aA}}}{100} \right)^2 + \left(\frac{L_{\mathrm{aP}}}{100} \right)^2 + \left(\frac{I_{\mathrm{A}}}{100} \right)^2 + \left(\frac{I_{\mathrm{P}}}{100} \right)^2 + \left(\frac{R}{100} \right)^2 + \left(\frac{E_{\mathrm{A}}}{100} \right)^2 + \left(\frac{E_{\mathrm{P}}}{100} \right)^2 \right]^{1/2}$$

where

S is the calibration factor, in volts per (metre per second squared);

e_S is the absolute uncertainty for the calibration factor, in volts per (metre per second squared), at calibrated levels and frequencies (see A.2);

L_{fA} is the frequency linearity deviation, expressed as a percentage of the reference calibration factor for the amplifier;

L_{fP} is the frequency linearity deviation, expressed as a percentage of the reference calibration factor for the accelerometer;

L_{aA} is the amplitude linearity deviation, expressed as a percentage of the reference calibration factor for the amplifier;

L_{aP} is the amplitude linearity deviation, expressed as a percentage of the reference calibration factor for the accelerometer;

I_A is the instability uncertainty for the amplifier gain, expressed as a percentage of the reference calibration factor;

I_P is the instability uncertainty for the accelerometer, expressed as a percentage of the reference calibration factor;

R is the tracking uncertainty for the amplifier range (errors in gain for different amplification settings), expressed as a percentage of the reference calibration factor;

E_A is the error caused by environmental effects on the amplifier, expressed as a percentage of the reference calibration factor;

E_P is the error caused by environmental effects on the accelerometer, expressed as a percentage of the reference calibration factor.