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

Part 7:
Primary calibration by centrifuge

Méthodes pour l'étalonnage de capteurs de vibrations et de chocs —
Partie 7: Étalonnage primaire par centrifugeur

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 5347-7 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 7:
Primary calibration by 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.

This part of ISO 5347 applies to rectilinear accelerometers with zero-frequency response, mainly of the strain gauge or piezoresistive type, and to primary standard and working pick-ups.

It is applicable for a calibration range from 10 m/s^2 to 1 000 m/s^2 (higher accelerations possible) at 0 Hz.

The limits of uncertainty applicable are ± 1 % of reading.

2 Apparatus

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

2.2 Balanced table or **arm**, rotating about a vertical axis with uniform angular speed. For the calibration range from 10 m/s^2 to 100 m/s^2 the table/arm shall be level within ± 0,5° of horizontal. For ranges higher than 100 m/s^2, levelling is allowed to within ± 2°.

The rotational frequency shall be uniform within ± 0,05 % of the nominal value.

The pick-up axis of sensitivity shall be aligned within ± 0,5°.

The radius of rotation to the centre of the pick-up mass element shall be measured with an uncertainty less than ± 0,1 %. If the accelerometer is substituted by impedances not sensitive to acceleration, the hum and noise when the centrifuge is rotating at the calibration speeds shall be at least 60 dB below reading.

2.3 Instrumentation for measuring rotational frequency, with an uncertainty of maximum ± 0,05 % of reading.

2.4 Voltage instrumentation for measuring accelerometer d.c. output, with an uncertainty of maximum ± 0,01 % of reading.

3 Preferred values

Six acceleration values, in metres per second squared, equally covering the accelerometer range, shall be chosen from the following series:

10; 20; 50; 100; 200; 500 or their multiples of ten.

The reference acceleration shall be 100 m/s^2 (second choice: 50 m/s^2).

4 Method 1 (with measurement of the radius of rotation)

4.1 Test procedure

Rotate the table or arm at different frequencies determined by calculation from the standard levels using the following formula:

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

where

n is the rotational frequency, in hertz;

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

Measure the pick-up output for every level.

Determine the reference calibration factor at the reference acceleration. Then determine the sensitivity for the other calibration amplitudes. The results shall be given as a percentage deviation from the reference calibration factor.

4.2 Expression of results

The calibration factor, S, in volts per (metre per second squared) [V/(m/s²)], is given by the following formula:

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

where

V is the accelerometer output, in volts;

n is the rotational frequency, in hertz;

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

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 99 % shall be used.

5 Method 2 (without measurement of the radius of rotation)

5.1 Test procedure

If the rotational radius cannot be measured with the specified accuracy, the pick-up can be rotated in two different positions, the radial distance between these to be measured with uncertainty maximum of ± 0,5 %.

Measure the two rotational frequencies giving the same pick-up output at the two positions.

5.2 Expression of results

The calibration factor, S, in volts per (metre per second squared), is given by the following formula:

$$S = \frac{V}{4\pi^2 n_2^2 \dfrac{\Delta r}{1-(n_2/n_1)^2}}$$

where

V is the accelerometer output, in volts;

n_1 is the rotational frequency at the first accelerometer position, in hertz;

n_2 is the rotational frequency at the second accelerometer position, in hertz;

Δr is the distance between the two accelerometer positions, in metres.

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 % (Method 2) or CL = 99 % (Method 1)], X_{CL}, shall be calculated from the following formula:

$$X_{\mathrm{CL}} = \pm \sqrt{X_{\mathrm{r}}^2 + X_{\mathrm{s}}^2}$$

where

X_{r} is the random uncertainty;

X_{s} is the systematic uncertainty.

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

$$X_{\mathrm{r(CL)}} = \pm\, t \left[\frac{e_{\mathrm{r}1}^2 + e_{\mathrm{r}2}^2 + e_{\mathrm{r}3}^2 + \ldots + e_{\mathrm{r}n}^2}{n(n-1)} \right]^{1/2}$$

where

$e_{\mathrm{r}1}$, $e_{\mathrm{r}2}$, 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, $X_{\mathrm{s(CL)}}$, shall be taken into account by using the following formula:

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

where

K equals 2,0 for the 95 % confidence level (CL = 95 % for Method 2) or K equals 2,6 for the 99 % confidence level (CL = 99 % for Method 1);

e_S is the absolute uncertainty for the calibration factor at calibrated levels, 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

A.2.1 Calculation of e_S for Method 1

The absolute uncertainty for the calibration factor, e_S, expressed in volts per (metre per second combination of errors from the following formula:

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

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 voltmeter, in volts;
- α is the table/arm levelling error, in degrees;
- β is the misalignment of the accelerometer axis of sensitivity, in degrees;
- a is the calibration acceleration, in metres per second squared (see 4.1);
- n is the rotational frequency, in hertz;
- e_n is the absolute uncertainty for the rational frequency, in hertz;
- $e_{\Delta n}$ is the absolute uncertainty for the rotational constancy, 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;
- P is the voltage supply to the accelerometer;
- e_P is the uncertainty in voltage supply to the accelerometer.

A.2.2 Calculation of e_S for Method 2

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

$$\frac{e_S}{S} = \pm \left\{ \left(\frac{e_V}{V} \right)^2 + \left[\frac{9{,}8(1 - \cos \alpha)}{a} \right]^2 + (1 - \cos \beta)^2 + \left(\frac{e_{\Delta r}}{\Delta r} \right)^2 + \left(\frac{2e_{n_2}}{n_2} \right)^2 + \left(\frac{2e_{n_1}}{n_1} \right)^2 + \left(\frac{a_H}{a} \right)^2 + \left(\frac{e_P}{P} \right)^2 + \left[\frac{2e_{\Delta n}}{(n_1 + n_2)/2} \right]^2 \right\}^{1/2}$$

where

- S is the calibration factor, in volts per (metre per second squared) (see 5.2);
- V is the accelerometer output, in volts;
- e_V is the absolute uncertainty for the accelerometer output voltmeter, in volts;
- α is the table/arm levelling error, in degrees;
- β is the misalignment of the accelerometer axis of sensitivity, in degrees;
- a is the calibration acceleration, in metres per second squared;
- Δr is the distance between the two accelerometer positions, in metres;
- $e_{\Delta r}$ is the absolute uncertainty for the distance between the two accelerometer positions, in metres;
- n_1 is the rotational frequency at the first accelerometer position, in hertz;
- e_{n_1} is the absolute uncertainty for the rotational frequency at the first accelerometer position, in hertz;
- n_2 is the rotational frequency at the second accelerometer position, in hertz;
- e_{n_2} is the absolute uncertainty for the rotational frequency at the second accelerometer position, in hertz;

a_H is the acceleration amplitude caused by hum and noise, in metres per second squared;

P is the voltage supply to the accelerometer;

e_P is the uncertainty in voltage supply to the accelerometer;

$e_{\Delta n}$ is the absolute uncertainty for the rotational constancy, in hertz.

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 error, e_S, calculated in accordance with A.2.1 or A.2.2, is only valid for the calibrated levels. 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:

$$\frac{e_{S_1}}{S} = \pm \left\{ \left(\frac{e_S}{S}\right)^2 + \left(\frac{L_{fA}}{100}\right)^2 + \left(\frac{L_{fP}}{100}\right)^2 + \left(\frac{L_{aA}}{100}\right)^2 + \left(\frac{L_{aP}}{100}\right)^2 + \left(\frac{I_A}{100}\right)^2 + \left(\frac{I_P}{100}\right)^2 + \left(\frac{R}{100}\right)^2 + \left(\frac{E_A}{100}\right)^2 + \left(\frac{E_P}{100}\right)^2 \right\}^{1/2}$$

where

S is the calibration factor, in volts per (metre per second squared) (see 5.2 or 6.2);

e_S is the absolute uncertainty for the calibration factor, in volts per (metre per second squared), at calibrated levels, calculated in accordance with A.2.1 or A.2.2;

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.