

INTERNATIONAL STANDARD

ISO
5347-6

First edition
1993-12-15

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

Part 6:

Primary vibration calibration at low frequencies

*Méthodes pour l'étalonnage de capteurs de vibrations et de chocs —
Partie 6: Étalonnage primaire de vibrations aux basses fréquences*



Reference number
ISO 5347-6:1993(E)

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 5347-6 was prepared by Technical Committee ISO/TC 108, *Mechanics: 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*:

- Part 0: Basic concepts
- Part 1: Primary vibration calibration by least interference
- 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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International Organization for Standardization

Case Postale 56 • CH-1211 Genève 20 • Switzerland

Printed in Switzerland

- *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 6:

Primary vibration calibration at low frequencies

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 at low frequencies. It applies to all kinds of pick-ups.

This part of ISO 5347 is applicable for a frequency range from 0,5 Hz to 20 Hz and a dynamic range from 1 m/s² to 200 m/s² (frequency-dependent) and from 0,5 mm to 1 000 mm.

The limits of uncertainty applicable are $\pm 0,5$ % of reading.

2 Normative reference

The following standard contains provisions which, through reference in this text, constitute provisions of this part of ISO 5347. At the time of publication, the edition indicated was valid. All standards are subject to revision, and parties to agreements based on this part of ISO 5347 are encouraged to investigate the possibility of applying the most recent edition of the standard indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

ISO 5347-1:1993, *Methods for the calibration of vibration and shock pick-ups — Part 1: Primary vibration calibration by laser interferometry.*

3 Apparatus

3.1 Equipment capable of maintaining room temperature at $23\text{ }^{\circ}\text{C} \pm 3\text{ }^{\circ}\text{C}$.

3.2 Guided fixture, to which the pick-up is attached.

3.3 Vibration-motion generator, having the following characteristics:

- frequency stability: better than $\pm 0,01$ % of reading over the measurement period;
- total distortion: 5 % max. in terms of acceleration in frequency band from 0,5 Hz to 100 Hz;
- hum and noise: 50 dB min. below reading;
- transverse vibration: maximum 2 % of axial motion.

NOTES

1 A flywheel (counterbalanced for the fixture mass) with a conical pin, working without play in a conical track on the fixture and giving the fixture and the pick-up a sinusoidal motion, can be used.

The connection (including oil film) between the fixture and the flywheel should be stiff enough so that harmonics caused by the energy shift from the fixture to the flywheel and vice versa are negligible.

The flywheel drive should be such that variations in the angular velocity of the flywheel do not exceed 0,2 %.

2 If a crankshaft is used, it should be borne in mind that the movement is not sinusoidal:

$$d = r(1 - \cos \alpha) + \frac{r^2}{2l} \sin^2 \alpha$$

where

- d is the displacement;
- r is the crankshaft radius;
- l is the length of the connecting rod;
- α is the crankshaft angle.

The error caused by distortion should be shown to be within the limits of error specified.

3 For small linear displacement amplitudes, there can be a significant difference between the calculated or measured displacement amplitude and the actual displacement along the axis of the pick-up being calibrated. Such difference may result from backlash, relative movement between parts of the calibration fixture, or rotational components of motion in a place containing the nominal axis of motion. A related source of error is disturbance of the nominally stationary part of the displacement-measuring equipment. All of these phenomena may be functions of frequency and of amplitude, and it is essential to ensure that the resulting errors are within the limits of error specified.

3.4 Linear displacement-measuring system, for example a precision linear transducer or a laser interferometer according to ISO 5347-1.

The system shall be statically calibrated at the calibration amplitudes. The uncertainty shall be not greater than $\pm 0,01$ mm.

3.5 Counting instrumentation, covering the range from 0,5 Hz to 20 Hz and with uncertainty maximum $\pm 0,01$ % of reading.

3.6 Voltage instrumentation for measuring true r.m.s., having the following characteristics:

- frequency range: 0,5 Hz to 20 Hz;
- uncertainty, maximum: $\pm 0,1$ % of reading.

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

3.7 Distortion-measuring instrumentation, capable of measuring total distortion of 0 to 10 % and having the following characteristics:

- frequency range: 0,5 Hz to 100 Hz;
- uncertainty, maximum: ± 10 % of reading.

3.8 Oscilloscope, for checking the waveform of the pick-up signal, with a frequency range from 0,5 Hz to 2 000 Hz.

4 Preferred amplitudes and frequencies

The following displacement amplitudes, in millimetres, shall be used:

0,5; 1,0; 2,0; 5,0; 10; 20; 50; 100; 200; 500; 1 000.

The following frequencies, in hertz, shall be used:

0,5; 1,0; 2,0; 5,0; 10; 20.

The reference displacement amplitude shall be 1 mm (second choice: 5 mm) and the reference frequency shall be 5 Hz (second choice: 1 Hz).

5 Method

5.1 Test procedure

Check and set the displacement amplitude measuring system statically, and determine the error in the amplitude. With the test pick-up mounted on the fixture, check for distortion and for deviations from rectilinear motion at the calibration frequencies. Check the amplitude dynamically using the displacement-measuring system; care shall be taken to confirm that any disturbance of the nominally stationary part of the displacement pick-up does not exceed 0,2 % of the nominal displacement amplitude.

At each of the amplitudes and frequencies, measure the output voltage of the pick-up to be calibrated.

Determine the reference calibration factor at the reference amplitude and reference frequency.

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

5.2 Expression of results

5.2.1 If the pick-up senses displacement, calculate the displacement sensitivity, S_d , in volts per metre, using the following formula:

$$S_d = \frac{V}{x}$$

5.2.2 If the pick-up senses velocity, calculate the velocity sensitivity, S_v , in volts per (metre per second) [V/(m/s)], using the following formula:

$$S_v = \frac{V}{2\pi f x}$$

5.2.3 If the pick-up senses acceleration, calculate the acceleration sensitivity, S_a , in volts per (metre per second), using the following formula:

$$S_a = \frac{V}{4\pi^2 f^2 x}$$

where

- V is the output from the pick-up to be calibrated, in volts (single) amplitude;
- x is the set displacement value checked for dynamic effects;
- f is the frequency, in hertz.

5.2.4 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 % (second choice: 95 % confidence level) shall be used.

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Annex A (normative)

Calculation of uncertainty

A.1 Calculation of total uncertainty

The total uncertainty of the calibration for the specified confidence level (for the purposes of this part of ISO 5347, CL = 99 % or 95 %), X_{CL} , shall be calculated from the following formula:

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

where

X_r is the random uncertainty;

X_s is the systematic uncertainty.

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

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

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, $X_{s(CL)}$, shall be taken into account by using the following formula:

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

where

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

e_s is the absolute uncertainty for the calibration factor for calibrated frequencies, amplitudes and amplifier gain settings (see A.2).

A.2 Calculation of the absolute uncertainty for the calibration factor, e_s , for calibrated frequencies, amplitudes and amplifier gain settings

The absolute uncertainty for the calibration factor, e_s , for calibrated frequencies, amplitudes and amplifier gain settings is calculated by the law of the combination of errors from the following formula:

$$\frac{e_s}{S_d} = \pm \left\{ \left(\frac{e_x}{x} \right)^2 + \left(\frac{e_v}{V} \right)^2 + \left[\frac{1}{2} \left(\frac{d_{tot}}{100} \right)^2 \right]^2 + \left(\frac{a_T T_2}{100 a_{rms}} \right)^2 + \left(\frac{a_H}{a_{rms}} \right)^2 \right\}^{1/2}$$

If the calibration factor has been calculated by using the value of f (see 5.2), add the following factor to the above formula:

$$\left(\frac{e_f}{f} \right)^2$$

If the calibration factor has been calculated by using the value of f^2 (see 5.2), add the following factor to the above formula:

$$\left(\frac{2e_f}{f} \right)^2$$

where

- S_d is the displacement sensitivity, in volts per metre (see 5.2);
- x is the preset displacement value checked for dynamic effects;
- e_x is the error for the preset displacement value, including dynamic effects;
- V is the pick-up output, in volts;
- e_V is the absolute error for the pick-up voltmeter output, in volts;
- d_{tot} is the total distortion and is equal to $100 \left(\frac{a_{\text{tot}}^2 - a_{\text{rms}}^2}{a_{\text{rms}}^2} \right)^{1/2}$, expressed as a percentage, in which a_{tot} is the total true r.m.s. amplitude;
- a_{rms} is the true r.m.s. amplitude at driving frequency;
- a_T is the transverse, rocking and bending vibration, in absolute measures;
- T_2 is the maximum transverse sensitivity of the pick-up, expressed as a percentage of the transducer sensitivity in the measuring direction;
- a_H is the amplitude caused by hum and noise;
- f is the frequency, in hertz;
- e_f is the absolute uncertainty for the frequency, in hertz.

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

The absolute uncertainty for the calibration factor, calculated in accordance with A.2, is only valid for the calibration frequencies, amplitudes and amplifier gain settings. The total absolute uncertainty for the calibration factor, $e_{S,t}$, over the complete frequency and amplitude range is calculated from the following formula:

$$\frac{e_{S,t}}{S} = \pm \left[\left(\frac{e_S}{S} \right)^2 + \left(\frac{L_{fA2}}{100} \right)^2 + \left(\frac{L_{fP2}}{100} \right)^2 + \left(\frac{L_{aA2}}{100} \right)^2 + \left(\frac{L_{aP2}}{100} \right)^2 + \left(\frac{I_{A2}}{100} \right)^2 + \left(\frac{I_{P2}}{100} \right)^2 + \left(\frac{R_2}{100} \right)^2 + \left(\frac{E_{A2}}{100} \right)^2 + \left(\frac{E_{P2}}{100} \right)^2 \right]^{1/2}$$

where

- S is the calibration factor;
- e_S is the absolute uncertainty for the calibration factor at reference frequency, amplitude and amplifier gain settings;
- L_{fA2} is the frequency linearity deviation, expressed as a percentage of the calibration for the amplifier for the pick-up to be calibrated;