INTERNATIONAL STANDARD

ISO 5347-20

First edition
1997-03-01

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

Part 20:
Primary vibration calibration by the reciprocity method

Méthodes d'étalonnage des capteurs de vibrations et de chocs —

Partie 20: Étalonnage primaire de vibrations par méthode réciproque

Reference number
ISO 5347-20:1997(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 5347-20 was prepared by Technical Committee ISO/TC 108, *Mechanical vibration and shock*, Subcommittee 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*

International Organization for Standardization
Case postale 56 • CH-1211 Genève 20 • Switzerland
Internet central@iso.ch
X.400 c=ch; a=400net; p=iso; o=isocs; s=central

Printed in Switzerland

— *Part 8: Primary calibration by dual centrifuge*

— *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: Vibration calibration by reciprocity method*

— *Part 21: Shock calibration by using laser doppler velocimeter*

— *Part 22: Accelerometer resonance testing — General methods*

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

This page intentionally left blank

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

Part 20:
Primary vibration calibration by the reciprocity method

1 Scope

This part of ISO 5347 specifies the instrumentation and procedure to be used for the primary calibration of accelerometers using the reciprocity method.

It applies to rectilinear accelerometers. The method is a calibration of the complete vibrator coil/accelerometer system. It is applicable over a frequency range from 40 Hz to 1 250 Hz and a dynamic range from 10 m/s^2 to 100 m/s^2 (frequency dependent).

The applicable limits of uncertainty are ± 1,0 % of the reading at the reference frequency (160 Hz or 80 Hz) and reference amplitude (100 m/s^2 or 10 m/s^2) and reference amplifier gain setting.

2 Symbols

Main symbol	Definition	Unit
f	frequency of vibration	Hz
M	mass of added weight	kg
n	number of weights (1 is the smallest)	—
Q	slope of plot (figure 3)	—
R	value of resistor	Ω
$\overline{S}$	sensitivity	V/(m·s^{-2})
$\overline{X}$	$\dfrac{\text{transducer output voltage}}{\text{open coil open voltage}}$	—
$\overline{Y}$	$\dfrac{\text{current through coil}^{1)}}{\text{transducer output voltage}}$	—
φ	phase	
1) Measured as volts.		

Subscript	Definition
0	no weight attached
n	weight No. n attached
i	imaginary
r	real
p	read from plot (figure 3)

3 Apparatus

In order to achieve the accuracy of measurement, the accelerometer and accelerometer amplifier shall be looked upon as one unit and shall be calibrated together.

The accelerometer shall be structurally rigid. The base strain sensitivity shall be less than $0{,}2 \times 10^{-8}$ m/s^2; at a base strain of $2{,}5 \times 10^{-4}$ the transverse sensitivity shall be less than 1 % and the stability of the accelerometer/amplifier combination shall be better than 0,2 % of the reading per year.

3.1 Equipment capable of maintaining the ambient conditions within the requirements specified in clause 4.

3.2 Frequency generator and indicator, having the following characteristics:

a) uncertainty for frequency: max. ± 0,01 % of the reading;

b) frequency stability: better than 0,01 % of the reading over the measurement period;

c) amplitude stability: better than ± 0,01 % of the reading over the measurement period.

3.3 Power amplifier/vibrator combination, having the following characteristics:

a) total distortion: 2 % max.;

b) transverse, bending and rocking acceleration: kept to a minimum; i.e. a maximum of 10 % of the acceleration in the intended direction at frequencies used; above 1 000 Hz, a maximum of 20 % is permitted;

c) hum and noise: 70 dB min. below full output;

d) acceleration amplitude stability: better than 0,05 % of the reading over the measurement period.

3.4 Seismic bloc for vibrator, with a mass at least 2 000 times the mass of the moving elements of the vibrator, fixture and transducer.

The seismic block shall be suspended by low-damped springs. If floor vibrations exert an influence, the suspension resonance frequency vertically and horizontally shall be less than 2 Hz.

3.5 Instrumentation for ratio measurements, having the following characteristics:

a) frequency range: 40 Hz to 1 250 Hz;

b) uncertainty: resolution and short-term stability better than ± 0,1 % of the reading; the range shall be sufficient to allow measurement of output noise.

3.6 Phase meter, having the following characteristics:

a) frequency range: 40 Hz to 1 250 Hz;

b) inaccuracy: ± 1°.

3.7 Resistor, having the following characteristics:

a) low inductive component;

b) power rating well above the actual power dissipation;

c) inaccuracy: ± 0,05 % for the calibration frequency range and power dissipated.

NOTE — In order to minimize the effect of the resistor on armature current, its resistance should be much smaller than the resistance of the armature. For example, less than 0,01 Ω in the case of a 0,5 Ω armature.

3.8 Weights, having the following characteristics:

a) range of mass spread over 10 equal intervals, with the largest mass equal to 1 to 2 times the mass of the moving assembly of the vibrator;

b) inaccuracy: max. ± 0,05 % of the mass of each weight.

3.9 Distortion-measuring instrumentation, capable of measuring a total distortion of 0 % to 5 % and having the following characteristics:

a) frequency range: 40 Hz to 10 kHz;

b) uncertainty: max. ± 10 % of the reading.

3.10 Oscilloscope (not mandatory), for checking the waveform of the signal of the accelerometer with a frequency range from 40 Hz to 5 000 Hz.

4 Ambient conditions

Calibration shall be carried out under the following ambient conditions:

a) room temperature: (23 ± 3) °C;

b) air pressure: (100 ± 5) kPa;

c) relative humidity: max. (50 ± 25) %.

5 Preferred amplitudes and frequencies

Four amplitudes and six frequencies equally spaced over the accelerometer range shall be chosen from the following series.

5.1 Acceleration

10 m/s^2, 20 m/s^2, 50 m/s^2, 100 m/s^2

Reference acceleration: 100 m/s^2 (second choice: 10 m/s^2).

5.2 Frequency

40 Hz, 80 Hz, 160 Hz, 315 Hz, 630 Hz, 1 250 Hz

Reference frequency: 160 Hz (second choice: 80 Hz).

6 Procedure

6.1 General

Calibration by reciprocity uses the reciprocal correspondence between the mechanical and electrical variables at the terminals of an electrodynamic transducer which is reversible, linear and passive. The transducer used in the methods described in this part of ISO 5347 is the coil of the electrodynamic exciter applying the vibration to the accelerometer to be calibrated and is located close to it.

A total of two vibrators or one vibrator with a double coil are necessary, including the one to be calibrated, but only one of them (coil) must have the three characteristics stated above. In experiment 1, this coil acts as a driving coil, and in experiment 2 as a velocity coil.

The calibration shall be performed at frequencies well below the resonance frequencies of the structure containing the driving coil and the transducer so that the phase shifts between these are kept to a minimum.

Vibrate the transducer during two different sets of conditions (6.1.1 and 6.1.2); the first condition requires measurements with and without weights being added.

After optimizing the settings, carry out the calibration at preferably 160 Hz (80 Hz second choice), 100 m/s^2 (10 m/s^2 second choice) and the reference position of the amplifier range switch. This gives the sensitivity.

Then carry out the calibration at the other selected acceleration levels and frequencies. These results are given as a percentage deviation from the sensitivity.

The equilibrium position of the coil in the gap of the magnet should be the same in both experiment 1 and experiment 2. In addition, the equilibrium position should not be allowed to drift from this constant value while the measurements are being made.

For every frequency and acceleration combination, the distortion, transverse, bending and rocking acceleration, hum and noise shall be measured and shall be within the limits given in clause 3.

During the calibration itself, all instruments not necessary for the calibration shall be disconnected.

Two vibrators or one vibrator with dual driving coils are used during two sets of conditions.

6.1.1 Experiment 1: Measurement of ratio of driving coil current to transducer output voltage

In experiment 1, compare the current through the driving coil with the output voltage from the transducer. The current through the driving coil passes a resistor in order to achieve a voltage relationship for comparison. The ratio without an added weight is Y_0 and the ratio when a weight of known mass is attached is Y_n.

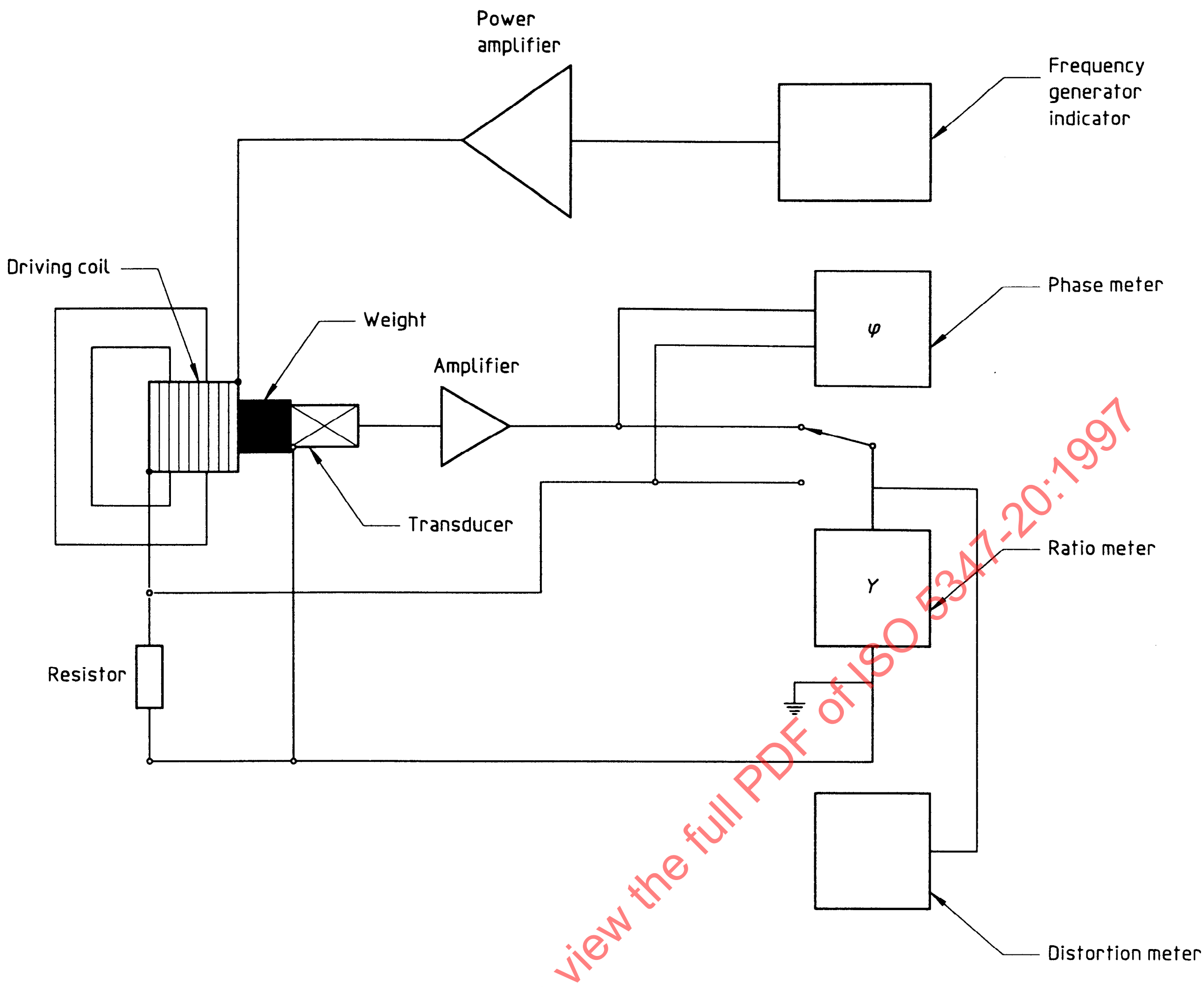

Figure 1 — Experiment 1

6.1.2 Experiment 2: Measurement of ratio of transducer output to open coil output

In experiment 2, determine the ratio of the output from the accelerometer to the output from the coil (which was the driving coil in experiment 1 but now acts as the velocity coil) using an external vibrator or a second built-in driving coil. This ratio (X_0) is determined with no added weight.

7 Computation of sensitivity

There are two ways of determining the sensitivity: by a graph or mathematically by the least-squares method.

Calculate the real and imaginary parts for $\overline{X}_0$, $\overline{Y}_0$ and $\overline{Y}_n$:

$\overline{X}_r = R \sin \varphi$ $\qquad Y_r = Y \cos \varphi$

$\overline{X}_i = R \cos \varphi$ $\qquad Y_i = Y \sin \varphi$

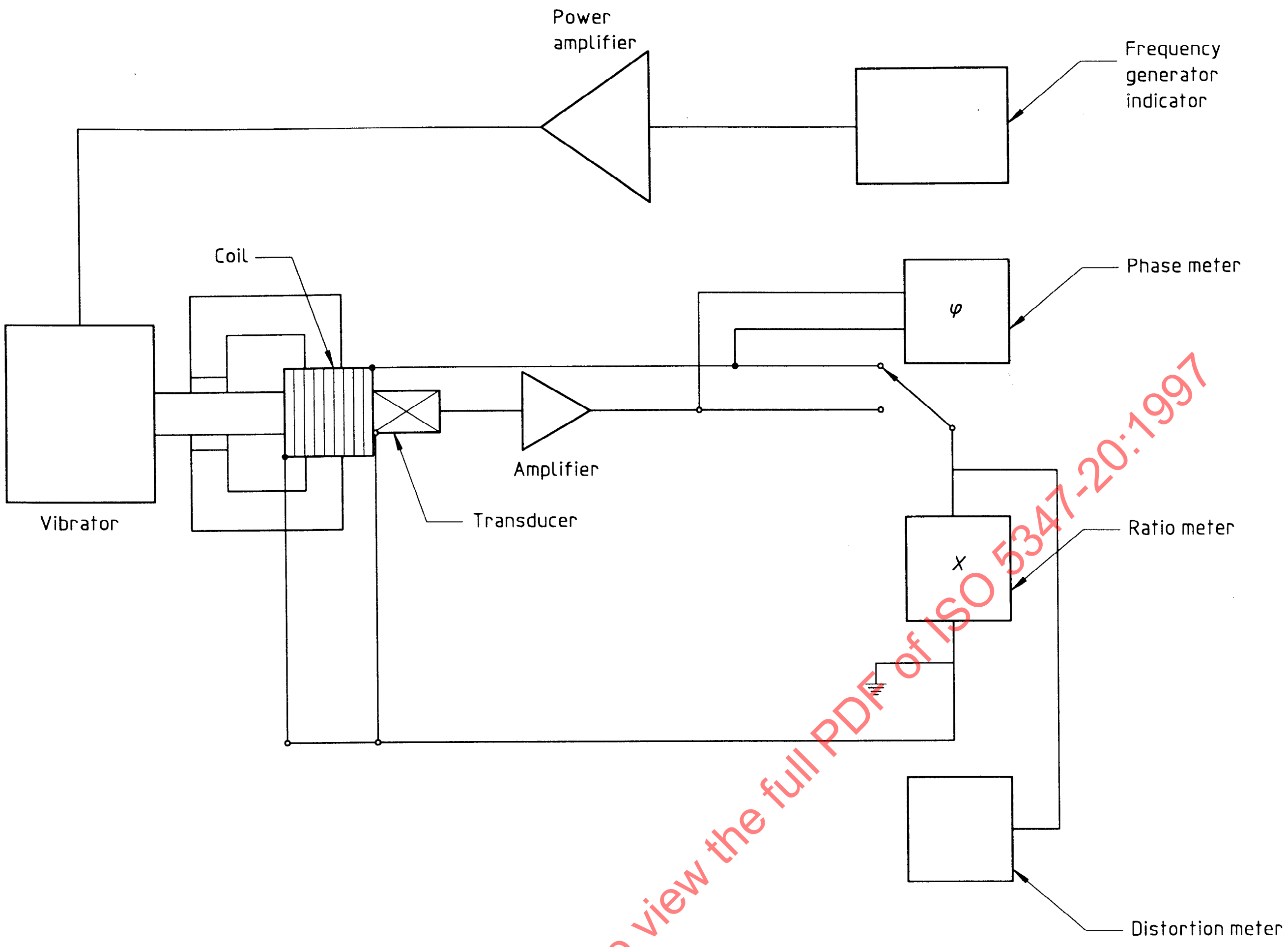

Figure 2 — Experiment 2

7.1 Graphical determination of sensitivity

Plot two plots, over different values of M_n:

$$Z_{n\mathrm{r}} = \frac{M_n}{Y_{n\mathrm{r}} - Y_{0\mathrm{r}}}$$

$$Z_{n\mathrm{i}} = \frac{M_n}{Y_{n\mathrm{i}} - Y_{0\mathrm{i}}}$$

Fit a straight line

$$Z = \frac{M_n}{Y_n - Y_0}$$

of slope

$$Q = \frac{Z_\mathrm{p} - Z_0}{M_\mathrm{p}}$$

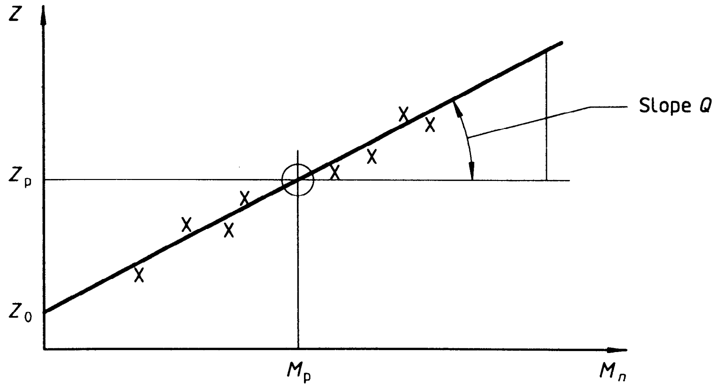

Figure 3 — Graphical determination of sensitivity

The individual points (figure 3) can be used as they are; uniform weighting of the masses, or the individual points in figure 3 can be weighted proportional to the mass; for example a mass which is 5 times the smallest mass should have a weighting factor of 5.

Select one point M_n and read from the curve values of Q, M_p, Z_p, Z_0 and from related measurements $\overline{X}_0$ and f for both the real and imaginary parts.

$$S = \sqrt{\frac{\overline{X}_0 \times \overline{Z}_0}{\mathrm{j} \times 2\pi f}} \left(\frac{1}{1 - \overline{Q}\left(\overline{Y}_p - \overline{Y}_0\right)} \right) \qquad \frac{\mathrm{V}}{\mathrm{m/s^2}}$$

By experience it is found that Q in most cases is negligible ($Q \approx 0$). When the mass of the accelerometer is small compared to the masses of the vibrator moving elements, $Y_p = Y_0$. In both cases the equations reduce to:

$$\overline{S} = \sqrt{\frac{\overline{X}_r \times \overline{Z}_r}{\mathrm{j} \times 2\pi f}} \qquad \frac{\mathrm{V}}{\mathrm{m/s^2}}$$

7.2 Mathematical determination of sensitivity

The least-squares straight line fit for uniform weighting of masses gives:

$$\overline{Z}_0 = \frac{\sum M_n^2 \sum \left(\frac{M_n}{\overline{Y}_n - \overline{Y}_0} \right) - \sum M_n \sum \left(\frac{M_n^2}{\overline{Y}_n - \overline{Y}_0} \right)}{W \sum M_n^2 - \left(\sum M_n \right)^2}$$

Weighting proportional to the mass gives:

$$\overline{Z}_0 = \frac{\sum\left(n^2 \times M_n^2\right)\sum\left(\dfrac{n^2 \times M_n}{\overline{Y}_n - \overline{Y}_0}\right) - \sum\left(n^2 \times M_n\right)\sum\left(\dfrac{n^2 \times M_n^2}{\overline{Y}_n - \overline{Y}_0}\right)}{\sum n^2 \sum\left(n^2 \times M_n^2\right) - \left[\sum\left(n^2 \times M_n\right)\right]^2}$$

where

n is the weighting factor corresponding to the mass M_n;

W is the total number of weights used.

$$\overline{S} = \sqrt{\frac{\overline{X} \times \overline{Z}_0}{\mathrm{j} \times 2\pi f}} \qquad \frac{\mathrm{V}}{\mathrm{m/s^2}}$$

When the calibration results are reported, the total calibration inaccuracy and the corresponding confidence level shall be calculated according to annex A.

A confidence level of 99 % shall be used (95 % second choice).