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

Part 10:
Primary calibration by high impact shocks

Méthodes pour l'étalonnage de capteurs de vibrations et de chocs — Partie 10: Étalonnage primaire de chocs à impact élevé

Reference number
ISO 5347-10:1993(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 5347-10 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*

Annexes A and B form an integral part of this part of ISO 5347.

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

Part 10:
Primary calibration by high impact shocks

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 high impact shock calibration of accelerometers. It applies to rectilinear accelerometers, mainly of the piezoelectric and piezoresistive type, to primary standards and working accelerometers.

This part of ISO 5347 is applicable for a time range from 10 µs to 100 µs and a dynamic range from 10^3 m/s^2 to 10^5 m/s^2.

The limit of uncertainty applicable is ± 10 % 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 °C ± 3 °C.

3.2 High impact shock machine, with two long thin steel rods, one acting as a hammer and the other as an anvil to which the accelerometer is attached.

The hammer-rod can be shot or permitted to fall freely and to strike the anvil-rod which is permitted to accelerate freely and later to be caught up by a spring or braking device.

At the strike, the longitudinal resonance frequency is excited in the anvil-rod.

The contact of the two rod surfaces and the cushion material between them shall be made so that the generated stress pulse approximates a half-sine pulse having a duration equal to half the period of resonance of the rod in its fundamental longitudinal mode.

A number of anvil-rods shall be used, one for each desired pulse duration.

The resonance period of the rod, T, in seconds, can be estimated from the following formula:

$$T = \frac{l}{2\ 500}$$

where l is the rod length, in metres.

In order to avoid coupling of reflected stress pulses in the hammer-rod into the anvil-rod at the moment of impact, the length of the hammer-rod should be about half the length of the anvil-rod.

Strain gauges, having a maximum effective length of 0,3 mm, shall be mounted on the anvil-rod in order to measure strain for acceleration calculations. The centre of the strain gauges shall be applied at a distance of one rod diameter from the end where the accelerometer is mounted. The cross-sectional area of the rod at the point where the strain gauges are applied shall be measured with an error of less than ± 1 %. The rod mass between the point where the strain gauges are applied and the point at which the accelerometer is mounted and the accelerometer mass shall be determined with an error of less than ± 1 %.

3.3 Acceleration/time and strain/time recording equipment, comprising a digital memory oscilloscope or digital transient recorder for two channels with peak amplitude detector and a three-digit indicator display for peak pulse amplitude, or a strip chart or *X-Y* recorder to obtain a readout of the stored transient.

The equipment shall have the following characteristics:

— range: 0,1 µs to 100 µs and 0 to 50 V;

— uncertainty for amplitude: maximum ± 2 % of reading;

— amplitude linearity: 1 % max. deviation from best fit line.

3.4 Filters.

The use of filters shall be avoided.

If filters have to be used, the −3 dB lower limiting frequency shall be lower than $0{,}008/T$ and the −3 dB upper limiting frequency shall be higher than $10/T$, where T is the pulse duration.

3.5 Strain gauge, with a d.c. voltage supply**, and amplifier**, with no filtering and having the following characteristics:

— frequency response: flat within ± 3 dB from $0{,}008/T$ to $10/T$, where T is the pulse duration;

— linearity: better than ± 0,05 % from best fit line;

— amplification tolerance: ± 0,5 % of signal;

— calibrated amplification ranges within ± 0,5 %.

3.6 Other apparatus requirements.

The accelerometer shall be structurally rigid. The base strain sensitivity shall be $< 0{,}2 \times 10^{-8}$ m/s² at a base strain of $2{,}5 \times 10^{-4}$ m/s², the transverse sensitivity < 2 % and the stability of the accelerometer/amplifier combination shall be better than 0,2 % of the reading per year.

If there are filters in the amplifier, the filter cut-off frequency settings shall comply with the filter settings specified in 3.4. The frequency response shall be flat within ± 3 dB from $0{,}008/T$ to $10/T$, where T is the pulse duration.

4 Preferred pulse durations and accelerations

Shock pulse durations shall be chosen from between 10 µs and 100 µs.

Accelerations shall be chosen from between 10^3 m/s² and 10^5 m/s².

5 Method

5.1 Test procedure

For high impact shock calibrations, the sinusoidal vibration calibration factor determined according to ISO 5347-1 shall be used as reference calibration factor.

The shock motion calibrations are then used to measure the amplitude linearity deviations at high accelerations.

By using rods of different lengths and consequently different resonance frequencies and dropping them from different heights, determine the shock sensitivity at the standard selected shock pulse durations and accelerations and for the standard amplifier range switch positions.

The results shall be given as a percentage deviation from the sinusoidal reference calibration factor.

5.2 Expression of results

Calculate the acceleration, a_{str}, in metres per second squared, from the strain measurements in accordance with the following formula (see also annex A):

$$a_{str} = \frac{E \times A}{m_1 + m_2} \times \varepsilon$$

where

E is the modulus of elasticity, in newtons per square metre;

A is the cross-sectional area of the rod, in square metres, at the point where the strain gauges are applied;

m_1 is the rod mass, in kilograms, between the point where strain gauges are applied and the transducer;

m_2 is the pick-up mass, in kilograms;

ε is the strain as a function of time.

Calculate the shock sensitivity, S_{sh}, expressed in volts per (metre per second squared) [V/(m/s^2)], using the following formula:

$$S_{sh} = \frac{m_1 + m_2}{E \times A} \times \frac{a_{peak}}{\varepsilon_{peak}}$$

where

m_1, m_2, E and A are as given above;

ε_{peak} is the peak value of the strain curve;

a_{peak} is the peak value of the acceleration curve, in volts.

The acceleration and strain curves shall always be checked directly on an oscilloscope or recorder without filters and amplifiers.

NOTE 1 If there is a zero shift in the signal, the zero point immediately before the shock and the shifted zero point immediately after the shock shall be connected by a straight line, this line being the baseline for acceleration determination.

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

A confidence level of 95 % shall be used.

Annex A
(normative)

Formulae for the calculating of acceleration

A schematic diagram for aid in calculating acceleration from strain measurements is shown in figure A.1

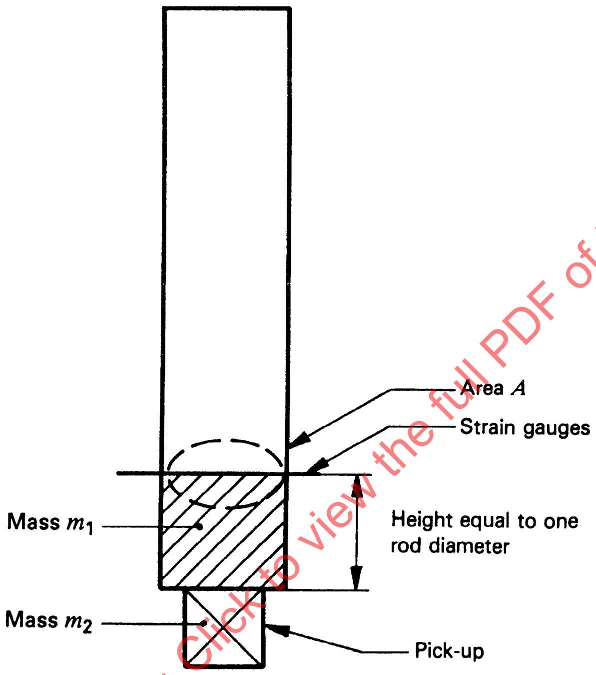

Figure A.1

The mass below the strain gauges shall be considered as being rigid.

At the cross-section at the point where the strain gauges are applied, the following formulae apply;

$$F = (m_1 + m_2) \times a$$

$$F = p \times A$$

$$p = E \times \varepsilon$$

$$E \times \varepsilon \times A = (m_1 + m_2) \times a$$

$$a = \frac{E \times A}{m_1 + m_2} \times \varepsilon$$

where

F is the force;

m_1 is the mass between the strain gauges and the pick-up;

m_2 is the mass of the pick-up;

A is the cross-sectional area at the point where the strain gauges are applied;

E is the modulus of elasticity;

ε is the strain measured by the strain gauges;

p is the pressure in pascals.

Annex B
(normative)

Calculation of uncertainty

B.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 = 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_{r1}, 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:

$$X_{s(95)} = \frac{K}{\sqrt{3}} \times e_{S,sh}$$

where

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

$e_{S,sh}$ is the absolute uncertainty for the shock calibration factor at calibrated levels, expressed in volts per (metre per second squared) (see B.2).

B.2 Calculation of the absolute uncertainty for the shock calibration factor, $e_{S,sh}$, at calibrated levels

The absolute uncertainty for the shock calibration factor, $e_{S,sh}$, in volts per (metre per second squared), at calibrated levels, is calculated by the law of combination of errors from the following formula:

$$\frac{e_{S,sh}}{S_{sh}} = \pm \left[\left(\frac{e_{m_1}}{m_1} \right)^2 + \left(\frac{e_{m_2}}{m_2} \right)^2 + \left(\frac{e_E}{E} \right)^2 + \left(\frac{e_A}{A} \right)^2 + \left(\frac{e_a}{a_{peak}} \right)^2 + \left(\frac{e_\varepsilon}{\varepsilon_{peak}} \right)^2 + \left(\frac{e_P}{P} \right)^2 \right]^{1/2}$$

where

S_{sh} is the shock sensitivity (amplitude-dependent), in volts per metre second squared;

m_1 is the rod mass, in kilograms, between the point where the strain gauges are applied and the accelerometer;

e_{m_1} is the uncertainty for the rod mass between the point where the strain gauges are applied and the accelerometer, in kilograms;

m_2 is the accelerometer mass, in kilograms;

e_{m_2} is the uncertainty for the accelerometer mass, in kilograms;

E is the modulus of elasticity, in newtons per metre squared;

e_E is the uncertainty fot the modulus of elasticity, in newtons per metre squared;

A is the cross-sectional area of the rod, in square metres, at the point where the strain gauges are applied;

e_A is the uncertainty for the cross-sectional area of the rod at the point where the strain gauges are applied, in square metres;

a_{peak} is the accelerometer output, in volts;

e_a is the uncertainty for the accelerometer output, in volts;

ε_{peak} is the strain value;

e_ε is the uncertainty in strain;

P is the voltage supply to the strain gauges;

e_P is the uncertainty for the voltage supply to the strain gauges.

If the accelerometer has a voltage supply, add the following factor to the above formula.

$$\left(\frac{e_{P_a}}{P_a}\right)^2$$

where

P_a is the voltage supply to the accelerometer;

e_{P_a} is the uncertainty for the voltage supply to the accelerometer.

B.3 Calculation of the total absolute uncertainty for the shock calibration factor, $e_{S,sh,t}$, outside the calibrated values

The absolute uncertainty for the shock calibration factor, calculated in accordance with B.2, is valid only for calibrated values. The total absolute uncertainty for the shock calibration factor, $e_{S,sh,t}$, in volts per (metre per second squared) outside calibration values is calculated from the following formula:

$$\frac{e_{S,sh,t}}{S_{sh}} = \pm\left[\left(\frac{e_{S,sh}}{S_{sh}}\right)^2 + \left(\frac{L_{fA1}}{100}\right)^2 + \left(\frac{L_{fP1}}{100}\right)^2 + \left(\frac{L_{aA1}}{100}\right)^2 + \left(\frac{L_{aP1}}{100}\right)^2 + \left(\frac{I_{A1}}{100}\right)^2 + \left(\frac{I_{P1}}{100}\right)^2 + \left(\frac{R_1}{100}\right)^2 + \right.$$
$$+ \left(\frac{E_{A1}}{100}\right)^2 + \left(\frac{E_{P1}}{100}\right)^2 + \left(\frac{L_{fA2}}{100}\right)^2 + \left(\frac{L_{fP2}}{100}\right)^2 + \left(\frac{L_{aA2}}{100}\right)^2 + \left(\frac{L_{aP2}}{100}\right)^2 + \left(\frac{I_{A2}}{100}\right)^2 + \left(\frac{I_{P2}}{100}\right)^2 + \left(\frac{R_2}{100}\right)^2 +$$
$$\left. + \left(\frac{E_{A2}}{100}\right)^2 + \left(\frac{E_{P2}}{100}\right)^2 + \left(\frac{L_{fL}}{100}\right)^2 + \left(\frac{L_{aL}}{100}\right)^2 + \left(\frac{I_L}{100}\right)^2 + \left(\frac{E_L}{100}\right)^2 + \left(\frac{E_C}{100}\right)^2 + \left(\frac{E_A}{100}\right)^2 + \left(\frac{E_M}{100}\right)^2\right]^{1/2}$$

where

S_{sh} is the shock sensitivity (amplitude-dependent), in volts per (metre per second squared);

$e_{S,sh}$ is the absolute uncertainty for the shock calibration factor, in volts per (metre per second squared) (see B.2);

L_{fA1} is the frequency linearity deviation, expressed as a percentage, for the strain gauge amplifier;

L_{fP1} is the frequency linearity deviation, expressed as a percentage, for the strain gauges;

L_{aA1} is the amplitude linearity deviation, expressed as a percentage, for the strain gauge amplifier;

L_{aP1} is the amplitude linearity deviation, expressed as a percentage, for the strain gauges;

I_{A1} is the instability error for the strain gauge amplifier gain, expressed as a percentage;

I_{P1} is the instability error for the strain gauges, expressed as a percentage;

R_1 is the tracking error for the strain gauge amplifier range (errors in gain for different amplification settings), expressed as a percentage;

E_{A1} is the uncertainty caused by environmental effects on the strain gauge amplifier, expressed as a percentage;

E_{P1} is the uncertainty caused by environmental effects on the strain gauges, expressed as a percentage;

L_{fA2} is the frequency linearity deviation, expressed as a percentage of the calibration factor for the amplifier for the pick-up to be calibrated;

L_{fP2} is the frequency linearity deviation, expressed as a percentage of the calibration factor for the pick-up to be calibrated;

L_{aA2} is the amplitude linearity deviation, expressed as a percentage of the calibration factor for the amplifier for the pick-up to be calibrated;

L_{aP2} is the amplitude linearity deviation, expressed as a percentage of the calibration factor for the pick-up to be calibrated;

I_{A2} is the instability uncertainty for the amplifier gain and source impedance error, expressed as a percentage of the calibration factor for the amplifier for the pick-up to be calibrated;

I_{P2} is the instability uncertainty for the pick-up to be calibrated, expressed as a percentage of the calibration factor;

R_2 is the range tracking error (errors in gain for different amplification settings), expressed as a percentage of the calibration factor for the amplifier for the pick-up to be calibrated;

E_{A2} is the uncertainty caused by environmental effects on the amplifier for the calibrated pick-up, expressed as a percentage of the calibration factor;

E_{P2} is the uncertainty caused by environmental effects on the pick-up to be calibrated, expressed as a percentage of the calibration factor;

L_{fL} is the frequency linearity deviation, expressed as a percentage of the reference calibration factor for the low-pass filter;

L_{aL} is the amplitude linearity deviation, expressed as a percentage of the reference calibration factor for the low-pass filter;

I_L is the instability error for the low-pass filter gain, expressed as a percentage of the calibration factor;

E_L is the uncertainty caused by environmental effects on the low-pass filter, expressed as a percentage;

E_C is the error caused by acceleration/time and strain/time curves deviation from the true harmonic, expressed as a percentage;

E_A is the uncertainty, expressed as a percentage in comparison measurements of acceleration peak and strain peak values; this error includes reading errors or chart recording and chart reading errors and signal channel difference errors;

E_M is the uncertainty caused by environmental effects on recording equipment, expressed as a percentage.