INTERNATIONAL STANDARD

ISO 16063-32

First edition
2016-09-15

Methods for the calibration of vibration and shock transducers —

Part 32: Resonance testing — Testing the frequency and the phase response of accelerometers by means of shock excitation

Méthodes pour l'étalonnage des transducteurs de vibrations et de chocs —

Partie 32: Essais de résonance — Essai de la fréquence et de la réponse de phase des accéléromètres au moyen d'excitations par chocs

Reference number
ISO 16063-32:2016(E)

Contents

Page

Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see the following URL: www.iso.org/iso/foreword.html.

The committee responsible for this document is ISO/TC 108, *Mechanical vibration, shock and condition monitoring*, Subcommittee SC 3, *Use and calibration of vibration and shock measuring instruments*.

This first edition of ISO 16063-32 cancels and replaces the first edition of ISO 5347-14:1993, which has been technically revised.

ISO 16063 consists of the following parts, under the general title *Methods for the calibration of vibration and shock transducers*:

— *Part 1: Basic concepts*

— *Part 11: Primary vibration calibration by laser interferometry*

— *Part 12: Primary vibration calibration by the reciprocity method*

— *Part 13: Primary shock calibration using laser interferometry*

— *Part 15: Primary angular vibration calibration by laser interferometry*

— *Part 16: Calibration by Earth's gravitation*

— *Part 17: Primary calibration by centrifuge*

— *Part 21: Vibration calibration by comparison to a reference transducer*

— *Part 22: Shock calibration by comparison to a reference transducer*

— *Part 31: Testing of transverse vibration sensitivity*

— *Part 32: Resonance testing — Testing the frequency and the phase response of accelerometers by means of shock excitation*

— *Part 41: Calibration of laser vibrometers*

— *Part 42: Calibration of seismometers with high accuracy using acceleration of gravity*

— *Part 43: Calibration of accelerometers by model-based parameter identification*

The following parts are under preparation:

— *Part 33: Testing of magnetic field sensitivity*

Methods for the calibration of vibration and shock transducers —

Part 32:
Resonance testing — Testing the frequency and the phase response of accelerometers by means of shock excitation

1 Scope

This part of ISO 16063 lays down detailed specification for instruments and procedures of testing the frequency and the phase response of accelerometers by means of shock excitation. It applies to the accelerometers of the piezoelectric, piezoresistive and variable capacitance types with the damping ratio less than critical and in the frequency range up to 150 kHz.

The method presumes that the frequency and the phase responses of the accelerometer under test gained by this method are the best possible characteristics for the mounted accelerometer on the condition that the recommendations for mechanical mounting of accelerometer stated in ISO 5348 are fulfilled and that the mass of the reference shock ball exceeds at least three times the mass of the accelerometer under test.

Phase response of the accelerometer under test gained by this method is considered to be some “virtual” characteristic of accelerometer presuming that there is zero phase shift between the input and output signals at a frequency of 0 Hz.

NOTE 1 It is intended that the user be aware that for the same accelerometer in the field application, the frequency and the phase responses might be different, depending on the mass and compliance of the test structure and the method of mounting. The method allows just a qualitative evaluation of the frequency and the phase response of accelerometers.

NOTE 2 It is intended that the user does not try to get better resolution of the initial parts of the frequency and phase responses of the accelerometer under test than the dynamic range of the adequate characteristic provides it. The best use of the frequency and the phase responses of the accelerometer gained by this method are to get the best fit lines for the initial parts of the mentioned characteristics.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For updated references, the latest edition of the referenced document (including any amendments) applies.

ISO 2041, *Mechanical vibration, shock and condition monitoring — Vocabulary*

ISO 5347-22, *Methods for the calibration of vibration and shock pick-ups — Part 22: Accelerometer resonance testing — General methods*

ISO 5348, *Mechanical vibration and shock — Mechanical mounting of accelerometers*

3 Factors influencing measurement reproducibility

The limits of the uncertainty of the frequency response measurement shall be as follows.

For the resonance frequency of the accelerometer under test, the absolute uncertainty is equal to the frequency analysis resolution and is an inverse value relative to the time-record length of the accelerometer signal. The recommended minimum number of lines in the frequency domain for this method is 400. Assuming that the resonance frequency is in the middle of the frequency span, the standard uncertainty for the resonance frequency is about 0,5 %.

NOTE 1 This uncertainty is presumed to have a uniform distribution within the frequency resolution band.

For the damping ratio of the accelerometer under test, the uncertainty is dependent on the signal-to-noise ratio of the measurement in a time domain.

Assuming that the measurements are carried out so that the maximum signal value is close to the upper limit of the dynamic range of measuring instrument and that the typical damping ratio for the piezoelectric accelerometers is about 0,01, the standard uncertainty for the damping ratio measurements is about 1 %.

NOTE 2 The signal analyser used for the damping ratio measurements is supposed to have at least an 80 dB dynamic range.

For the phase response of the accelerometer under test, the absolute uncertainty is equal to the amplitude resolution in phase; that means resolution in the amplitude of the measuring instrument, corrected by the phase noise suppression procedure for the unwrapped phase. For a typical 40 dB phase noise suppression, the resulting resolution in phase appears to be about 1 % or about 5° in phase domain.

The mentioned uncertainties are the lowest values provided by the instruments, used for the acquisition of the time signal and the frequency analysis. The expanded uncertainties can be larger, depending on the complexity of the frequency response of the accelerometer under test.

NOTE 3 To prove the robustness of the measurements of the resonance frequency and damping ratio of the accelerometer under test, multiple measurements can be carried out.

4 Apparatus and other devices

4.1 Environmental conditions

The equipment shall be capable of maintaining the following environmental conditions:

— room temperature (23 ± 5) °C;

— relative humidity should be less than 90 %.

4.2 Reference shock ball

4.2.1 General

A reference shock ball for mounting an accelerometer under test shall be made of steel hardened to more than HRC50 and polished.

NOTE A typical ball from a ball bearing is very convenient to answer this requirement.

4.2.2 Reference shock ball dimensions

The reference shock ball shall have a flat surface with a thread to mount the accelerometer under test (see Figure 1).

4.2.3 Options for the reference shock ball diameter range

The requirements related to the actual dimensions to the shock balls are not very strict.

On one hand, the diameter of the shock ball shall be small enough to provide its highest possible natural frequency.

On the other hand, the diameter of the shock ball shall be large enough to get a mass of the reference shock ball that exceeds three times the mass of the accelerometer under test.

From the practical point of view for the majority of the accelerometers, the diameters of two balls are preferable:

— a ball with the dimensions D = 32 mm, B = 20 mm, L = 10 mm for the accelerometers with the natural frequencies lower than 100 kHz;

— a ball with the dimensions D = 19 mm, B = 10 mm, L = 7,5 mm for the accelerometers with the natural frequencies lower than 150 kHz.

Other possible dimensions of the ball may also be used for the purpose of this test.

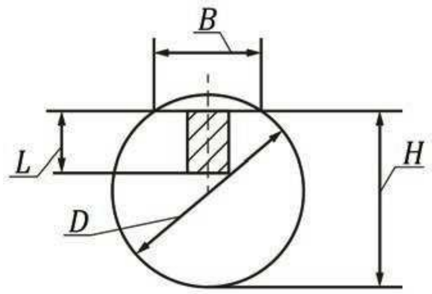


Figure 1 — Reference shock ball dimensions

NOTE 1 The following formulae can be used to calculate the natural frequencies of the ball.

The natural frequency of the first rotatory resonance of the ball can be calculated from Formula (1):

$$f_{\text{ball}} = 1{,}834\ 6 \times \frac{c_S}{D} \tag{1}$$

where c_S is the velocity of the shear waves in steel (3 251 m/s).

The natural frequency of the first radial resonance of the ball can be calculated from Formula (2):

$$f_{\text{ball}} = 0{,}816\ 0 \times \frac{c_D}{D} \tag{2}$$

where

c_D is the velocity of dilatation waves in steel (5 941 m/s);

D is the diameter of the ball.

The natural frequency of the first longitudinal resonance of the ball can be calculated from Formula (3):

$$f = 0{,}5 \times \frac{c_E}{H} \tag{3}$$

where c_E is the velocity of the extension waves in steel (5 250 m/s).

In practice, only Formula (3) provides the lowest frequency of the ball's resonance and has to be taken into account.

The shock pulse duration that is provided by this method is usually fairly large compared to the period of the natural oscillations of the ball. That is why the natural resonances of the ball are not usually induced when using this method. Moreover, the accelerometer under test typically dampens the higher resonances of the ball. So the user shall normally consider having the resonance frequency of an accelerometer under test to be at least not more than 1,5 times higher than the natural frequency of the ball:

$$f_{acc} / f_{ball} \leq 1{,}5 \quad (4)$$

where

f_{acc} is the resonance frequency of accelerometer, kHz;

f_{ball} is the resonance frequency of the ball, kHz.

NOTE 2 The advantages of the method in this part of ISO 16063 compared to the methods described in ISO 5347-22 are that

— the sphere shape provides the maximum mass for the smallest possible size of the reference element;

— the sphere shape provides very high damping ratio for the natural oscillations of the reference element (the raindrop shape of the reference element is considered to provide even more effective damping of the natural oscillations).

4.2.4 Requirements for the mounting surface and the thread tolerances of a reference shock ball

The flat surface of the reference shock ball used for mounting an accelerometer under test shall be ground and have a surface roughness value (expressed as the arithmetical mean deviation) R_a, of less than 1 µm.

The flatness of the ground surface shall be such that the surface is constrained between two parallel planes at a distance apart of 5 µm.

The drilled and tapped holes for mounting an accelerometer under test and accessories shall have a perpendicularity tolerance to the surface of less than 0,5°.

The thread used for mounting an accelerometer shall be slightly loose fit, i.e. have class 2 tolerance (for example, 10-32 class 2).

4.3 Impact ball

An impact ball for exciting natural oscillations of an accelerometer under test shall also be made of steel hardened to more than HRC50 and polished.

NOTE A typical ball from a ball bearing is very convenient to answer this requirement.

The impact ball shall have a diameter from 8 times to 16 times smaller than the diameter of a shock ball.

For the typical diameter of the shock ball of 32 mm, a 4 mm or 2 mm impact ball will be suitable.

4.4 Signal analyser

For the purpose of this method, a signal analyser comprising a feature of a digital oscilloscope is recommended as a primary instrument.

For acquiring and analysing the signal of the natural oscillations of an accelerometer under test, a signal analyser having a data acquisition bandwidth higher than 3 times highest analysed frequency and an amplitude resolution not less than 16 bit shall be used.

NOTE The acquiring and analysing features can be shared among the digitizing equipment and personal computer.

4.5 Conditioning amplifier

A conditioning amplifier shall be used to provide the correct coupling frequency response during the acquisition of the signal of the accelerometer under test.

NOTE The correct coupling frequency response presumes the lower cut-off frequency of the measuring chain to be the same as for the working measurements of accelerometer under test.

At the same time, the conditioning amplifier should have a lower-pass filter to suppress undesirable high frequency signal of an accelerometer out of the range of interest during its test.

The conditioning amplifier should be used at a gain where signal clipping can be prevented as the accelerometer under test may have a 20 dB to 60 dB higher signal than at its reference frequency in the low frequency range.

4.6 Auxiliary devices and means

— A **vise** to fasten the reference shock ball during the mounting of the accelerometer under test.

— The silicon or other **oil** or **wax** to be put on the mounting surfaces of the accelerometer, including the mounting stud.

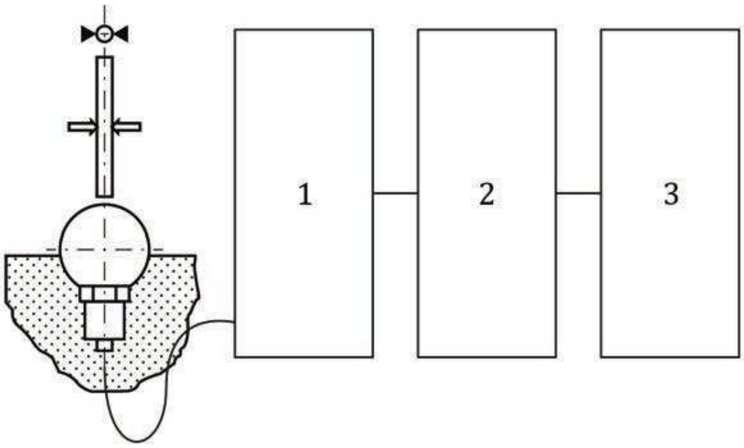
— A **pincer** to catch and a **release mechanism** to hold the impact ball.

— A **6 mm** and **4 mm guidance tubes** to guide the impact ball.

— A **stand** to hold the guidance tube.

— A **box** covered from the inner surface with packaging foam to mount the reference shock ball with the accelerometer under test and to catch the impact ball.

The general scheme of the apparatus and means to get the frequency and phase response of an accelerometer under test is shown in Figure 2.



Key

1 conditioning amplifier

2 dynamic signal analyser

3 recording instrument

Figure 2 — General scheme of the setup for testing the frequency and the phase response of an accelerometer by means of its shock excitation

5 Procedure

5.1 Assembling the structure under test

5.1.1 Mounting the accelerometer under test

Mounting the accelerometer under test shall be carried out under well-defined conditions in accordance with ISO 5348.

— Put the reference shock ball into the vise flat side up and fix it.

— Mount the accelerometer under test and its accessories on the reference shock ball according to the manufacturer’s recommendations.

NOTE For obtaining the best results, put a small amount of silicon or machine oil (grease) or wax on the flat surface of the shock ball and the accelerometer’s stud.

— Use the torque wrench to apply the specified torque to the accelerometer under test.

— Take off excess oil, grease or wax from the surface of the reference shock ball.

— Clean the sphere surface of the reference shock ball with some alcohol and let it get dry.

5.1.2 Mounting a reference shock ball

Attach the cable to the accelerometer under test according to the manufacturer’s recommendations.

Place the reference shock ball with an accelerometer under test in the box on the foam so that the sensing axis of the accelerometer is vertical and the accelerometer is beneath the shock ball. The foam shall have a small hollow to put the accelerometer in it.

If the accelerometer has a top cable connector, then there shall be a hole in the foam for the outlet of a connector and a cable. If the accelerometer has a side cable connector, then there shall be a horizontal groove in the foam for the outlet of a connector and a cable. The box should have windows on the side and on the bottom for the cable outlet.

The reference shock ball shall not touch any parts of the box or other structures except the foam.

The foam shall be thick and rigid enough to keep the weight of the shock ball together with the accelerometer under test but not more than really necessary.

NOTE Users are encouraged to try different types of packaging foam available for the most heavy shock ball.

The upper surface of the foam shall be flat or a little bit rounded to the edges to provide the impact ball to run approximately in the same place after each drop. Care should be taken to avoid bouncing of the impact ball from the elements of the box providing an adequate size of the foam surface. Care should be taken to avoid losing the impact ball in the box by sealing possible joints and holes on the surface of the foam.

The typical structure of the foam and the box for mounting the reference shock ball with the accelerometer under test is shown in Figure 3.

5.1.3 Mounting the guidance tube for the impact ball

Choose a guidance tube of an adequate diameter and length for the impact ball and put it as vertically as possible in the holder.

The diameter of the guidance tube should be 1,5 times to 3 times larger than the diameter of the shock ball. The larger ratio is typical for the smaller shock balls.

The length of the guidance tube shall provide an adequate output transient signal of the accelerometer under test with the peak value either equal to the specified upper limit of the accelerometer under test or to the upper acceleration of interest.

The first general rule for this method is that the peak value of the transient signal is proportional to the velocity of the impact ball. The velocity of the impact ball grows with the square root of the height of the guidance tube and is influenced by the friction of the impact ball on the walls of the guidance tube.

Move the box (or the holder) on the table so that the lower end of the guidance tube is over the top point of the reference shock ball.

Leave the space between the lower end of the guidance tube and the reference shock ball to be in the range from two to five diameters of the impact ball.

Check that the reflection of the open end of the guidance tube is on the top point of the shock ball.

The assembled setup ready for resonance testing with the installed reference shock ball, a guidance tube and impact balls is shown in Figure 3.

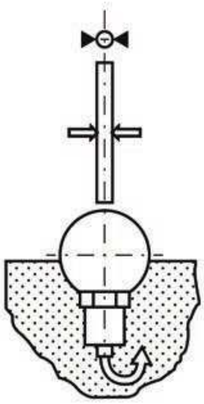


Figure 3 — Assembled setup ready for resonance testing

5.2 Connecting the instruments

Connect the output of the accelerometer under test to the input of the conditioning amplifier.

Select an adequate sensitivity of the conditioning amplifier for the accelerometer under test, so that the maximum value of the input signal is within a range 20 dB below the overload.

Select the upper limiting cut-off frequency of the conditioning amplifier to be at least two times higher than the supposed first resonance frequency of the accelerometer under test.

Connect the output of the conditioning amplifier to the input of a dynamic signal analyser.

NOTE For other types of accelerometers, their coupling devices can be connected to the constant current line drive source or to the direct input of the analyser.

5.3 Setting the signal analyser

5.3.1 Initializing the analyser

Activate the dynamic signal analyser for signal acquisition in the time domain.

5.3.2 Specifying the measurement parameters

Specify the window in the time domain; for example, choose

— windowed time channel, and

— exponential decaying type of the time window equal to 10 ms.

Specify the initial channel amplitude, frequency and time range.

Specify the triggering time delay for the pre trigger and averaging parameters, for example

— choose necessary slope in the trigger setup, depending on the polarity of initial part of the signal,

NOTE 1 Users are advised to be aware of the polarity of the signal from the accelerometer under test when the impact ball impacts the reference shock ball.

— use trigger level within ±10 % of the input range,

— set channel delay until necessary time delay appears, and

NOTE 2 Practically, from two times to five times sampling intervals of the negative delay are enough to see the initial part of the signal of the accelerometer under test (the "prehistory" of the signal).

— set the averaging parameters in the time domain (if necessary).

5.3.3 Configuring the display

Set linear mode for frequency axis, linear or logarithmic magnitude for amplitude axis, unwrapped phase mode and automatic auto scaling for all channels.

5.3.4 Configuring the markers

Set automatic marker setup to a peak mode, automatic calculating mode for frequency and damping for a single-degree-of-freedom system in terms of ISO 2041 (if applicable) and choose start and stop frequencies.

The number of the stop frequency for calculating mode for frequency and damping should be such that it covers the first resonance frequency of the accelerometer under test but does not exceed the second resonance frequency.

Users are encouraged to find their personal preferred settings for tests of the specified accelerometer. The settings mentioned above should be considered only as initial ones to start the test of the accelerometer.

5.4 Testing

Activate trigger setup of the dynamic signal analyser for single event signal acquisition in the time domain.

Pick up the impact ball with the pincers and let it drop through the centre of the guidance tube on the shock reference ball.

Watch the signal on the screen of the analyser. The signal shall have a small (one or two points) prehistory, the initial impulse and the evolving oscillations.

Adjust the trigger level and trigger delay setup to answer the above-mentioned requirement.

Check if the whole duration of the signal of the accelerometer under test fits the screen. If the record length is not enough to acquire the whole signal, then it should be increased.

Adjust the time decay parameter of the exponential window for time domain to be equal approximately 0,25 of the record length.

Adjust the channel range of the input signal so that the amplitude of the signal is within the dynamic range of the analyser but without an overloading.

To get the best measurement results in the frequency domain, it is recommended to change the trigger delay of the trigger setup from negative to positive so that the initial part of the signal of the accelerometer under test is omitted.

In this case, the shock pulse itself (its velocity component) is excluded from the output signal of the accelerometer. The drawback of this method is that in theory, there appears some phase shift in the phase response of the accelerometer under test.

Practically, omitting one or two initial oscillations of the signal of accelerometer would be enough to get a good initial part of the frequency response without significant distortion of the phase response.

6 Processing the results

6.1 Recording the time signal

A typical time record for an accelerometer under test is shown in Figure 4.

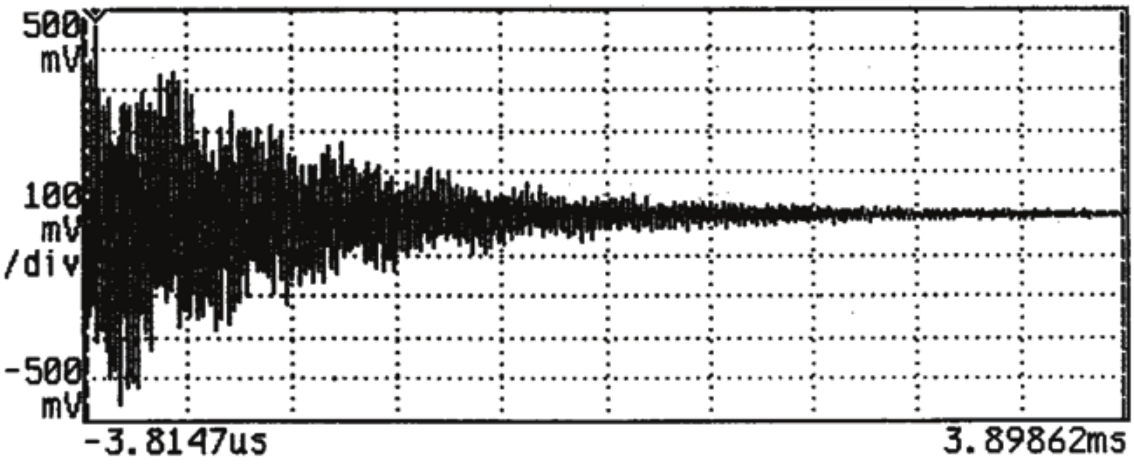


Figure 4 — Typical signal of a "ringing" accelerometer under test in the time domain

6.2 Processing the time signal

The adjustments stated in 5.3 generally make it possible to get all the necessary data for the frequency and phase responses of the accelerometer under test.

The procedure presumes that the following results shown in Figure 5 for the processed time signal are obtained in a frequency domain:

— the frequency response of the accelerometer under test in a linear or logarithmic mode with the markers at a flat part of the frequency response of the accelerometer under test and at its first peak value, indicating resonance frequency and damping factor for a single-degree-of-freedom system in terms of ISO 2041. The frequency response is displayed beginning from the minimum frequency for the frequency resolution inverse to the record length;

— the phase response of the accelerometer under test.

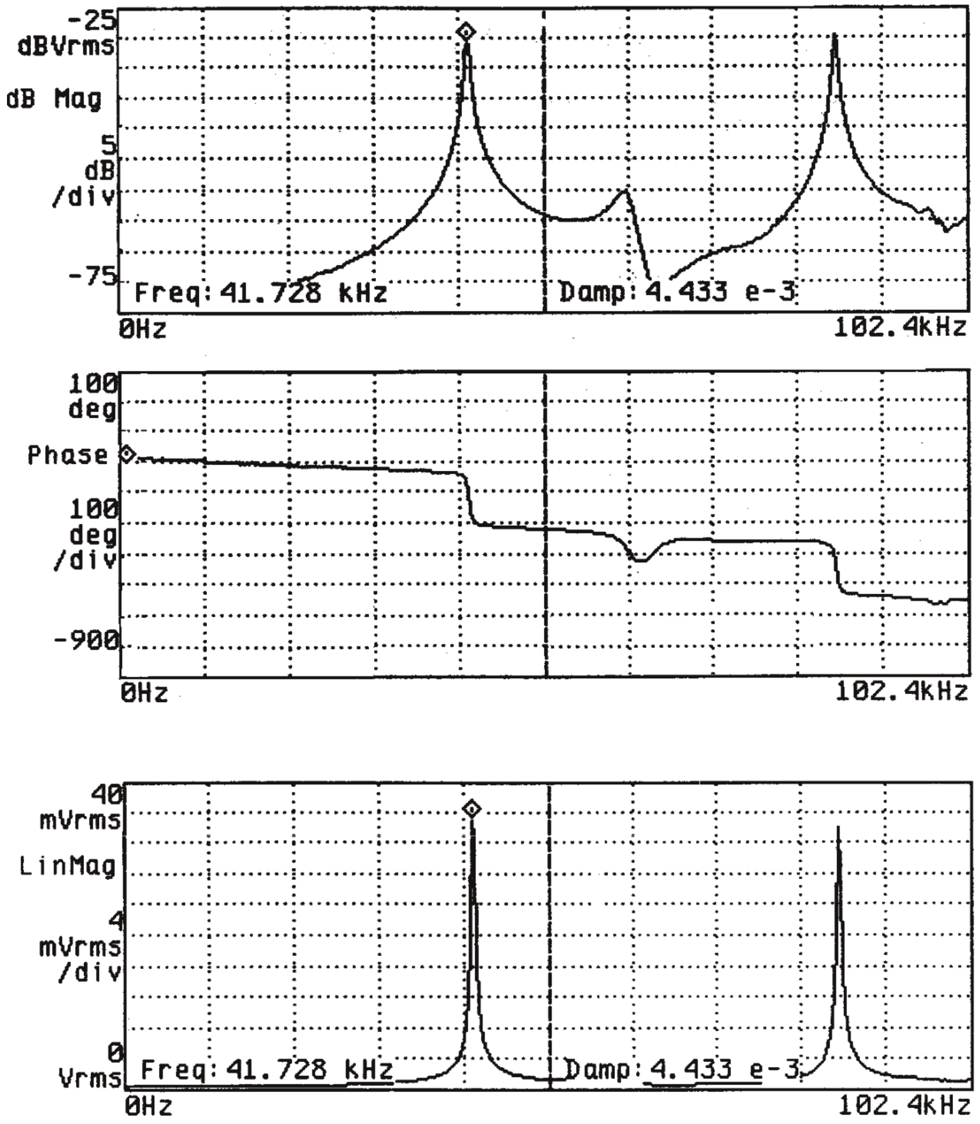


Figure 5 — Frequency and a phase response of accelerometer, measured by means of its shock excitation

NOTE A Q factor as a quantity characterizing the amplification of the accelerometer signal at resonance and equal to one-half of the reciprocal of the damping ratio (see ISO 2041) seems to be the most adequate characteristic for the purpose of this part of ISO 16063.

7 Reporting the results

7.1 Reporting the measurement results

When the measurement results are reported, in addition to the measurement method, at least the following conditions and characteristics shall be stated.

a) ambient air temperature;

b) mounting technique:

— mass and diameter of a reference shock ball;

— mounting torque (if the accelerometer is stud-mounted);

- — oil or grease (if used);

c) conditioning amplifier settings (if adjustable), for example:

- — gain;
- — cut-off frequencies of the filters;

d) measurement results:

- — mounted resonance frequency (see ISO 2041);
- — Q factor or damping ratio (see ISO 2041);
- — frequency response of the accelerometer under test;
- — phase response of the accelerometer.

ICS 17.160
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