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Mechanical vibration — Laboratory method for evaluating vehicle seat vibration —

Part 2:
Application to railway vehicles

Vibrations mécaniques — Méthode en laboratoire pour l'évaluation des vibrations du siège de véhicules —

Partie 2: Application aux véhicules ferroviaires

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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).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, 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 www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 108, *Mechanical vibration, shock and condition monitoring*, Subcommittee SC 4, *Human exposure to mechanical vibration and shock.*

This second edition cancels and replaces the first edition (ISO 10326-2:2001), which has been technically revised.

The main changes are as follows:

— propositions of new excitation signals to measure seat transmissibility: a lower level of narrowband vibration, and measured or reproduced real train stimuli to better consider the non-linearity of the human-seat system;

— propositions to calculate the SEAT "predicted" value from the measured seat transmissibility and real train stimuli.

Annex B gives an example to build an excitation signal for seat testing from a trains' vibration characteristics.

A list of all parts in the ISO 10326 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

Although the vibration felt by passengers in railway vehicles is always of low magnitude, the fact nevertheless remains that acceleration at the seat-buttock and seat-backrest interfaces can sometimes be greater than excitations transmitted by the vehicle frame. Consequently, the aim of laboratory tests to be carried out with railway seats is fundamentally to refine existing knowledge about their overall dynamic behaviour and that of their different components: seat frame, suspension system, linings, coverings, etc. In the long run, the knowledge should provide useful guidance in choosing the optimum components, and for improving passenger comfort further in the process.

Laboratory tests can be performed under clearly defined and reproducible excitation conditions, to complement studies carried out in the field. They consequently represent an essential study method complementary to the investigations performed in the field.

The vibration at the base of railway seats is of the random, broad-band type. The spectra, which are of complex form and non-stationary, depend on the vehicle itself, on its load, on wheel profile conditions, on track geometry and quality, etc. In this document, therefore, it is stipulated to excite the seat, occupied by a test person, by means of various types of excitation (such as pseudo-random; sinusoidal; and realistic, as discussed in Clause 11):

— A broad-band pseudo-random vibration successively in the three directions *X, Y* and *Z*. The vibration spectra are of sufficiently simple form and of sufficient magnitude to cover the majority of actual spectra observed on track, whilst nevertheless remaining quite different from the latter.

— Similar broad-band pseudo-random vibration in the three direction *X, Y* and *Z* simultaneously. It considers the cross-axis responses (response in a direction caused by an excitation in another direction), which represents a more realistic test condition. Also, it shortens the test duration.

— Investigations carried out under the effect of sinusoidal vibration can allow detection of possible non-linearities.

— If the seat vibration exposure is known, specific spectra and phase (either simulated or measured) can be used in the laboratory. This specific excitation can be successively used in the three directions *X, Y* and *Z* on the platform, or used simultaneously if the simulator has the abilities. The advantage of such stimuli is the representability of the actual response of the seat in its environment. As the seat and human are non-linear systems, having the right input excitation provides confidence in the measured output vibration of the seat interfaces.

Calculations, using broad-band pseudo random excitations, are, however, truly valid only on the assumption that the human-seat system considered is sufficiently linear. To check this assumption under laboratory conditions, this document stipulates an extra testing phase during which the seat is excited in a purely sinusoidal, high-amplitude mode at the different frequencies encountered during tests under random excitations, and corresponding to the peaks of the frequency response function. If the system shows non-linearity it is advised to used input spectra and phase representative of the vibration exciting the seat.

As a result, the magnitudes measured at the different response points of the human-seat system during laboratory tests, using broad-band pseudo random excitations, could under no circumstances be used for comparison with limits or acceptable values. By contrast, it is stipulated using the measurements to determine the frequency response function of the human-seat system at seat pan and backrest level in the three directions *X, Y* and *Z*. These frequency response functions suffice for characterizing the vibratory behaviour of the seat with its occupant. The directions of excitation, favourable or harmful frequencies, and corresponding gains are thus clearly demonstrated. These inputs are relevant to a comparison of seats with different construction arrangements.

The frequency range relevant to railway conditions is limited to 0,5 Hz to 50 Hz. Railway seats transmit vibration with frequencies lower than 0,5 Hz without amplification. However, vibration with frequencies of over 50 Hz, as sustained by seats in service, is generally of too small a magnitude to be felt by seated passengers. For suspension seats, ISO 10326-1 is recommended.

The discomfort for passengers of railway vehicles can be assessed using ISO 2631-4 or EN 12299.

Mechanical vibration — Laboratory method for evaluating vehicle seat vibration —

Part 2: Application to railway vehicles

1 Scope

This document defines specifications covering laboratory tests for seats designed for passengers and crew in railway tractive and trailer vehicles.

It concerns tri-axial rectilinear vibration within the frequency range 0,5 Hz to 50 Hz. It specifies the input test vibration to be used at seat testing.

This document makes it possible to characterize, in the form of frequency response functions, the manner in which vibration is transmitted to the seat occupant. It also provides an estimator showing the behaviour of the seat in terms of dynamic comfort perceived by the seated person.

Different types of excitations can be used and are described depending on knowledge of the vibration environment encountered by the seat and the capability of the vibration simulator.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

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

ISO 5347 (all parts), *Methods for the calibration of vibration and shock pick-ups*

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

ISO 8041-1, *Human response to vibration — Measuring instrumentation — Part 1: General purpose vibration meters*

ISO 10326-1:2016, *Mechanical vibration — Laboratory method for evaluating vehicle seat vibration — Part 1: Basic requirements*

ISO 13090-1, *Mechanical vibration and shock — Guidance on safety aspects of tests and experiments with people — Part 1: Exposure to whole-body mechanical vibration and repeated shock*

ISO 16063 (all parts), *Methods for the calibration of vibration and shock transducers*

3 Terms, definitions, symbols and abbreviated terms

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 2041 apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.2 Symbols and abbreviated terms

The following symbols and abbreviated terms are used in this document:

a_{rms} root-mean-square (rms) value of acceleration, m/s^2

a_W weighted root-mean-square value of acceleration (using frequency weighting described in ISO 2631-1), m/s^2

$W(f)$ appropriate frequency weighting for vibration discomfort (as described in ISO 2631-1)

$a(t)$ instantaneous value of an acceleration time history, m/s^2

$a(t,B_e,f)$ instantaneous value of the acceleration time history $a(t)$, filtered in the frequency range $(f - B_e/2)$ to $(f + B_e/2)$, m/s^2

$b(t)$ instantaneous value of an acceleration time history, m/s^2

$b(t,B_e,f)$ instantaneous value of the acceleration time history $b(t)$, filtered in the frequency range $(f - B_e/2)$ to $(f + B_e/2)$, m/s^2

$b'(t,B_e,f)$ instantaneous value of the acceleration time history $b(t)$, filtered in the frequency range $(f - B_e/2)$ to $(f + B_e/2)$, with phase shifted by $\pi/2$, m/s^2

B acceleration measuring point on the backrest of a seat occupied by a subject

B_e resolution bandwidth of a frequency analysis, Hz

$C_{ab}(f)$ real part of $G_{ab}(f)$, (m/s^2)^2/Hz

d displacement amplitude at a single frequency, m

f frequency, Hz

f_r frequency corresponding to a peak of the frequency response function, Hz

$G_{aa}(f)$ acceleration power auto spectral density function of the time history $a(t)$, being the mean-square value of acceleration per unit frequency bandwidth, (m/s^2)^2/Hz

$G_{ab}(f)$ cross power spectral density function of two acceleration time histories, $a(t)$ and $b(t)$, being a complex function, also called acceleration cross spectral density, (m/s^2)^2/Hz

$|G_{ab}(f)|$ modulus of $G_{ab}(f)$, (m/s^2)^2/Hz

$G_{bb}(f)$ acceleration power auto spectral density function of the time history b(t), being the mean-square value of acceleration per unit frequency bandwidth, (m/s^2)^2/Hz

$H(f)$ frequency response function, being a dimensionless complex function of frequency

P acceleration measuring point on the test platform

PSD power spectral density

$Q_{ab}(f)$ imaginary part of $G_{ab}(f)$, (m/s^2)^2/Hz

S acceleration measuring point on the seat pan of the seat occupied by a subject

t time, s

T	duration of signal measurement and analysis, s
T_R	transmissibility (dimensionless)
x, y and z	letters used in characterizing the direction of vibration at seat pan and backrest, points S and B
X, Y and Z	letters used in characterizing the direction of platform vibration at point P
$\gamma_{ab}^2(f)$	coherence function between the two accelerations $a(t)$ and $b(t)$, being a dimensionless function in the range 0 to 1
$\Theta_{ab}(f)$	phase of $G_{ab}(f)$, being a real function, rad

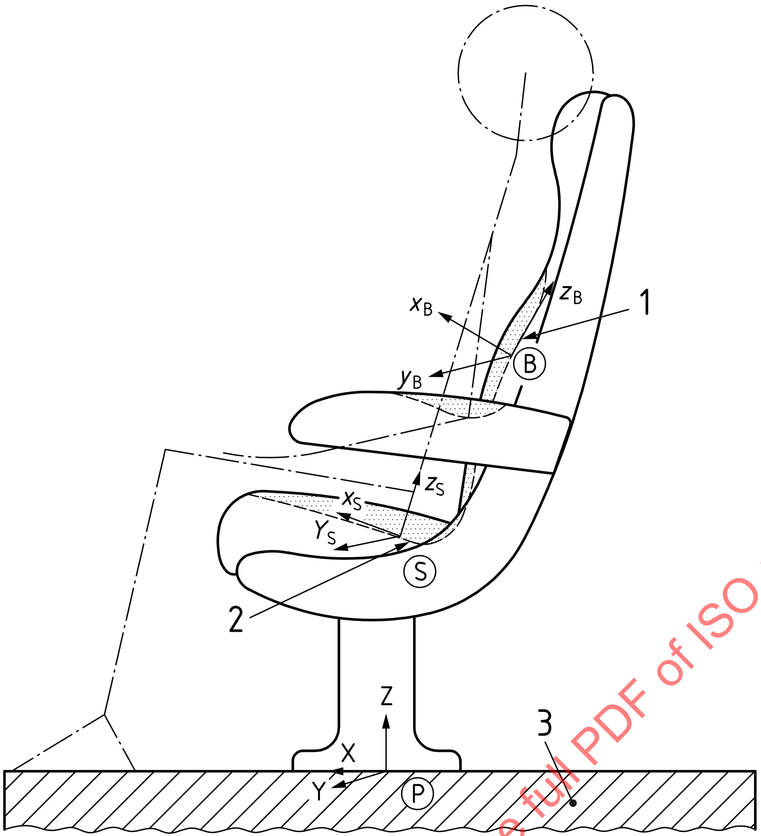
The following subscripts are used in this document:

i	direction of platform vibration, taking the values X, Y or Z
k	direction of vibration at points S or B, taking the values x, y or z
rms	root-mean-square value
s	subscript denoting that the results of three consecutive tests have been averaged
w	subscript characterizing a parameter calculated on the basis of frequency-weighted signals
α	subscript characterizing the location of an acceleration measuring point: S (seat pan) and B (backrest)

4 Direction of vibration

The coordinate axes X, Y and Z for the evaluation of human exposure to whole-body vibration in accordance with this document are defined in ISO 2631-1 by the orthogonal biodynamic coordinate system shown in Figure 1. For the purposes of this document, two such basicentric coordinate systems are used, with their origins at the interface at the buttocks and the seat cushion, and at the interface of the back of a seated person and the backrest of the seat. Their axes are approximately parallel to the axes shown in Figure 1.

The coordinate axes for describing rectilinear vibration of the vehicle are defined by an orthogonal coordinate system parallel to the principal axes of the vehicle. The X-axis is parallel to the longitudinal axis, the Y-axis parallel to the transverse axis and the Z-axis upwards perpendicular to the plane defined by the X and Y axes. The coordinate system for the description of the vehicle vibration is usually not parallel to the coordinate systems for the seat occupant because of practical reasons such as seat cushion angles or actual position of the seat with respect to the longitudinal axis of the vehicle.



Key

1 seat backrest

2 seat pan

3 platform

B output accelerations on the backrest

S output accelerations on the seat pan

P input accelerations from the vibrating platform

NOTE The arrows indicate the positive directions.

Figure 1 — Directions of vibration measurements

5 Characterization of vibration and of its transmission

5.1 Characterization of vibration

5.1.1 General

Three quantities shall be used to describe the vibration, root-mean-square acceleration, acceleration power spectral density and acceleration cross spectral density.

5.1.2 Root-mean-square acceleration, a_{rms}

The root-mean-square value of the acceleration signal, a_{rms}, shall be calculated by a method equivalent to that described by the following Formula (1):

$$a_{rms} = \left[\frac{1}{T} \int_0^T a^2(t) \mathrm{d}t \right]^{1/2} \quad (1)$$

5.1.3 Acceleration power auto spectral density, $G_{aa}(f)$

The acceleration power spectral density, $G_{aa}(f)$, shall be estimated by a method equivalent to that described by the following Formula (2):

$$G_{aa}(f)=\frac{1}{B_e\cdot T}\int_0^T a^2(t,B_e,f)\mathrm{d}t \tag{2}$$

5.1.4 Acceleration cross spectral density, $G_{ab}(f)$

This parameter is used for connecting two acceleration signals, one $a(t)$ or input acceleration for seat excitation, the other $b(t)$ or output acceleration response of human-seat system at a given interface point. The cross power spectral density, $G_{ab}(f)$, shall be estimated by a method equivalent to that described by the following Formula (3):

$$G_{ab}(f)=C_{ab}(f)-\mathrm{j}Q_{ab}(f)=|G_{ab}(f)|\mathrm{e}^{-\mathrm{j}\Theta_{ab}(f)} \tag{3}$$

where

$$C_{ab}(f)=\frac{1}{B_e\cdot T}\int_0^T a(t,B_e,f)\cdot b(t,B_e,f)\mathrm{d}t\,;$$

$$Q_{ab}(f)=\frac{1}{B_e\cdot T}\int_0^T a(t,B_e,f)\cdot b'(t,B_e,f)\mathrm{d}t\,;$$

$$|G_{ab}(f)|=\sqrt{C_{ab}^2(f)+Q_{ab}^2(f)}\,;$$

$$\Theta_{ab}(f)=\arctan\frac{Q_{ab}(f)}{C_{ab}(f)}$$

5.2 Characterization of vibration transmission

5.2.1 General

The following parameters shall be used to characterize the transmission of vibration from their input at the seat fastening point at the floor or platform, acceleration signal $a(t)$, up to their output at a human-seat interface point, acceleration signal $b(t)$.

5.2.2 Frequency response function, $H(f)$

This is a dimensionless complex function of frequency f. It shall be calculated by means of a method equivalent to that described by the following Formula (4):

$$H(f)=G_{ab}(f)/G_{aa}(f) \tag{4}$$

5.2.3 Coherence function, $\gamma_{ab}^2(f)$

This is a dimensionless real function of frequency f. It shall be calculated by means of a method equivalent to that described by the following Formula (5):

$$\gamma_{ab}^2(f)=\frac{|G_{ab}(f)|^2}{G_{aa}(f)\cdot G_{bb}(f)} \tag{5}$$

5.2.4 Transmissibility, T_R

This is a real, dimensionless value defined as the ratio of the root-mean-square acceleration measured at the human-seat interface, to the same value measured at the seat mounting plate (platform).

NOTE 1 The transmissibility is strongly dependent on the input vibration, in particular on its power spectral density function.

NOTE 2 For the transmissibility at the single (resonance) frequency of a seat, ISO 10326-1 uses the symbol, *T*.

5.2.5 Weighted transmissibility, T_{Rw} and SEAT factor

T_{Rw} is the transmissibility calculated on the basis of accelerations weighted according to ISO 2631-1. The frequency weighting curves and their tolerances shall be in accordance with ISO 8041-1.

The SEAT factor, defined in ISO 10326-1, indicates if dynamic comfort is improved or not by the seat behaviour. If SEAT > 1, the seat increases dynamic discomfort. If SEAT < 1, the seat attenuates uncomfortable vibration. SEAT predicts the vibration discomfort on a non-rigid seat relative to the vibration discomfort on a rigid seat in the same vibration environment, following Formulae (6) and (7):

$$\text{SEAT} = \frac{a_{wS}}{a_{wP}} \tag{6}$$

where

a_{wS} weighted root-mean-square value of acceleration measured on the seat pan;

a_{wP} weighted root-mean-square value of acceleration measured on the platform.

$$\text{SEAT}_{\text{measured}} = \left[\frac{\int_{0,5}^{50} W^2(f) \cdot G_{SS}(f) \mathrm{d}f}{\int_{0,5}^{50} W^2(f) \cdot G_{PP}(f) \mathrm{d}f} \right]^{1/2} \tag{7}$$

where

$G_{SS}(f)$ acceleration power auto spectral density function of the acceleration measured on the seat pan;

$G_{PP}(f)$ acceleration power auto spectral density function of the acceleration measured on the platform;

$W(f)$ appropriate frequency weighting for vibration discomfort (as described in ISO 2631-1).

A predicted SEAT value for a train seat can also be calculated from measurements of vibration in a train and measurements of seat transmissibility obtained using random vibration in a laboratory, using Formula (8):

$$\text{SEAT}_{\text{predicted}} = \frac{\left[\int_{0,5}^{50} G_{TT}(f) \left| H(f)^2 \right| W^2(f) \mathrm{d}f \right]^{1/2}}{\left[\int_{0,5}^{50} G_{TT}(f) W^2 \mathrm{d}f \right]^{1/2}} \tag{8}$$

where

$G_{TT}(f)$ acceleration power auto spectral density function of the acceleration measured on the trains' floor at the point of interest;

$W(f)$ appropriate frequency weighting for vibration discomfort (as described in ISO 2631-1);

H(*f*) frequency response function between the acceleration measured at the seat and the acceleration measured at the platform;

H(f) is the transfer function as defined in Formula (4) using the autospectral and crosspectral density defined in Formulae (2) and (3).

6 General observations

The laboratory testing method described in this document calls for the use of a test bench whereby, rectilinear vibration can be applied at the fastening points of a seat to be tested, with an occupant, in the directions *X*, *Y* and *Z*, either successively with a unidirectional test bench or simultaneously with a multi-axis test bench.

This document defines the method to be used in characterizing the vibration transmission from the base of the excited seat (point P in Figure 1) in a single or in multiple directions *X*, *Y* or *Z*, with up to two points located at the human-seat interfaces, one point (point S) on the seat pan, the other point (point B) on the backrest. At each of these two points, responses shall be measured simultaneously in the three directions *X*, *Y* and *Z*, and the corresponding frequency response functions, transmissibilities as well as weighted transmissibilities shall be calculated.

The input test vibration to be used at seat testing is specified in Clause 11.

7 Measurement positions

Nine accelerations shall be measured in accordance with the layout in Figure 1:

— three input accelerations on the vibrating platform, at point P;

— three output accelerations on the seat pan at point S;

— three output accelerations on the backrest at point B.

Point P shall be located on the platform less than 100 mm away from the vertical projection of point S.

8 Instrumentation

The measuring equipment shall be in accordance with ISO 10326-1:2016, Clause 4 and Clause 5, and instrumentation in accordance with ISO 8041-1.

For measurement at point S, at the seat pan, a thin semi-rigid mounting disc containing accelerometers, as defined in ISO 10326-1:2016, 4.2.3, shall be located along the centre-line of the seat pan at the interface with the occupant's buttocks (between the ischial tuberosities). The shape of the seat pan and its material shall be capable of adapting to the morphology of the occupant, so as not to cause any discomfort to the latter. The seat pan shall incorporate at point S a semi-rigid mounting disc for simultaneously measuring accelerations along the three orthogonal axes X_S, Y_S and Z_S as given in Figure 1.

For measurement at point B, on the backrest, the semi-rigid mounting disc shall be located along the center-line of the backrest, at the highest contact point between the back of the subject and the seat backrest. For practical reasons, it is usually not possible perfectly align the accelerometers in the disc with the axes of motion of the platform. In a tolerance range within 15° of the appropriate axes, the accelerometers may be considered as aligned parallel to the axes of interest. For deviations greater than 15°, acceleration should be measured along two axes and the acceleration vector sum along the axis of interest should be calculated.

9 Safety requirements

The safety precautions given in ISO 13090-1 shall be followed.

10 Test seats and test persons

10.1 Test seats

The seat used for the test shall be representative of the serial production models. If required, and in accordance with indications provided by the seat manufacturer, the seat may be run-in before testing and shall be adjusted to the stature and mass of the subject if means are provided for either of these.

When the seat incorporates fastening devices to the vehicle, it shall be fastened to the test platform by means of these devices, so as to ensure that the influence of stiffness and damping characteristics of the fasteners will be included in the test.

When the seat does not incorporate such fastening devices, it shall be fastened to the test platform in a safe and sufficient manner.

When the seat has a built-in position adjusting device, the normal position defined as being that used in service most frequently by the occupant shall be laboratory-tested. If more seat positions seem relevant, it is recommended to conduct the test with the test persons adopting the corresponding postures.

When the seat has a built-in position adjusting device, the normal position defined as being that used in service most frequently by the occupant shall be laboratory-tested. If more seat positions seem relevant, it is recommended to conduct the test with the test persons adopting the corresponding postures.

Preliminary running-in shall be carried out in laboratory. To this end, an inert mass of 75 kg + 750 g shall be placed on the seat pan at the spot defined in 10.2. The seat shall be subjected, for 2 h, to sinusoidal vertical excitation with a frequency equal to the lowest among the resonance frequencies of this system. Their amplitude shall be adjusted to obtain a rms acceleration of the mass of 3 m/s^2.

10.2 Test persons

Testing one person at a time, a minimum of two different persons should be used to test a seat, even if the seat is a multi-occupant seat design. It is advised to test the seat with more persons representative of the population in terms of size and height.

Before the test, the test person shall find a position which he/she can maintain throughout the test. In the particular case of a driver's seat, the test person shall take the normal posture for his/her work station. For passengers' seats offering various positions through seat pan or backrest inclinations, it is recommended to test more than one posture. Depending on the range of possible positions, 2 or 3 postures can be evaluated, for example: “normal upright”, “fully inclined backward” and when available “inclined forward”.

The feet of the test person shall rest flat on the platform or, on a rigid device if the seat has an adjustable footrest. The test person’s back shall naturally rest against the backrest with the elbows resting on the armrest, when the seat is so equipped, and the hands resting flat on the thighs.

In the specific case of a multi-seat unit, the test person shall position himself/herself at the place where vertical seat pan accelerations under vertical excitation have the highest root-mean-square value. This place shall be determined by preliminary tests.

The test person shall have occupied the seat for a sufficiently long time before the start of the testing. This shall ensure deformation and possible time-related yield or creep of the seat pan materials as well as stabilization of the temperature of seat pan and backrest accelerometers. A period of some 10 min is frequently necessary for this purpose.

A minimum of two test persons shall be used successively. The lighter person should be between 52,25 kg and 55 kg and the heavier person between 90 kg and 94,5 kg. In order to meet these mass requirements, the mass of each test person may be increased by as much as 10 % by ballast carried in a belt around the waist. It is advised to use more persons in different morphologic groups, representative of the future users of the seat.

NOTE To measure the posture of the subjects in the seat, the guidelines indicated in ISO/TR 10687 can be used.

11 Input test vibration

11.1 General

The dynamic behaviour of the human-seat system under test can be studied under the effect of two types of vibration excitation:

— broad-band pseudo-random vibration of specific amplitude. It can be either unidirectional or multidirectional (*X*, *Y*, *Z*) excitation. It shall also be investigated under the effect of sinusoidal vibration in order for possible non-linearities to be detected.

— realistic vibration that can be measured or simulated, representing the excitation spectra, magnitude and phase of the future seat environment. It can be either unidirectional or multidirectional (*X, Y, Z*) excitation.

Either broadband pseudo-random vibration or more realistic vibrations can be used as input test vibration.

11.2 Pseudo-random excitation

11.2.1 Generation of the excitation signal

The excitation signal of the vibrating table shall be of the pseudo-random type.

This type of excitation prevents any spectral leakage in the analysis. The spectrum can easily be shaped so as to excite only those frequencies in the frequency range of interest. In particular, it can be used to compensate for the frequency response of the test facility and so provide a flat spectrum within the frequency range of interest, as required by Formula (9) and Formula (10). Moreover, the evaluation can be performed by averaging the results of a small number of sequences. The excitation signal shall be formed by 18 consecutive equally long sequences, each lasting 5 s or more, depending on the frequency resolution; 5 s is the minimum time to satisfy the requirement for a resolution bandwidth of 0,2 Hz. The total duration of an excitation shall therefore be at least 18 × 5 s = 90 s.

The time history of each sequence of the excitation signal shall be formed by a sum of pure sinusoidal components, the number of which depends on the frequency resolution. The amplitude of each component shall follow from the power spectral density given by Formula (9) and Formula (10). The phase of each component shall be a random variable comprised between 0 and 2π with uniform density probability.

Annex A shows, by way of example, a detailed flowchart of the control signal generating process.

As a simpler alternative, using a random number generator, pseudo-random excitation can also be generated as described in 11.2.5.

11.2.2 Power auto spectral density

The power auto spectral density of the excitation generating the accelerations for each of the directions *X*, *Y* and *Z* shall be as defined by the following equations in the frequency range 0,5 Hz to 50 Hz.

$$G_{aa}(f) = 0{,}05 f^4 \,(\mathrm{m/s^2})^2/\mathrm{Hz^5} \text{ for } f < 1\,\mathrm{Hz} \tag{9}$$

$$G_{aa}(f) = 0{,}05 \,(\mathrm{m/s^2})^2/\mathrm{Hz} = \text{const} \text{ for } 1\,\mathrm{Hz} \le f \le 50\,\mathrm{Hz} \tag{10}$$

The resolution bandwidth shall be 0,2 Hz or less.

11.2.3 Root-mean-square acceleration

The value of the root-mean-square acceleration in the frequency range 0,5 Hz to 50 Hz shall be 0,8 m/s^2.

11.2.4 Tolerances

When performing the tests, the tolerances to be observed for the power spectral density of accelerations measured on the vibrating table at point P shall be at maximum ±20 % of the prescribed value at each frequency over the whole frequency range 0,5 Hz to 50 Hz. The tolerance to be met is ±0,16 m/s^2 of the root-mean-square value.

11.2.5 Multi-axis excitation

If the test bench allows using three-axis (or more) excitation simultaneously, such vibration can also be used to measure the seat transmissibility. Pseudo-random vibration can be generated according to 11.2.1 or by using a random number generator to produce independent 90 s random vibration excitation in each of the three axes of excitation. To obtain the same power spectral density described in 11.2.2, high-pass and low-pass filtering and equalisation to the response of the simulator in each axis should be performed:

— Cut off frequencies of the low and high pass filters should be respectively 0,5 Hz and 50 Hz.

— Equalisation should provide a root-mean-square acceleration in the frequency range 0,5 Hz to 50 Hz of 0,8 m/s^2 for each axis.

— Tolerances for the root-mean-square value of the excitation measured on the simulator (point P) shall be ±0,16 m/s^2. Tolerances at each frequency of the power spectrum density should be ±20 % of the prescribed value.

Three incoherent random excitations can therefore be generated in *X*, *Y* and *Z* direction and used at the same time.

11.3 Sinusoidal excitation

The seat shall also be excited under pure sinusoidal conditions, at those frequencies for which the moduli of the frequency response functions, determined during the tests under pseudo-random excitation, go through maximum values.

Failing this, the seat shall be excited at the frequencies 1,5 Hz and 10 Hz.

Two amplitudes of acceleration shall be used successively: (0,5 ± 0,1) m/s^2 and (1 ± 0,1) m/s^2 (peak to peak).

Annex A shows, by way of example, a detailed flowchart of the control signal generating process.

11.4 Realistic excitation representing the dynamic environment of the tested seat

For a more realistic response of the seat, it is advised to use a more representative excitation. Compared to a pseudo-random excitation, a realistic magnitude and spectrum provide a dynamic response of the seat that considers its non-linear behaviour and determine which resonances are to be excited.

Realistic excitations measured or simulated in the three directions (X, Y, Z) on the floor of the train may be used as inputs for the test bench. Measured acceleration signals should be high and low pass filtered with cut-off frequencies respectively at 0,5 Hz and 50 Hz and equalized to consider the frequency response of the test bench.

To get better coherence in the measured seat transmissibility, a second process is proposed and can be used:

— Generate an independent 90 s random vibration excitation in each of the three axes of excitation with a random number generator;

— Filter the random signal generated with a filter designed from the realistic acceleration (measured or simulated) using the method described in Annex B;

— Equalize the signal to consider the frequency response of the test bench to reach the desired root mean square acceleration.

Unidirectional excitation can be used. If the test bench has the abilities, multi-axis excitation is preferred.

12 Parameters adopted for characterizing the vibration transmission

12.1 Pseudo-random and realistic excitations

For either pseudo-random or more realistic excitations (unidirectional or multi-axis), the same criteria should be calculated to describe the dynamic behaviour of the tested seat.

For each of the measuring points S and B, the following parameters characterizing the transmission of the vibration shall be determined:

— the frequency response function $H(f)_{\alpha ik}$ (shall be given in modulus and phase every 0,2 Hz or less, from 0,5 Hz to 50 Hz);

— the coherence function $\gamma^2(f)_{\alpha ik}$;

— the transmissibility $T_{\mathrm{R}\alpha ik}$; and

— the weighted transmissibility $T_{\mathrm{Rw}\alpha ik}$ and the SEAT value (measured or predicted).

It may occur that the coherence function values associated with some frequency response functions are relatively low. This is generally the case when the seat response accelerations as measured in a direction differing from that of the vibrating table excitation are occasionally quite weak. In the case of frequencies where the coherence associated with a frequency response function is less than 0,6, the value adopted for the frequency response function shall be nil. The calculated value, modulus and phase, however, shall be reported in the test results.

12.2 Sinusoidal excitation

For each value f_r of the frequency which, under pseudo-random excitation, produced a well-pronounced peak in the $H(f)$ modulus graph, two new values shall be calculated for the frequency response function modulus $H(f_\mathrm{r})_{\alpha ik}$ under sinusoidal excitations with amplitudes of 0,5 m/s^2 and 1 m/s^2 respectively.

The difference between these two values of the frequency response function modulus $H(f_\mathrm{r})$ shall be calculated. This difference shall be expressed as a percentage of the higher value.

A difference in excess of 30 % can be held as signifying non-linear behaviour for the frequency concerned and for the response and excitation directions involved.

13 Test procedure

13.1 Initial procedure

The seat shall be mounted on the test platform, run-in and adapted to the test person. The inclination of the seat transducers shall be adjusted to coincide with the directions given in Figure 1.

The components of the measuring chain shall be selected, placed into position and connected. Accelerometers shall be calibrated in accordance with the specifications given in the relative parts of ISO 5347 and ISO 16063, and shall be mounted, especially at point P, in accordance with the recommendations given in ISO 5348.

13.2 Tests under pseudo-random and realistic excitations

The first test person shall position himself/herself on the seat. The following procedure should be repeated for each seat position to be evaluated.

The tests shall be carried out under *X*, *Y* and *Z* directions of excitation, either successively or simultaneously.

The excitation for a given direction shall be in conformity with the specifications given in Clause 11. The corresponding test shall last 90 s at a minimum. Each test shall be repeated until the moduli of the frequency response functions from three consecutive tests do not differ more than ±5 % of their arithmetic mean over the whole frequency range 0,5 Hz to 50 Hz. The frequency response functions, coherence functions and transmissibilities averaged over these three tests constitute the final results and shall be expressed in the form $H_s(f)_{\alpha ik}$, $\gamma_s^2(f)_{\alpha ik}$ and $T_{Rs\alpha ik}$.

The second test person and the potential following persons shall position themselves on the seat and a new test series shall be carried out in accordance with the specifications described above.

13.3 Tests under sinusoidal excitation

The sinusoidal excitations in accordance with 11.3 shall be applied.

Each test shall be repeated until the moduli of the frequency response functions from three consecutive tests do not differ more than ±5 % of their arithmetic mean. The mean values obtained constitute the final results and shall be expressed as frequency response function modulus $H_s(f_r)_{\alpha ik}$.

If the test showed non-linear behaviour of the seat-person system, it is recommended to use more realistic excitation signals, as described in 11.4, than pseudo-random vibration.

14 Test report

14.1 Seat

The devices for mounting the seat and fastening it to the test platform shall be accurately described. The measuring points on the seat pan and the backrest shall be stated in detail.

An indication of the state of the seat, basically if its new or used in transport should be described, as test results may depend on the age of the seat and its maintenance.

14.2 Test persons

The mass, height, gender and age of each of the two subjects shall be indicated.

The place occupied during tests shall be reported in the case when a multi-seat unit is used.

The position of the seat should also be described (upward, backrest fully inclined backward, backrest frontward).

14.3 Measuring chain

The measuring chain shall be described in accordance with the requirements given in ISO 10326-1.

14.4 Results

The test results shall be presented in accordance with the following specifications.

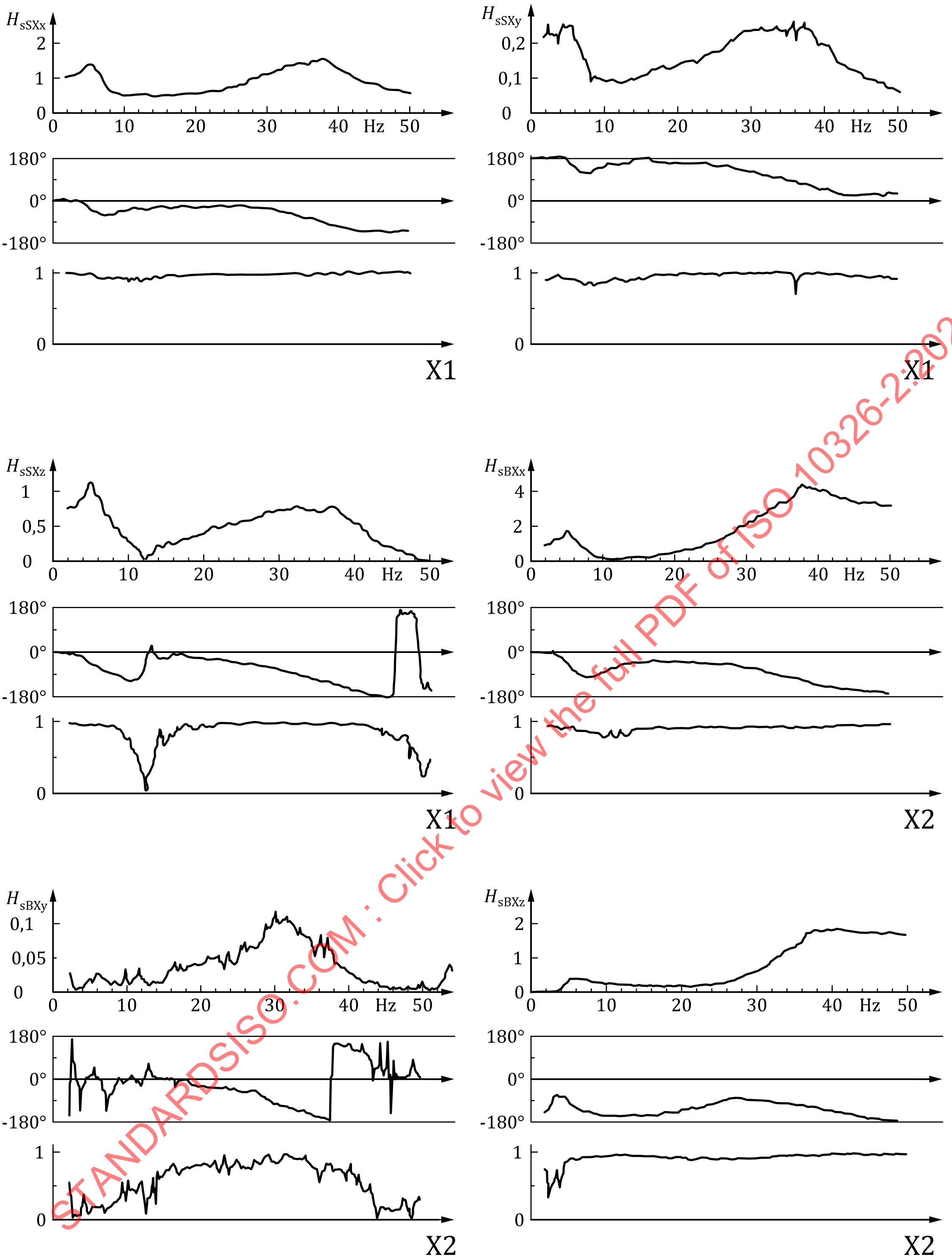
The results of tests under pseudo-random excitation shall be presented in numerical and graphic form.

Each frequency response function modulus, frequency response function phase and coherence function shall be described by a set of values, each of which being associated with a frequency varying between 0,5 Hz and 50 Hz by steps of 0,2 Hz or less.

The graphs shall be presented in accordance with Figure 2.

The transmissibility and SEAT values shall be reported as well as the root-mean-square acceleration values used for calculating them.

The results of tests under sinusoidal excitation shall be presented in accordance with Table 1.



Key

X1	point S	First graph of each subfigure	frequency response modulus
X2	point B	Second graph of each subfigure	frequency response phase
		Third graph of each subfigure	coherence function

Longitudinal pseudo-random excitation (X-direction)

Test person No. 1 Mass: 55 kg Height: 1,66 m Gender: female Age: 32 years

Figure 2 — Results from testing under pseudo-random excitation (general example)

Table 1 — Results from testing under sinusoidal excitation (general example)

Frequency response modulus at frequency f_r (which results from testing under pseudo-random excitation) [a]		
	5 Hz	36 Hz
H_{sSXx}		
With sinusoidal excitation amplitude 0,5 m/s^2	1,38	1,59
With sinusoidal excitation amplitude 1 m/s^2	1,07	1,55
Difference as percentage of the highest value, %	22	3
H_{sSXy}		
With sinusoidal excitation amplitude 0,5 m/s^2	0,24	0,25
With sinusoidal excitation amplitude 1 m/s^2	0,23	0,21
Difference as percentage of the highest value, %	4	16
H_{sSXz}		
With sinusoidal excitation amplitude 0,5 m/s^2	1,13	0,78
With sinusoidal excitation amplitude 1 m/s^2	1,04	0,67
Difference as percentage of the highest value, %	8	14
H_{sBXx}		
With sinusoidal excitation amplitude 0,5 m/s^2	2,02	4,64
With sinusoidal excitation amplitude 1 m/s^2	2,39	4,84
Difference as percentage of the highest value, %	15	4
H_{sBXy}		
With sinusoidal excitation amplitude 0,5 m/s^2	0,055	0,12
With sinusoidal excitation amplitude 1 m/s^2	0,050	0,13
Difference as percentage of the highest value, %	9	8
H_{sBXz}		
With sinusoidal excitation amplitude 0,5 m/s^2	0,53	1,78
With sinusoidal excitation amplitude 1 m/s^2	0,46	1,99
Difference as percentage of the highest value, %	13	11
[a] Longitudinal sinusoidal excitation (X-direction).		
Test person No. 1 Mass: 55 kg Height: 1,66 m Gender: female Age: 32 years		

Annex A
(informative)

Example of excitation generating process

A.1 General

This annex gives examples of the methods that may be used in generating command signals to the test-machine actuators.

The following two excitation methods are used:

— pseudo-random excitation;

— sinusoidal excitation at only those resonance frequencies which appear during tests with pseudo-random excitation.

A.2 Pseudo-random excitation

This excitation shall be the sum of pure, randomly phase-shifted sinusoidal excitations.

If the resolution bandwidth B_e is 0,2 Hz, the excitation may cover the frequency range 0,4 Hz to 50 Hz.

The excitation spectrum is therefore made up of (50 Hz - 0,4 Hz)/0,2 Hz + 1 = 249 lines.

This document defines the excitation by its acceleration power spectral density $G_{aa}(f)$, see 11.2.

A displacement signal is generally used to control the test machine. If in the amplitude spectrum of this displacement (with frequency resolution B_e) the line at frequency f has a displacement amplitude d, then the corresponding acceleration power spectral density, $G_{aa}(f)$, has the following value, as shown in Formula (A.1):

$$G_{aa}(f) = d^2 8\pi^4 f^4 / B_e \tag{A.1}$$

Consequently, d follows from Formula (A.2):

$$d = \frac{\sqrt{2\ B_e\ G_{aa}(f)}}{4\ \pi^2\ f^2} \tag{A.2}$$

where $G_{aa}(f)$ is as given by Formula (9) and Formula (10).

The test may be performed on the basis of the flowchart shown in Figure A.1.

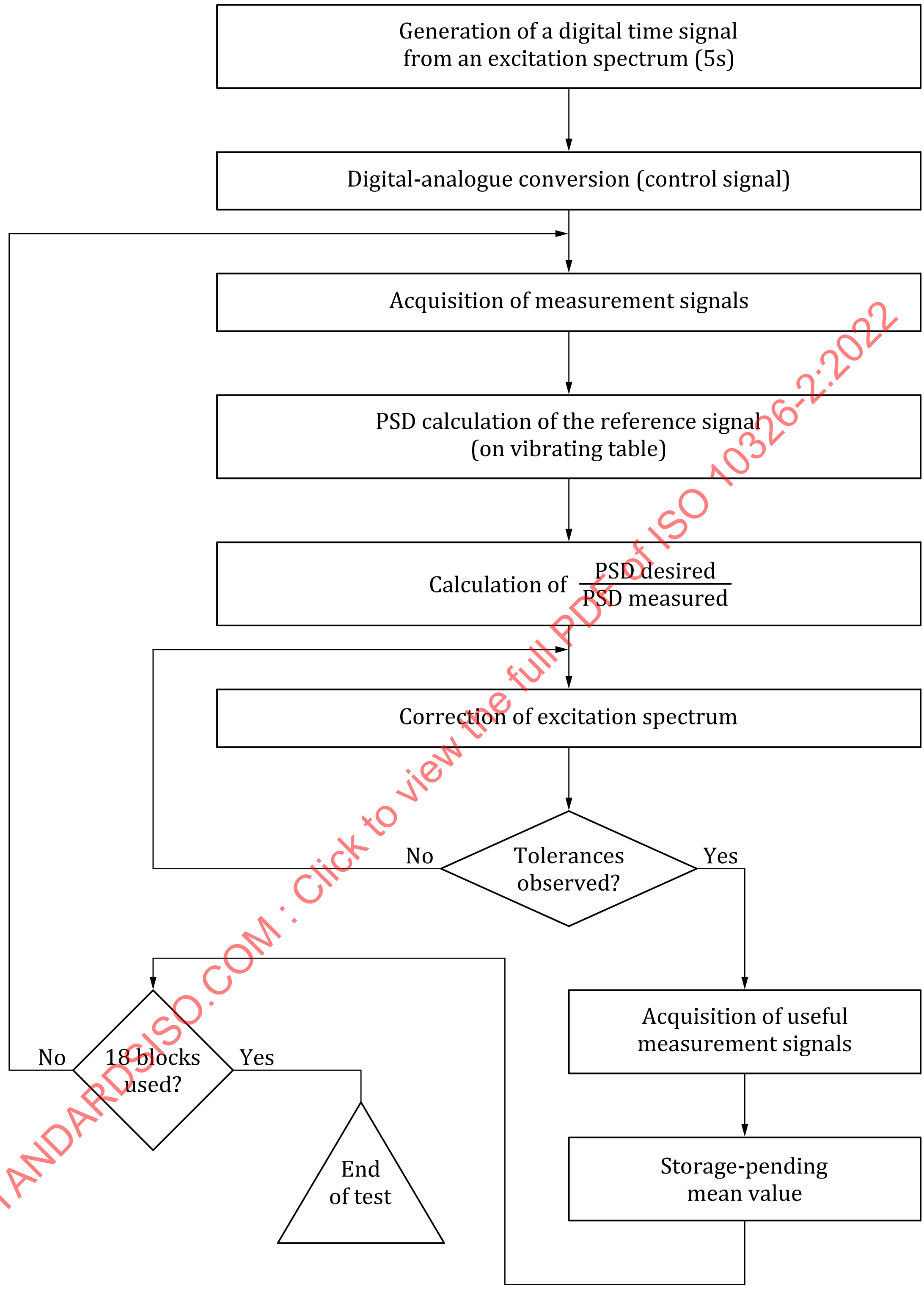


Figure A.1 — Flowchart for test procedure with pseudo-random excitation

A.3 Sinusoidal excitation

Each test may be carried out according to the flowchart shown in Figure A.2.

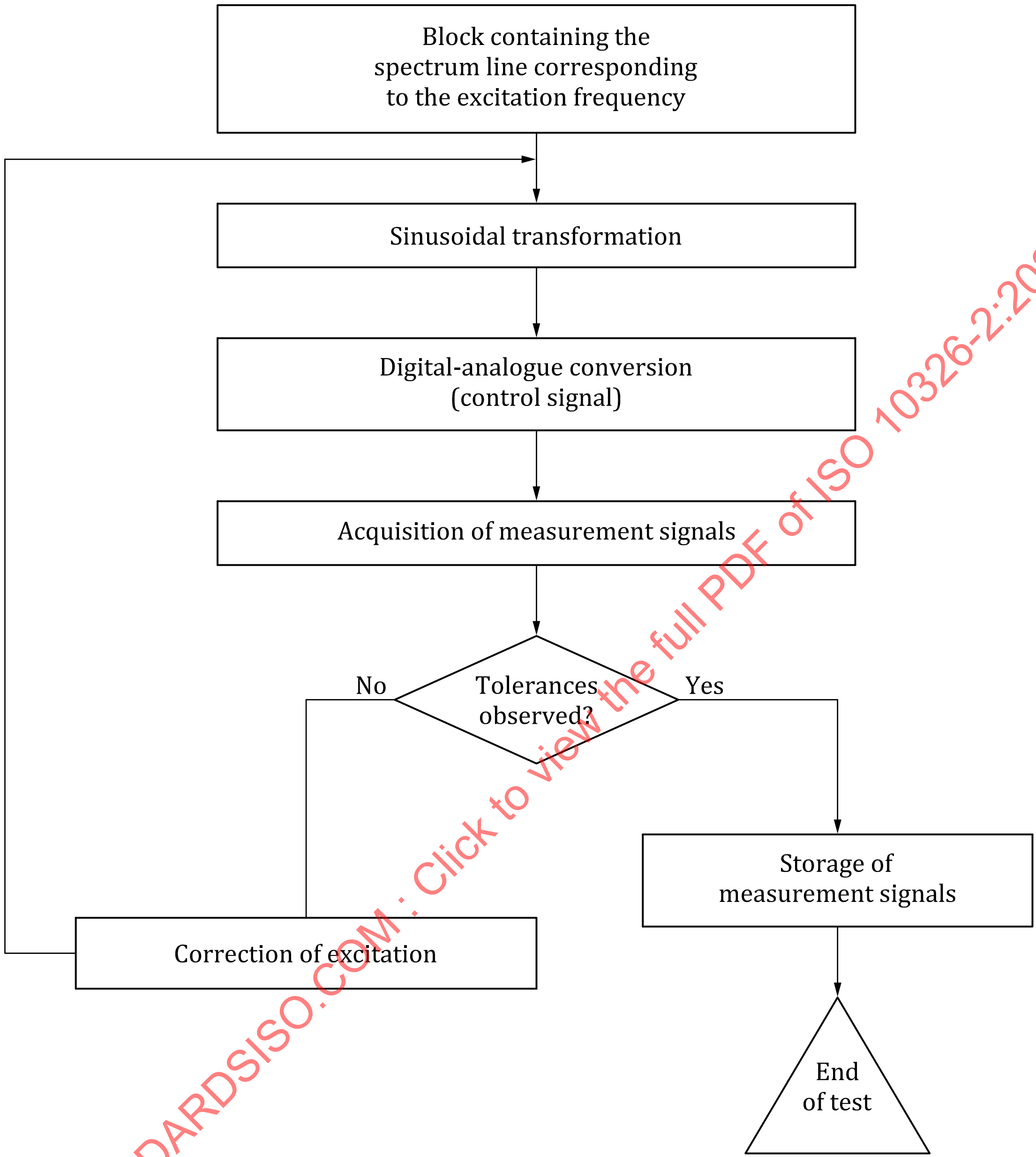


Figure A.2 — Flowchart for test procedure with sinusoidal excitation

Annex B
(informative)

Realistic vibration excitation for seat testing

B.1 General

This annex describes a method to generate excitation signals to perform seat testing from measured or simulated train floor excitation.

Because the seat-person system may be highly nonlinear, the transmissibility and SEAT values obtained may depend on the excitation signal used. To obtain representative results, it is recommended to use more realistic excitations.

The vibration encountered by the seat depends on many parameters: type of trains, speed, quality of the tracks. If measurement or simulation of the train's floor acceleration are known in the three directions, *X*, *Y* and *Z*, they can be used to generate excitation inputs for the test bench.

The relevant train's floor accelerations measured or simulated can be used as excitation signals. If used in a direct approach, acceleration should be high and low passed filtered at 0,5 Hz and 50 Hz respectively and calibrated to consider the frequency response of the test bench (see Figure B.1).

This annex proposes another method to generate excitation signals, which provides better coherency in the seat transmissibility. This method includes the design of filters following the spectrum of the train's floor acceleration.

B.2 Design filters from the measured or simulated train floor acceleration

Once the relevant train's floor accelerations are provided in the three directions *X*, *Y* and *Z* from measurements or simulations, filters can be designed from their spectrum. A random signal can be generated and filtered with the designed filter so the spectrum on the measured acceleration and the filterd random signal have the same spectrum. Using the filtered signal as an excitation input for the simulator will allow better coherency for the seat transmissibility.

The various steps are described below and illustrated with the corresponding Matlab code applied to a measured train floor acceleration.

Measured accelerations

Figure B.1 shows the bandpass-filtered time-domain acceleration in the *X*-, *Y*- and *Z*-axes.

Corresponding Matlab code:

```
load('AccData');%load the measured data file

accX = floor_acceleration_X;
accY = floor_acceleration_Y;
accZ = floor_acceleration_Z;

fs = 400; %sampling rate used for data acquisition

%bandpass filtering at 0,5 Hz (High Pass) and at 50 Hz (Low Pass)
[accXf] = bandpass(accX,[0.5 50],fs);
[accYf] = bandpass(accY,[0.5 50],fs);
[accZf] = bandpass(accZ,[0.5 50],fs);

l=length(accXf);
t=linspace(0,90,l);

figure(1)
subplot(3,1,1)
plot(t,accXf)
ylabel('X-axis')
title('Bandpass filtered measured acceleration [m.s-2]')

subplot(3,1,2)
plot(t,accYf)
ylabel('Y-axis')

subplot(3,1,3)
plot(t,accZf)
xlabel('Time [s]')
ylabel('Z-axis')
```