INTERNATIONAL STANDARD

ISO 10056

First edition
2001-08-15

Mechanical vibration — Measurement and analysis of whole-body vibration to which passengers and crew are exposed in railway vehicles

Vibrations mécaniques — Mesurage et analyse des vibrations globales du corps auxquelles sont exposés les passagers et le personnel de bord dans les véhicules ferroviaires

Reference number
ISO 10056:2001(E)

PDF disclaimer

This PDF file may contain embedded typefaces. In accordance with Adobe's licensing policy, this file may be printed or viewed but shall not be edited unless the typefaces which are embedded are licensed to and installed on the computer performing the editing. In downloading this file, parties accept therein the responsibility of not infringing Adobe's licensing policy. The ISO Central Secretariat accepts no liability in this area.

Adobe is a trademark of Adobe Systems Incorporated.

Details of the software products used to create this PDF file can be found in the General Info relative to the file; the PDF-creation parameters were optimized for printing. Every care has been taken to ensure that the file is suitable for use by ISO member bodies. In the unlikely event that a problem relating to it is found, please inform the Central Secretariat at the address given below.

ISO copyright office
Case postale 56 • CH-1211 Geneva 20
Tel. + 41 22 749 01 11
Fax + 41 22 749 09 47
E-mail copyright@iso.ch
Web www.iso.ch

Printed in Switzerland

Contents

Page

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.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 3.

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.

Attention is drawn to the possibility that some of the elements of this International Standard may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

International Standard ISO 10056 was prepared by Technical Committee ISO/TC 108, *Mechanical vibration and shock*, Subcommittee SC 2, *Measurement and evaluation of mechanical vibration and shock as applied to machines, vehicles and structures*.

Annex A of this International Standard is for information only.

Introduction

This International Standard specifies a method which can be applied to the railway environment for the measurement and analysis of vibration, bearing in mind that mechanical vibration in a railway vehicle has specific characteristics.

It supplements ISO 2631-1 which deals in a general way with all the situations encountered by man in his day-to-day activities (work, travel, etc.), and describes measurement of whole-body vibration and its effects.

Mechanical vibration — Measurement and analysis of whole-body vibration to which passengers and crew are exposed in railway vehicles

1 Scope

This International Standard defines a method for measuring and analysing the mechanical vibration of railway vehicles during field tests. It deals with periodic, random and transient vibration over the range of frequencies from 0,5 Hz to 80 Hz which are transmitted to the whole human body. This International Standard covers standing and seating positions only.

This International Standard is not applicable to vibration transmitted to the hand-arm system, nor to very-low-frequency lateral, vertical or rotational motion which may be associated with kinetosis (motion sickness). This International Standard does not propose methods for assessing the effects of vibration. This is covered by ISO 2631-1 and, for fixed guideway transport systems, by ISO 2631-4.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this International Standard. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of ISO and IEC maintain registers of currently valid International Standards.

ISO 2041, *Vibration and shock — Vocabulary.*

ISO 2631-1, *Mechanical vibration and shock — Evaluation of human exposure to whole-body vibration — Part 1: General requirements.*

ISO 2631-4, *Mechanical vibration and shock — Evaluation of human exposure to whole-body vibration — Part 4: Guidelines for the evaluation of the effects of vibration and rotational motion on passenger and crew comfort in fixed-guideway transport systems.*

ISO 8002, *Mechanical vibrations — Land vehicles — Method for reporting measured data.*

ISO 10326-2, *Mechanical vibration — Laboratory method for evaluating vehicle seat vibration — Part 2: Application to railway vehicles.*

3 Terms, definitions, symbols and abbreviated terms

3.1 Terms and definitions

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

3.2 Symbols and abbreviated terms

In this International Standard, the following symbols and abbreviated terms are used:

a	root-mean-square value of acceleration, m/s^2
$a(t)$	instantaneous value of an acceleration time history, m/s^2
b	class width, m/s^2
B	acceleration measuring point on the backrest of a seat occupied by a subject
f	frequency, Hz
FFT	fast Fourier transform
h	probability histogram of the root-mean-square values of acceleration
h_{c}	cumulative probability histogram of the root-mean-square values of acceleration
m	index characterizing the class of an observation
$n(m)$	number of observations in class m
n_{T}	total number of observations
N	number of samples per elementary block
N_{b}	number of elementary blocks
P	acceleration measuring point on the floor (platform)
$p[...]$	probability that the condition in brackets is met
PSD	power spectral density
S	acceleration measuring point on the seat pan of the seat occupied by a subject
t	time, s
Δt	sampling interval, s
X	Fourier transform of acceleration, m/s^2
τ	duration of an elementary block, s

The following subscripts are used in this International Standard:

j	index characterizing the direction of vibration measured at point α and taking the values x, y, z (see Figure 1)
k	index characterizing the number of an elementary block of data
w	index characterizing a parameter calculated on the basis of weighted signals
α	index characterizing the location of the point for the measurement of acceleration: P (platform, floor), S (seat pan) and B (backrest)

4 Characterization of vibration in railway vehicles

4.1 Principal causes of vibration or amplification of vibration

4.1.1 Track

Although railway tracks ensure high-quality guidance, the track still has irregularities which cause vibration, such as the following:

— variation in track level (z-direction), alignment (y-direction) or gauge;

— welding or manufacturing defects of the rails;

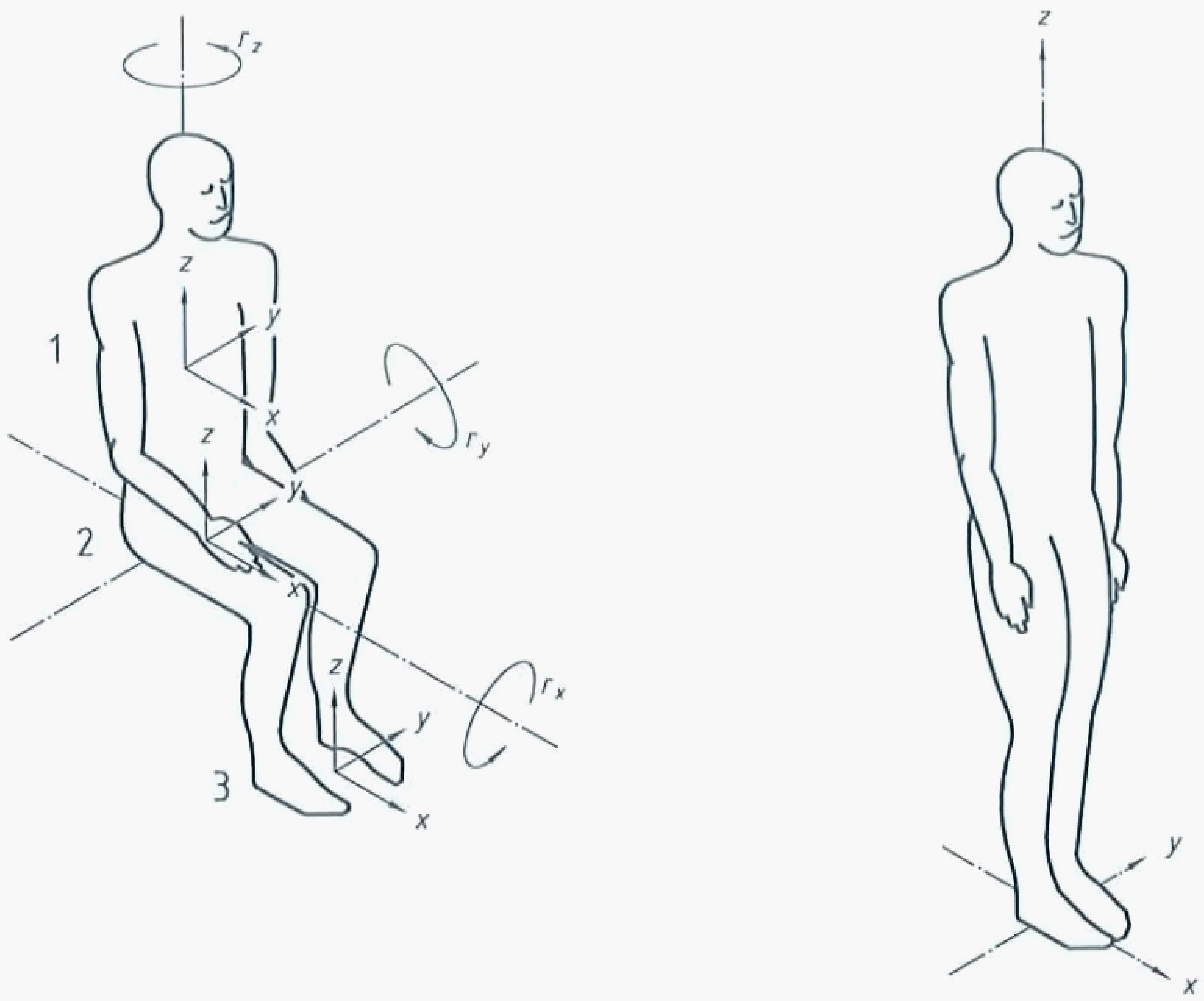
— rail joints;

— turnout;

— variable vertical stiffness of the track (e.g. bridges);

— level crossings;

— transition curves and super-elevation ramps, which can cause low-frequency vibration.



Key

1 Seat back

2 Seat surface

3 Feet

a) Principal basicentric axes for seating position **b) Basicentric axes for standing position**

Figure 1 — Basicentric axes of the human body

4.1.2 Contact between wheel and rail

Excitation of a rail vehicle is particularly localized at the wheel-to-rail contact. The rail-wheel contact forces are non-linear functions of displacement and velocity and produce vibration in the railway vehicle.

4.1.3 Vehicle

The body of a railway vehicle is a flexible complex structure whose natural vibration can at times be important. Moreover, its behaviour is influenced by its load, by the relative position of the bogies, by the various suspension parts (such as springs, dampers, etc.) and by adjacent vehicles in a train.

Defects in the running surfaces of the wheels (such as flats), and out-of-balance or eccentric wheelsets are sources of periodic vibration, the amplitude and frequency of which are a function of the speed.

Rotating machinery (such as motor compressor sets, diesel engines and air-conditioning equipment) can also create vibration which often also is periodic. Furthermore, acceleration and deceleration (e.g. braking) can excite both periodic and non-periodic vibration.

The non-linear behaviour of certain components (e.g. special dampers, buffers, transverse stops, etc.) can produce transient vibration.

The seat can amplify the vibration and can sometimes add some non-linearities, especially at its resonant frequencies. The response of the seat depends among other things on the way it is fixed, the mass and posture of the occupant of the seat, and the shape and material of the seat itself.

4.2 Nature of vibration

Railway vibration signals

- are of a random nature, can include periodic features and can cover a wide range of frequencies, but their energy level inside the vehicle is relatively low,
- have certain well-defined resonances (e.g. in the vertical direction the vehicle body has a natural frequency on the secondary suspension of about 1 Hz and a natural frequency of bending generally between 8 Hz and 15 Hz),
- are not stationary but may be considered as partially stationary, and
- can be permanent (e.g. vibration caused by track irregularities), temporary (e.g. vibration caused by air-conditioning units) or occasional (e.g. vibration caused by level crossings or turnout).

4.3 Direction of vibration

Generally speaking, at any point of the vehicle, the vibration accelerations are characterized by six components: three translational components and three rotational components along and around the x-, y- and z-axes, respectively. However, it is assumed that for rotational vibration the distance to the centre of rotation is large enough to consider this vibration as translational.

For more details of measurement of rotational vibration, see ISO 2631-4.

5 Method of measurement

5.1 General

The physical parameters to be measured are the translational accelerations on the floor and, depending on the aim of the test, at the man-seat interface (and optionally at the man-back interface).

The term "measuring equipment" used hereafter refers to a set of devices which makes it possible to measure and to record the signals. The signals (whether recorded or in real time) may be subject to further processing which is described in clause 6.

NOTE In many applications, part of the signal analysis is carried out during the measurement, before the measured signals are recorded. This activity is called "pre-processing".

In this International Standard "method of measurement" refers to the ways in which the measuring equipment is applied in order to collect the data which are the subject of the tests to be carried out.

5.2 Measuring equipment

5.2.1 General

The measuring equipment normally consists of

— transducers (accelerometers) and some conditioning amplifiers,

— filters (band limitation and frequency weighting) and measuring amplifiers, and

— recorders.

This set of equipment forms a measuring chain.

The characteristics of the equipment should be consistent. The accuracy of the measuring chain is defined by the characteristics of the individual components as well as by certain characteristics of the complete measuring chain.

5.2.2 Transducers and conditioning amplifiers

Since in many cases it is not possible to separate the transducer and conditioning amplifier, these two devices should be treated together and should meet the following conditions:

— minimum measuring range:	floor: 0 to 50 m/s^2,
	man-seat and man-back interface: 0 to 20 m/s^2;
— minimum frequency range:	0,4 Hz to 100 Hz (flat to within $\pm$ 0,5 dB);
— non-linearity plus hysteresis:	$\leqslant$ 1 % of the measured value;
— cross axis sensitivity:	$\leqslant$ 5 %;
— effect of temperature:	on zero: $\leqslant$ 3 % of the measuring range,
	on sensitivity: $\leqslant$ 0,05 % per degree Celsius.

5.2.3 Band-limiting and frequency-weighting filters

To eliminate very-low-frequency as well as too-high-frequency components which are not in the range of vibration relevant to this International Standard, and also to improve the measuring signal-to-noise ratio, band-pass filters should be used.

Lower and upper frequency band limitation shall be achieved by at least two-pole high-pass and low-pass filters, respectively, with Butterworth characteristics, having therefore an asymptotic slope of at least 12 dB per octave. The corner frequencies of the band-limiting filters are one-third octave outside the nominal frequency band.

Within the nominal frequency band and one-third octave from the frequency limits, the tolerance of the combined frequency weighting and band limiting is ± 1 dB. Outside this range, the tolerance is ± 2 dB. One octave outside the nominal frequency band, the attenuation may extend to infinity. (For tolerances, see also ISO 8041.)

5.2.4 Recorders

Recorders should meet the following specifications:

a) FM recorders

— minimum frequency range: 0 to 156 Hz,

— cut-off frequency: 156 Hz (– 0,5 dB);

b) PCM recorders

— minimum frequency range: 0 to 128 Hz;

c) digital recorders (recording to a digital medium)

— minimum frequency range: 0 to 128 Hz.

If PCM recorders or digital recording are used, anti-aliasing filters shall be used. (Usually these filters are built into the recorders.)

5.3 Measurement location

The acceleration shall be measured on the floor and, depending on the aim of the test, at the man-seat interface (and optionally at the man-back interface). The acceleration at a given point in a railway vehicle is dependent on the position of this point in the vehicle. Therefore the measurements should be carried out at the following locations:

— on the floor: over the bogie centre(s) and, optionally, at the centre of the vehicle body, and, depending on the aim of the test, on the vestibule floor;

— for seating position if investigated: on and under seats at the centre and, optionally, at both ends of the vehicle body.

In the driver's cabin, the measurement should be carried out near the place where the seat is mounted.

The accelerometers should be mounted on the floor as close as possible (less than 100 mm if possible) to the vertical projection of the centre of the seat pan, and on the vestibule floor when studying the standing position for local transport.

Other measurement locations may be used depending on the particular aim of the test.

5.4 Measurement directions

The coordinates of the human body are those defined in Figure 1 in accordance with ISO 2631-1. However, a human body-centred coordinate system is not always well suited for characterizing the comfort or motion relationship in railway environments. ISO 2631-4 therefore defines the following alternative coordinate system when measuring at the car structure (floor):

— z-axis: vertical, upwards perpendicular to the floor;

— x-axis: longitudinal, along the direction of travel;

— y-axis: lateral at right angle to the direction of travel.

NOTE For roll (rotational motion about the x-axis), see 4.3.

ISO 10326-2 defines the coordinate systems when measuring at seat interfaces.

Measurements shall be made in the directions of the coordinate systems chosen, which shall be stated in the test report.

5.5 Mounting of the accelerometers

5.5.1 Measurement on the floor

When mounting accelerometers to the floor, the following points should be borne in mind.

a) The accelerometer shall as far as possible carry the same movement as the part of the structure to which the seat is mounted.

b) The signals coming from the accelerometer shall not be affected either by any resonance of the accelerometer mounting or by local modes of the surface to which it is mounted. Therefore it is necessary to ensure that the mounting system of the accelerometer and the place where it is mounted are as rigid as possible.

More detailed recommendations are given in ISO 5348.

5.5.2 Measurement at man-seat and man-back interfaces

The requirements to be followed when mounting accelerometers at the man-seat or man-back interface are as specified in ISO 10326-2.

5.6 Measurement duration

The duration of the measurement shall be at least 20 min, divided into representative sequences of 5 min each.

6 Method of analysis

6.1 General

Vibration in railway vehicles shall be evaluated in accordance with ISO 2631-1 and ISO 2631-4. The signals measured during the tests should be processed to obtain r.m.s. values of the weighted acceleration signal. Moreover, to take into account the fluctuating nature of the railway vibration encountered (see 4.2), a statistical method is used for the analysis of all the r.m.s. values of the weighted signal calculated every 5 s. This enables the lowest frequencies to be taken into consideration and sufficient variability of the r.m.s. values to be obtained.

The upper frequency limit of analysis may be restricted to a frequency below 80 Hz, if previous test results have shown this to be justifiable.

6.2 Calculation of the r.m.s. values of the weighted acceleration

To calculate the r.m.s. values of the weighted acceleration, the signal should be processed using one of the following methods:

a) analog method;

b) analog/digital (hybrid) method;

c) digital method.

The principles of these methods are presented in Figures 2 to 4.

Another digital method for calculation of r.m.s. values is as follows:

— tape recorder;

— sampler;

— analog/digital converter;

— digital weighting filter;

— numerical calculation of r.m.s. values.

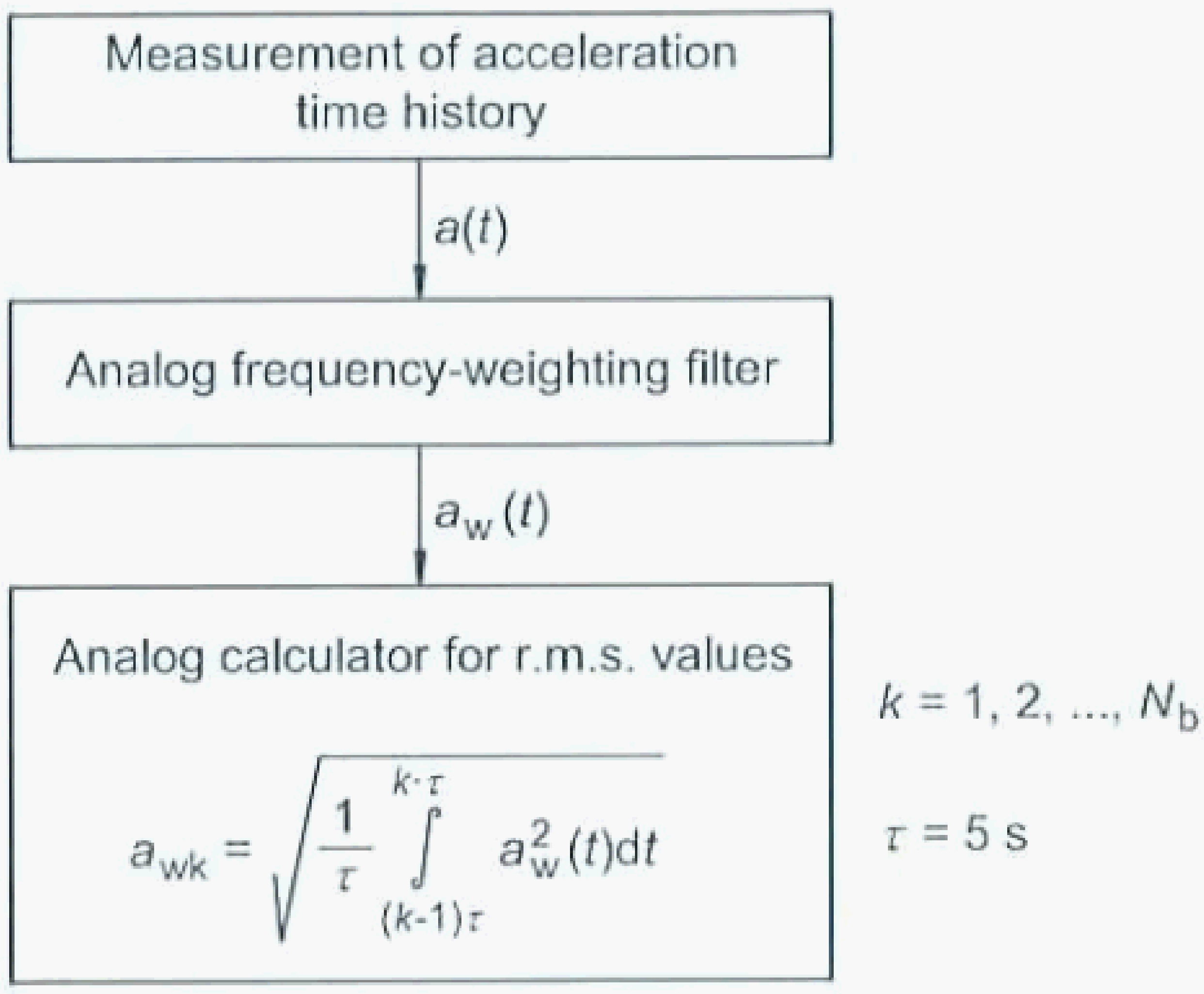


Figure 2 — Analog method for the calculation of r.m.s. values

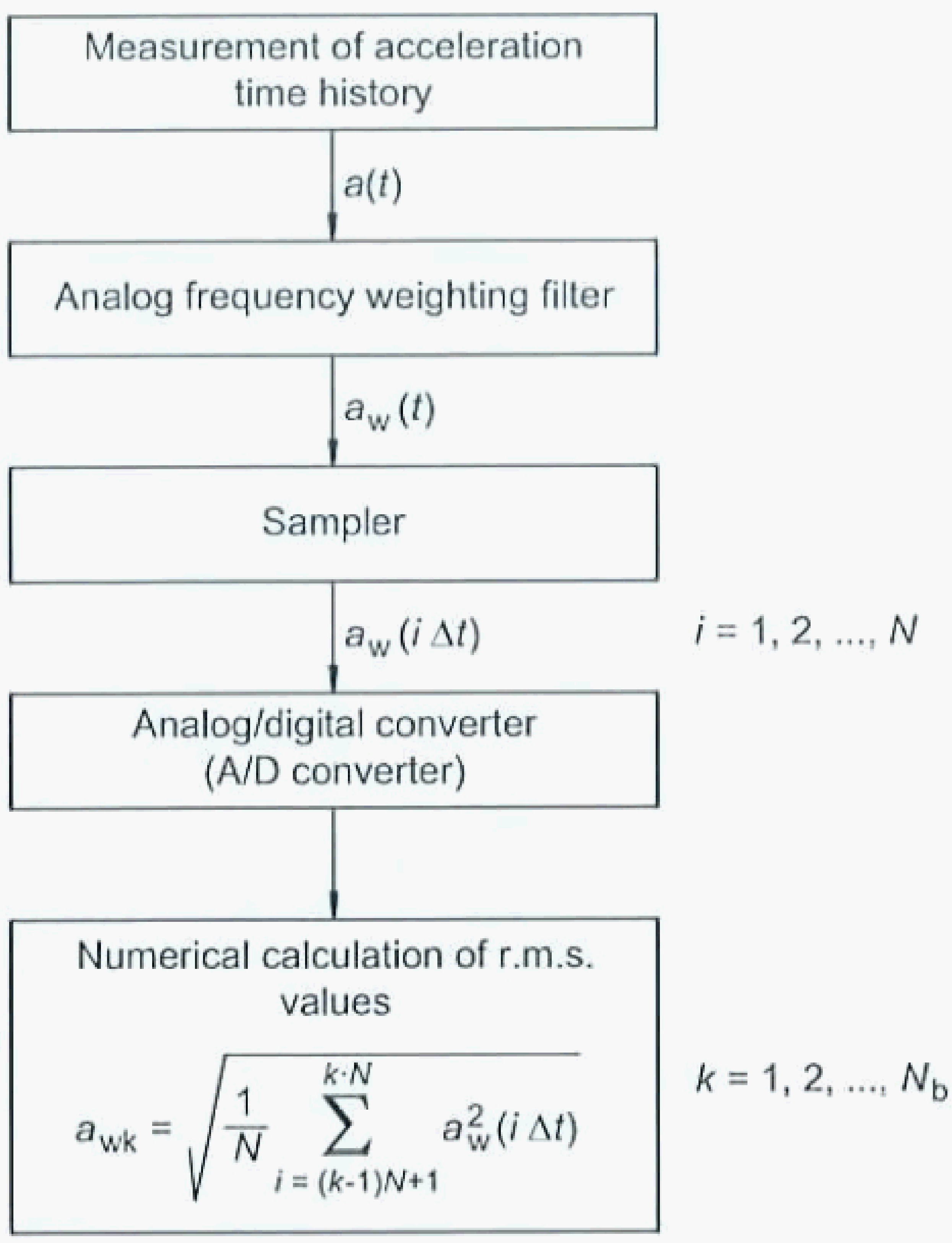
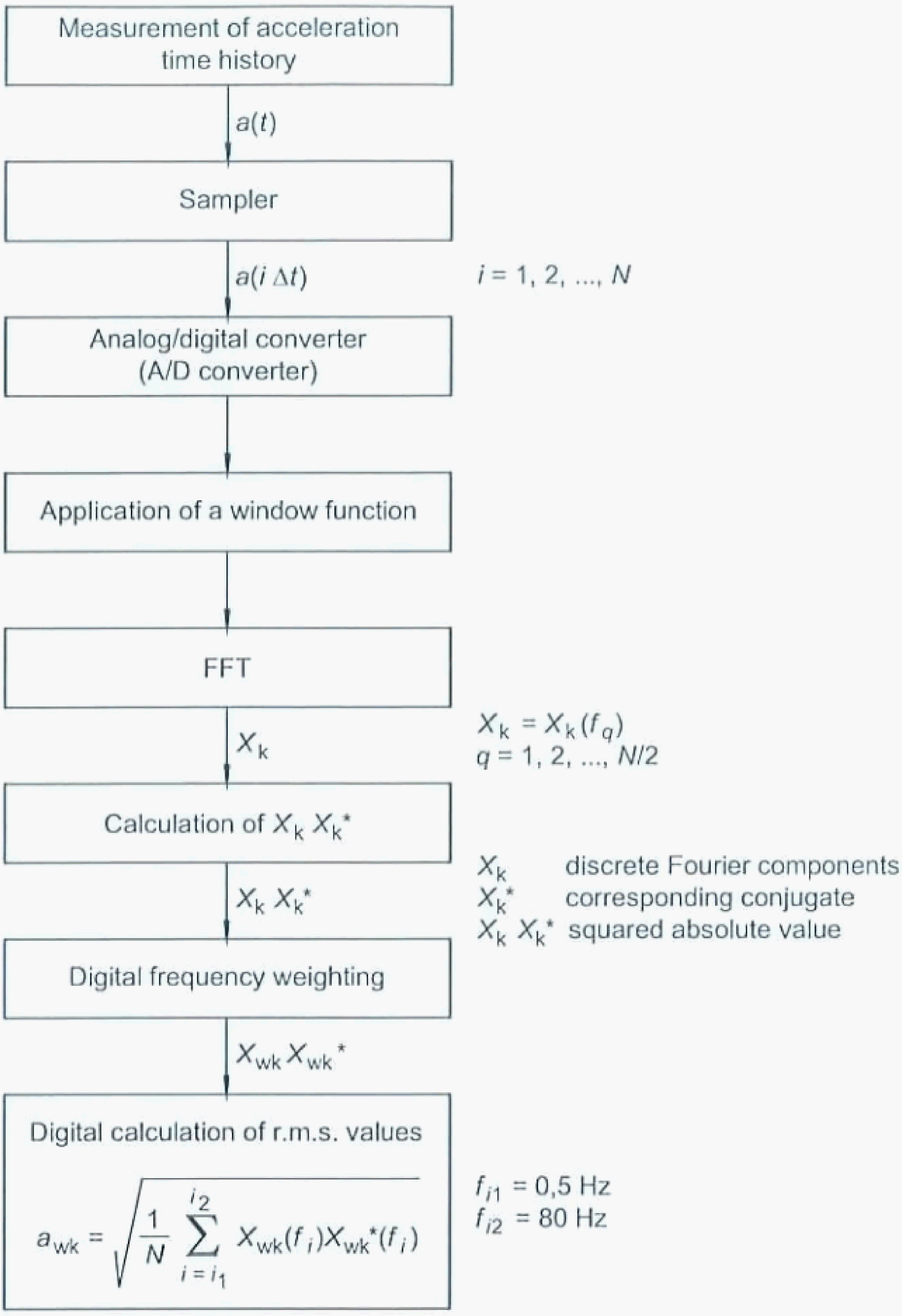


Figure 3 — Hybrid (analog/digital) method for the calculation of r.m.s. values



$$a_{wk} = \sqrt{\frac{1}{N} \sum_{i=i_1}^{i_2} X_{wk}(f_i) X_{wk}^*(f_i)}$$

NOTE There are also other digital methods.

Figure 4 — Digital method for the calculation of r.m.s. values

6.3 Statistical analysis method

The data for comfort indices are determined from certain statistical parameters: average value of the r.m.s. values and characteristic parameter of the higher r.m.s. values (e.g. 95th and 99th percentile). To evaluate these, the histogram of r.m.s. values of the weighted acceleration signal a_w is used.

A probability histogram, $h(m)$, and a cumulative probability histogram, $h_c(m)$, can be constructed (see examples in Figures 5 and 6):

$$h(m) = n(m)/n_T \quad (1)$$

$$h_c(m) = \sum_{i=0}^{m} h(i) \quad (2)$$

where m is the integer number $a_w(m)/b$ rounded down to the nearest integer.

Figures 5 and 6 represent a probability histogram and the corresponding cumulative probability histogram

$$h_c(m) = p[a_w \leqslant a_w(m)] \quad (3)$$

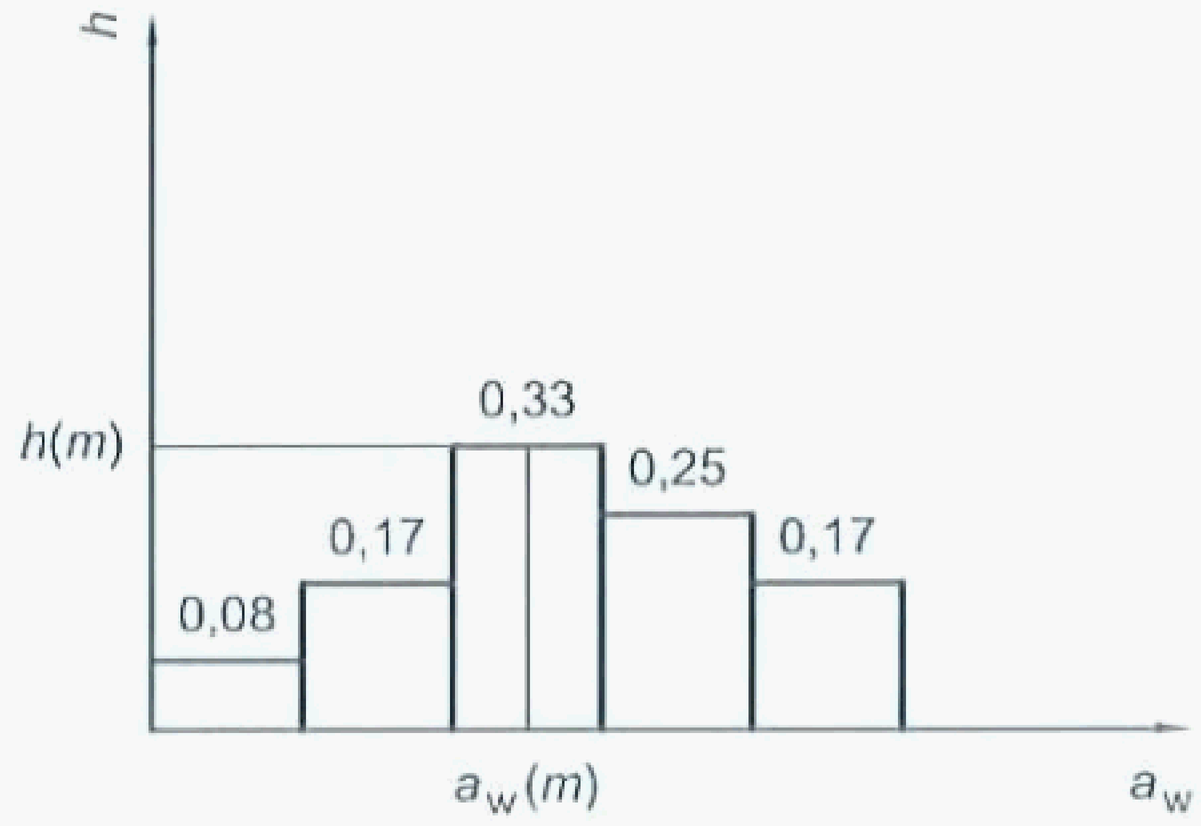


Figure 5 — Example of a probability histogram $h(m)$

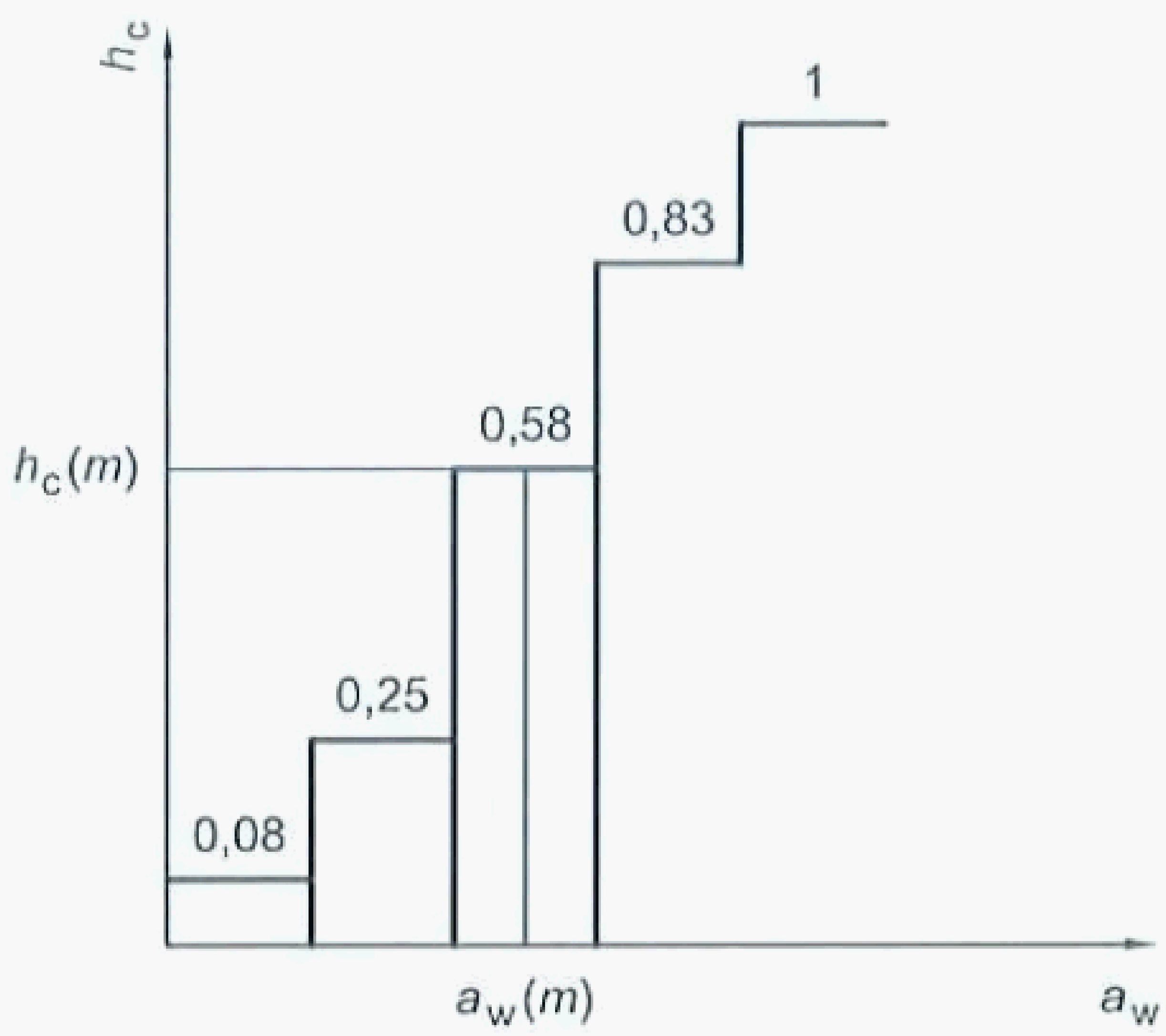


Figure 6 — Example of the corresponding cumulative probability histogram $h_c(m)$

7 Test report

7.1 General

The results shall be reported in accordance with ISO 8002. In addition the information stated below should be supplied. Annex A contains an example of a test report.

7.2 Basis and aim of the test

The test report shall indicate the standard which has been followed. The purpose of the test (e.g. evaluation of comfort, of a vehicle) should be stated.

7.3 Evaluation method

The frequency range considered, the frequency weighting function used, the measurement locations and directions, as well as the measurement duration shall be stated. Further particular characteristics of the evaluation method should be presented (e.g. number of tests).

7.4 Test conditions

The following information concerning the test conditions should be given.

a) Description of the vehicle:

- all arrangements which may have an influence on the vibratory behaviour should be specified, in particular
    - vehicle (rail-car, coach, locomotive, etc.),
    - type (saloon, compartments, etc.),
    - load conditions of vehicle (empty, nominal load, etc.), and
    - structural arrangements (steel, aluminium, type of suspension, type of bogie, number of kilometres per wheelset since reprofiling, etc.).

b) Description of seat:

- type (single, multiple, etc.);
- covering (synthetic, fabric);
- special features (arm-rest, foot-rest, head-rest, foldaway table, reclined, etc.);
- position (in a row, face to face, location and orientation in the vehicle).

c) Description of occupant:

- in cases where the measurements are carried out at the man-seat or man-back interface, the height and mass of the occupant shall be indicated;
- age and gender may also be given.

d) Description of the track:

- route section and geographical location (including distance points) at which the measurement has been carried out;

— type of track (gauge, sleeper type, rail-support system, rail profile);

— description of the quality of the track;

— details of the track (radius of curvature, level crossings, turnout, etc.).

e) Running speed:

— vehicle speeds used during the tests.

7.5 Measuring chain

The measuring chain should be described in accordance with ISO 8002.

7.6 Measurement results

a) Spectral analysis:

— standard spectra representative of the vibration at different points of the seat pan and/or seat back interfaces and of the vehicle floor shall be given.

b) Statistical results:

— the following statistical information calculated on the basis of the root-mean-square values of acceleration should be given:

  — histogram and cumulative histogram,

  — width of class and number of classes;

— evaluated statistical parameters may also be indicated (mean value, standard deviation, 95th percentile, 99th percentile, maximum value, etc.).

Annex A
(informative)

Example of a test report

A.1 Aim of the tests

Measurement of comfort on a VVV saloon coach.

A.2 Evaluation method

The measurements have been carried out in accordance with ISO 10056:2001, *Mechanical vibration — Measurement and analysis of whole-body vibration to which passengers and crew are exposed in railway vehicles.*

Measurement on the floor (platform) of the vehicle along the vehicle-related three axes x, y and z and measurement at the interfaces between the seats and the seated test subject along the three axes x, y and z of the coordinate system of the seat pan and along the x-axis of the coordinate system of the backrest.

Tests carried out on line A – B, track 1, comprising two test zones:

— kilometre point AAAA to BBBB = zone 1, and

— BBBB to CCCC = zone 2.

Tests carried out twice.

A.3 Test conditions

A.3.1 Description of the vehicle

VVV coach type A10rtu.

Vehicle in running order and empty.

Distance covered by running gear between 210 000 km and 320 000 km.

Initial profile of wheel: UIC S 1002.

YYY bogies.

The test vehicle was located in third position in the test train which consisted of seven vehicles.

A.3.2 Description of the seat

Separate seat with separate arm-rests.

Textile covers.

One of a row in the middle of the coach and one at the end of the coach.

A.3.3 Occupants

Subject 1 (middle of coach)

Height: 1,72 m   Mass: 72 kg

Age: 52 years   Gender: masculine

Subject 2 (end of coach)

Height: 1,76 m   Mass: 77 kg

Age: 40 years   Gender: masculine

A.3.4 Track

The principal characteristics of the track are contained in Table A.1, the presentation of which is not unified.

Table A.1 — Principal characteristics of the track

Zone 1: AAAA to BBBB (30 km)				
Average gauge	Straight track:	1 437 mm		
	Curves:	1 450 mm		
Level (current values)	Straight track:	3 mm		
	Curves:	3 mm		
Variations of versine (10 m base)	Straight track:	± 2,5 mm		
	Curves:	± 2,5 mm		
Curve radii	Average:	2 000 m	Mean super-elevation[a]:	65 mm
	Minimum:	658 m	Maximum super-elevation:	160 mm
Type of rail[b]	CWR UIC 50			
Running speed	120 km/h			
Zone 2: BBBB to CCCC (150 km)				
Average gauge	Straight track:	1 442 mm		
	Curves:	1 450 mm		
Level (current values)	Straight track:	4 mm		
	Curves:	3 mm		
Variations of versine (10 m base)	Straight track:	± 3 mm		
	Curves:	± 3 mm		
Curve radii	Average:	1 500 m	Mean super-elevation[a]:	105 mm
	Minimum:	885 m	Maximum super-elevation:	160 mm
Type of rail[b]	CWR UIC 60			
Running speed	140 km/h			

a The super-elevation may also be expressed as cant angle, if the gauge is known.

b CWR = continuously welded rails

A.4 Measuring chain

A.4.1 Accelerometers

Manufacturer:	Firm X	
Type:	A1B2	
Measuring range:	50 m/s^2	
Frequency range:	0,1 Hz to 300 Hz	
Non-linearity:	< 1 %	
Cross sensitivity:	3 %	
Effect of temperature:	on zero:	< 2 %
	on sensitivity:	0,05 %/°C.

A.4.2 Filters

The characteristics of the filters used (band limitation and frequency weighting) conform to those of ISO 2631-1. Their overall tolerances are as follows:

— overall tolerance within the frequency band: ± 0,5 dB;

— attenuation from one octave outside of the band: 36 dB per octave.

A.4.3 Magnetic recorders

Manufacturer:	Firm Y
Type:	FM recorder C3D4
Frequency range:	0 to 1 250 Hz
Cut-off frequency:	1 250 Hz (– 0,5 dB)

Simplified diagrams for the recording and the evaluation processes are shown in Figure A.1.

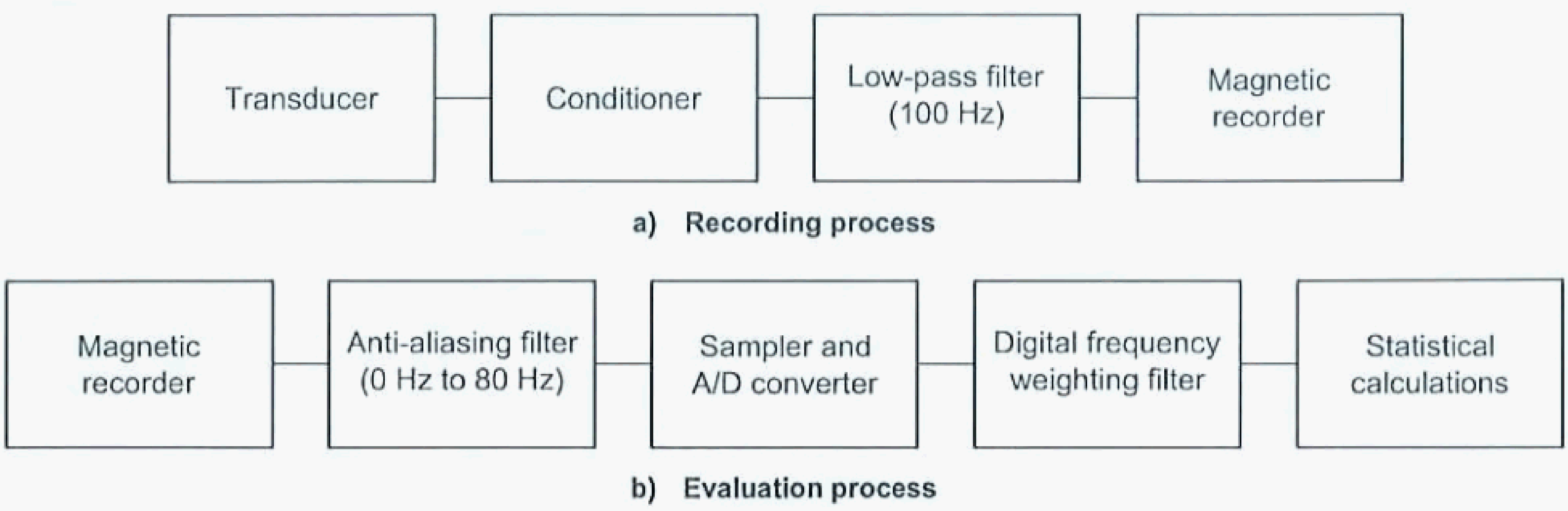


Figure A.1 — Simplified diagrams for the recording and the evaluation processes

A.5 Characterization of vibration

A.5.1 General

The vibration is characterized by spectra calculated every 5 s and by power spectral densities (PSD) over 5 min, as well as by statistical distributions of the r.m.s. values over 5 min.

A.5.2 Spectral analysis

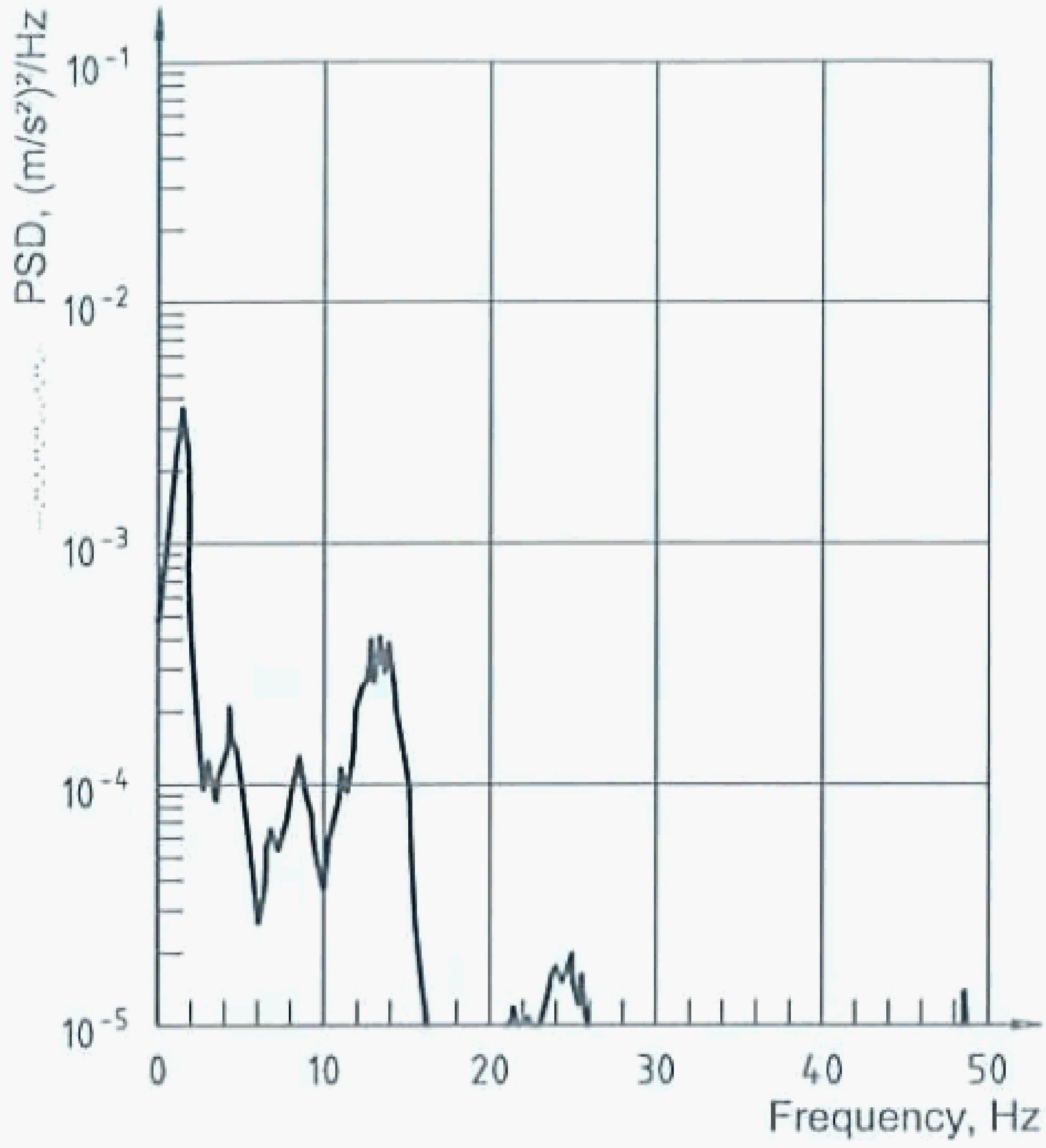
Figure A.2 gives the power spectral densities recorded at seat-pan level and at the backrest and weighted in accordance with ISO 2631-1 frequency-weighting curves. For vertical acceleration, W_k has been used.

Figure A.3 shows the power spectral density recorded at floor level without frequency weighting but with band limitation.

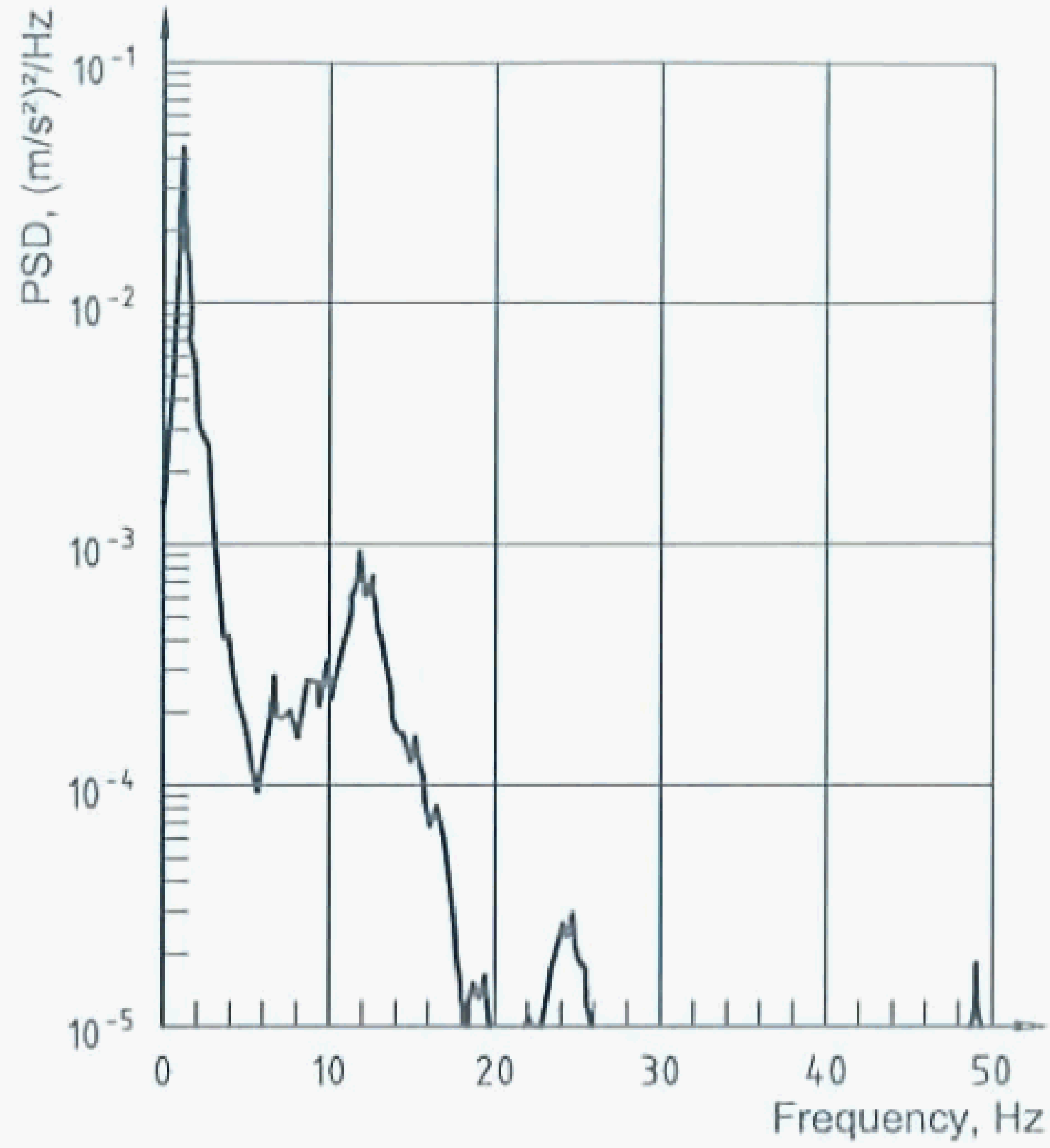
A.5.3 Statistical distribution

Figure A.4 shows the distribution histograms over 5 min of the r.m.s. values of acceleration at seat-pan level and at the backrest, weighted in accordance with ISO 2631-1 frequency-weighting curves. For vertical acceleration, W_k has been used.

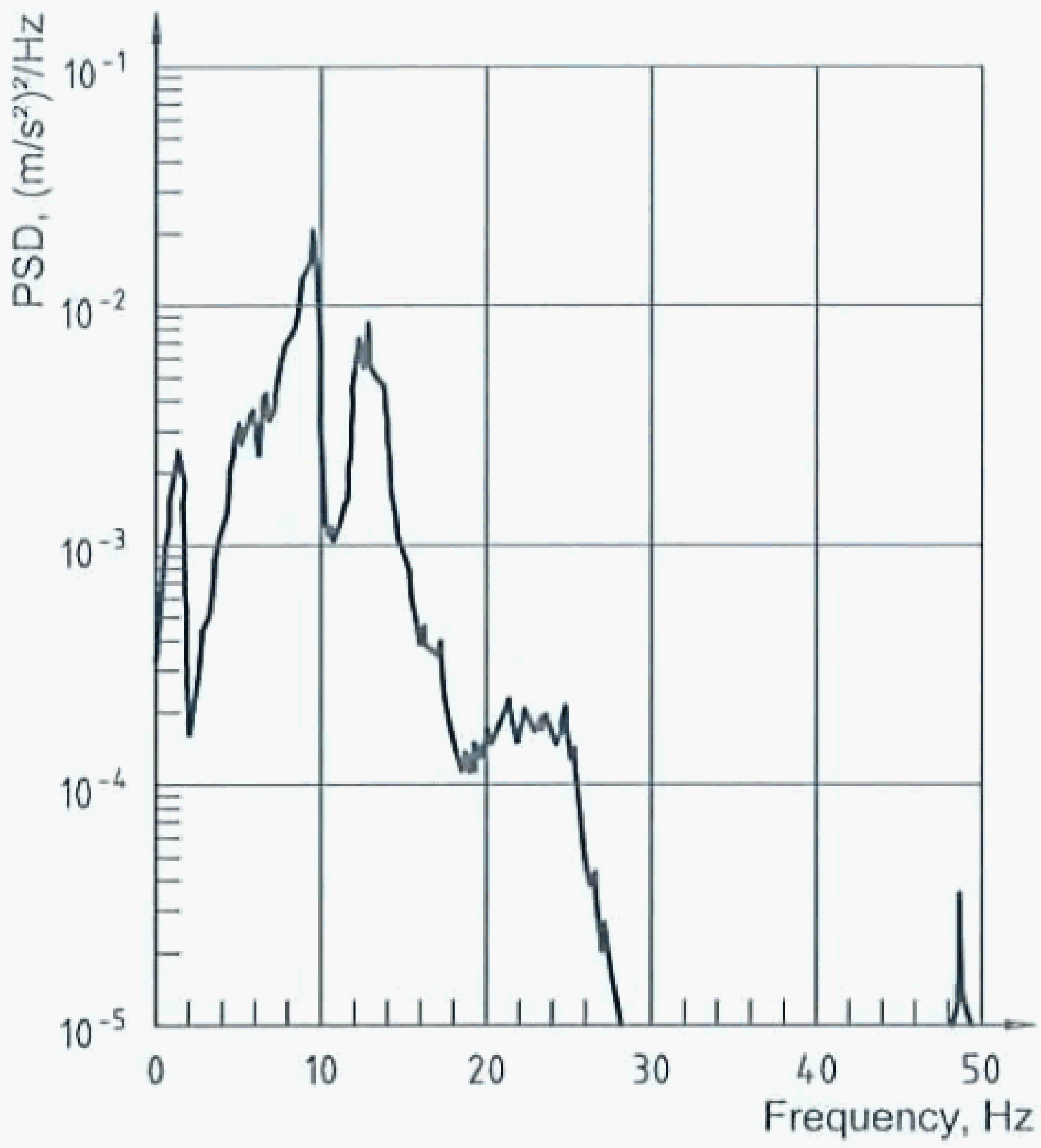
Figure A.5 shows the cumulative distribution histograms over 5 min of the same r.m.s. values.



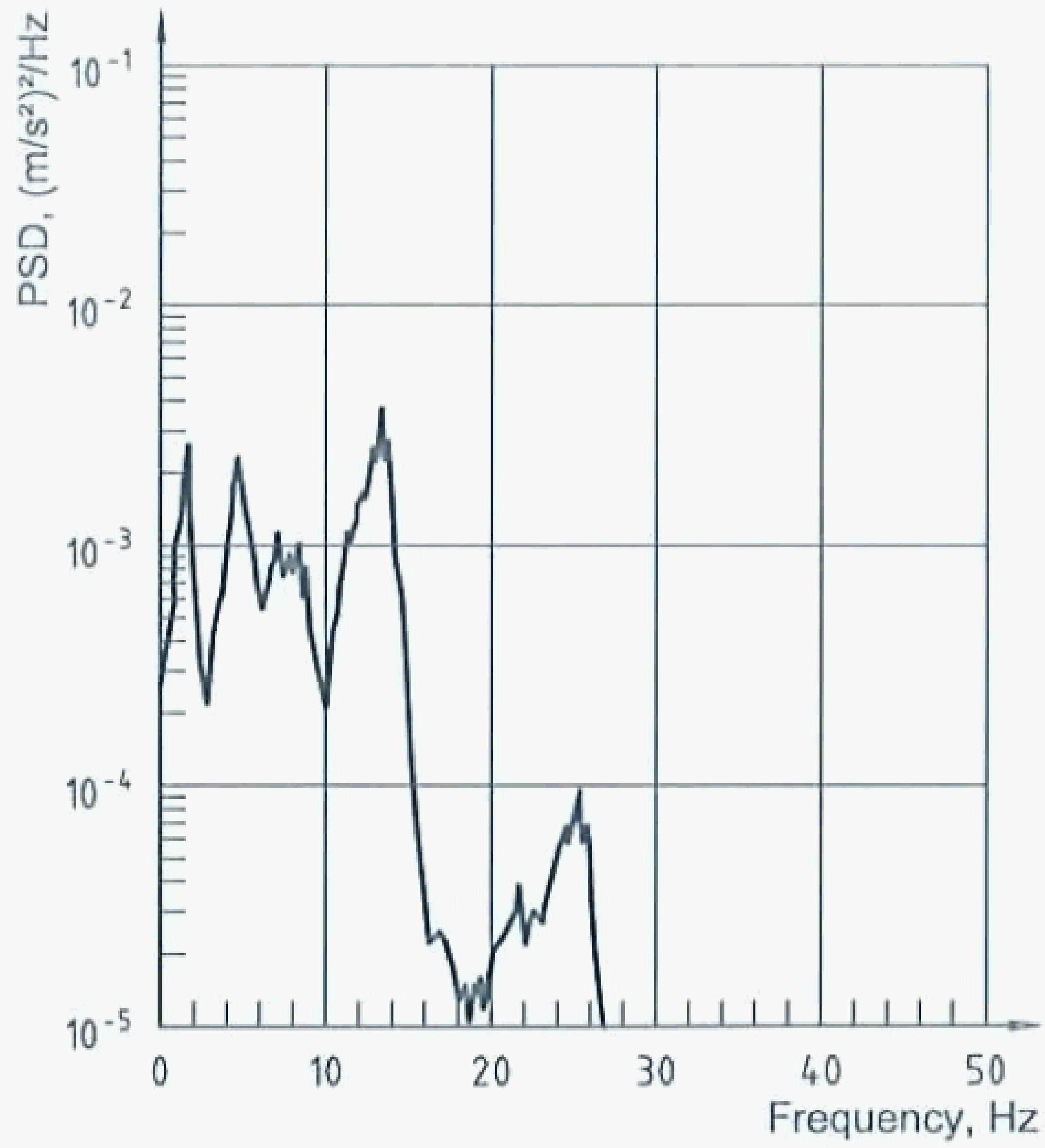
a) **Seat pan, *x*-direction**



b) **Seat pan, *y*-direction**

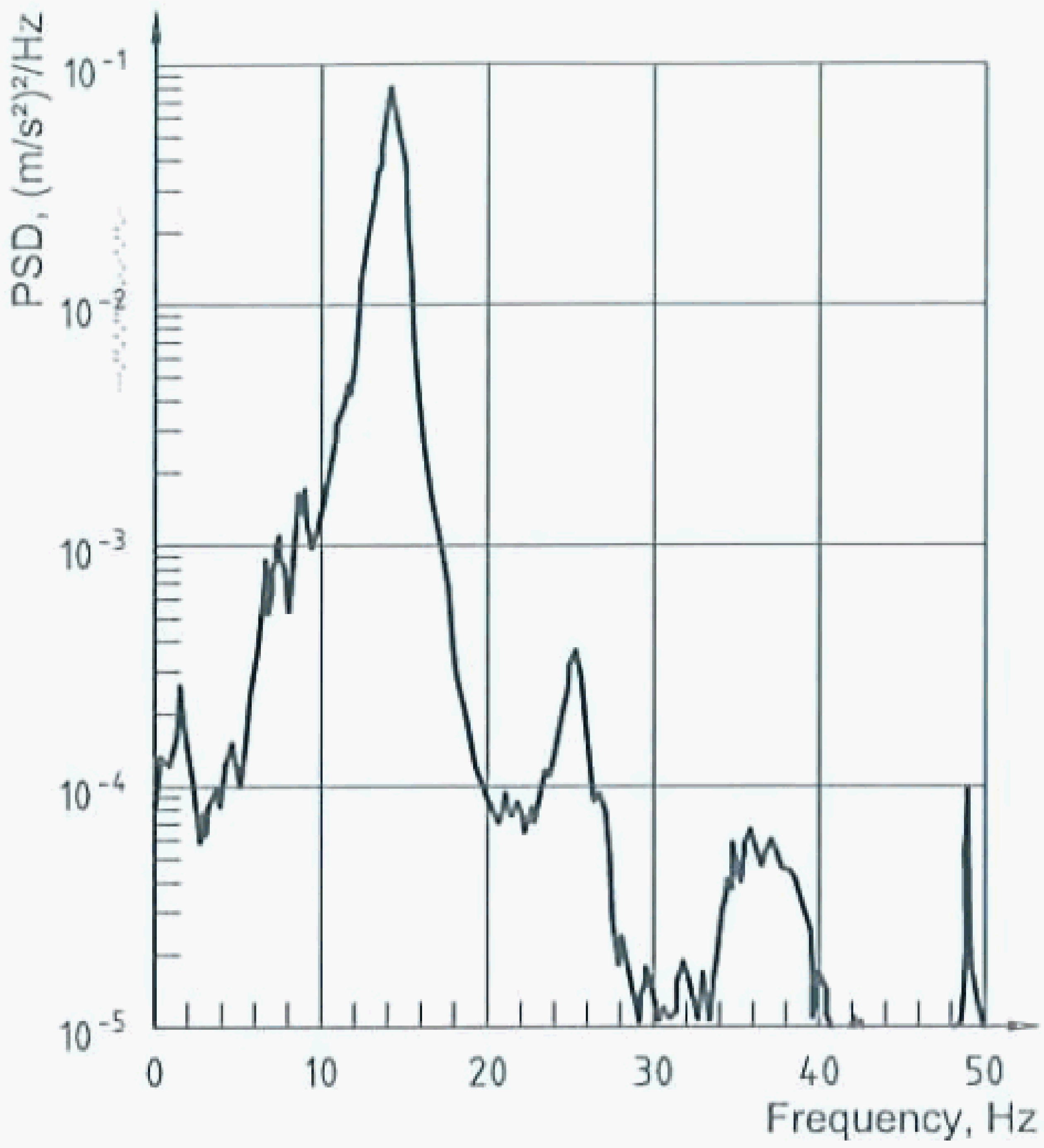


c) **Seat pan, *z*-direction**

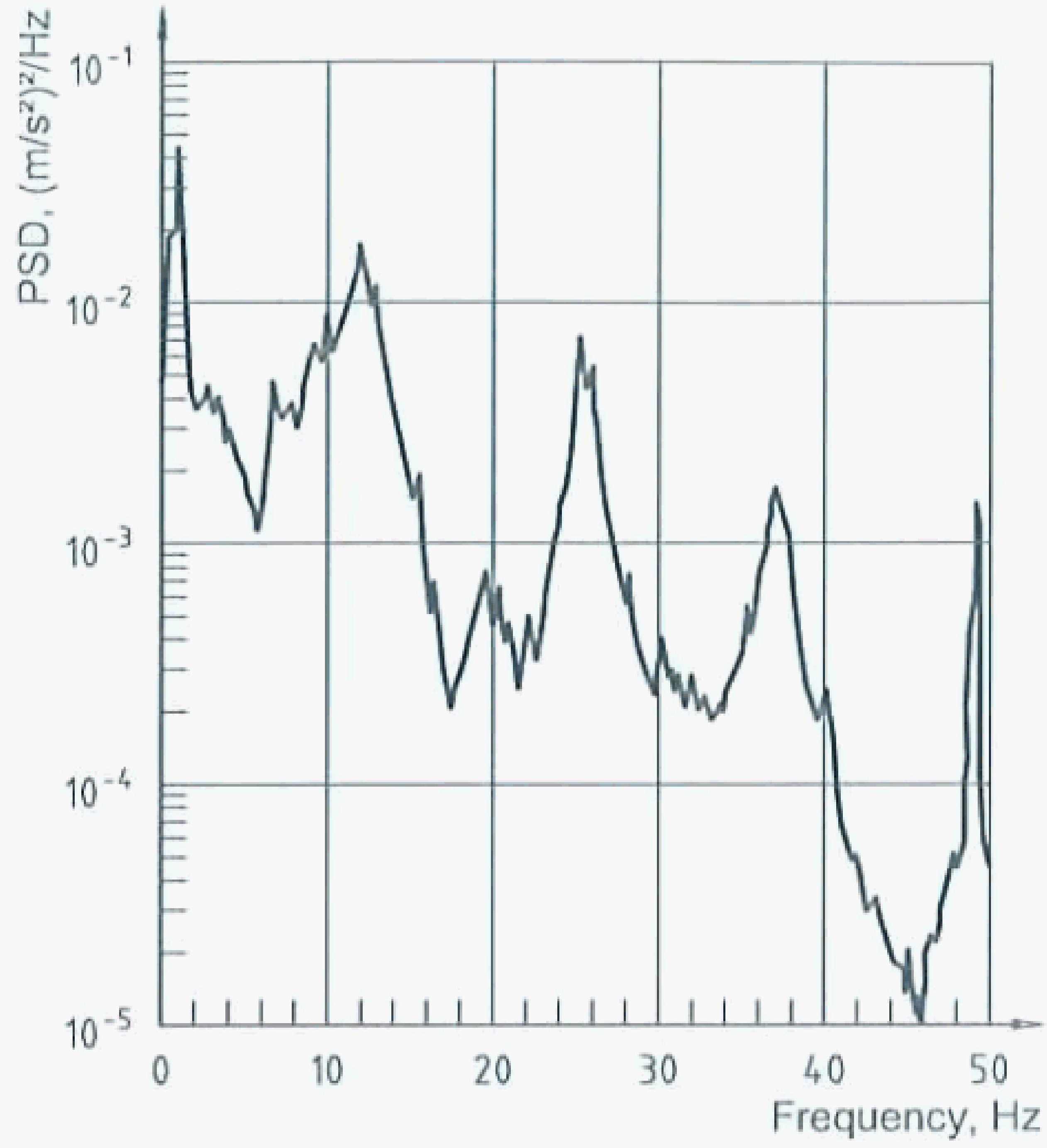


d) **Backrest, *x*-direction**

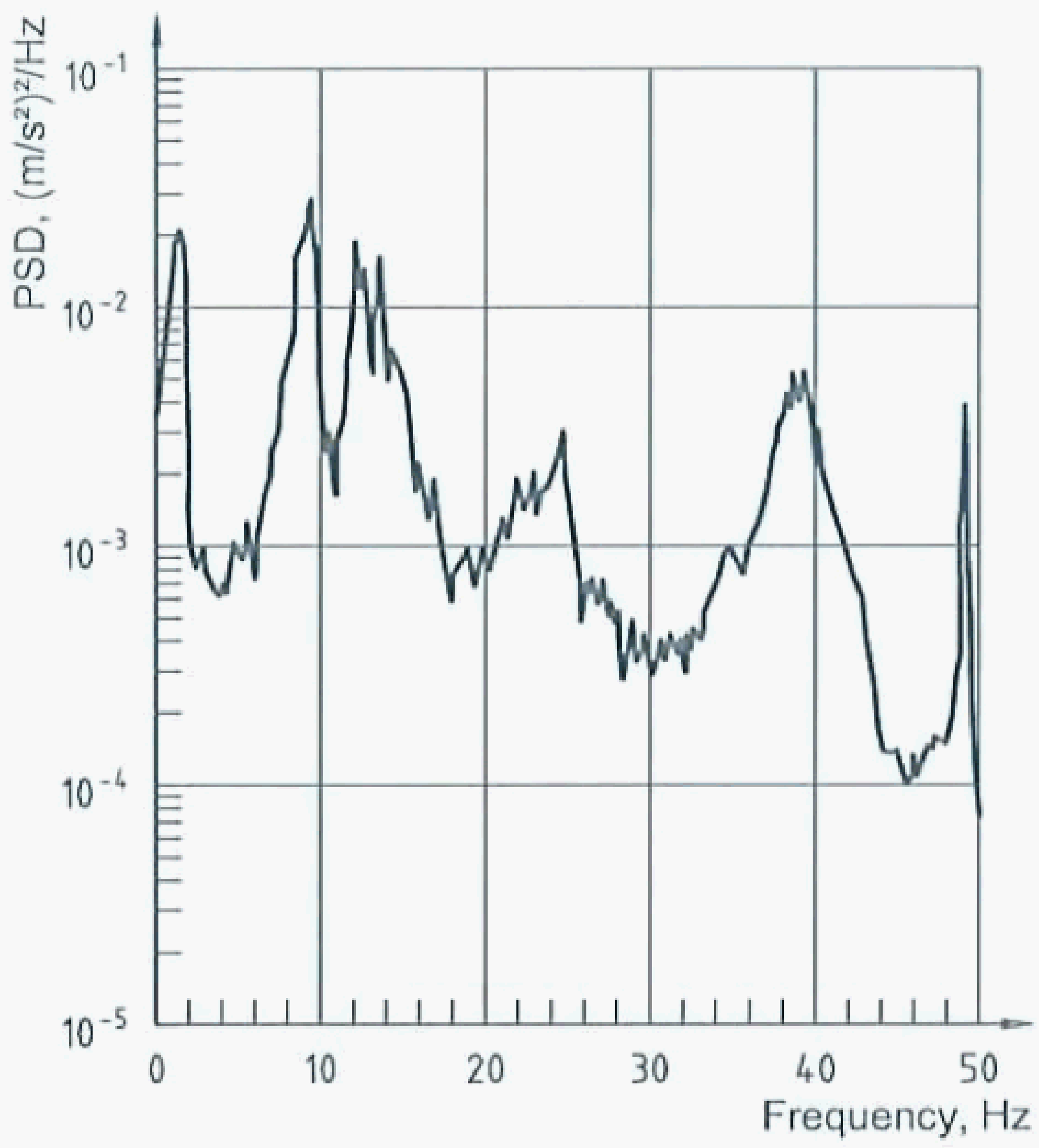
Figure A.2 — Weighted power spectral densities (PSD) at the seat pan and backrest interfaces measured in zone 1 (mean values over 5 min)



a) **Floor, *x*-direction**



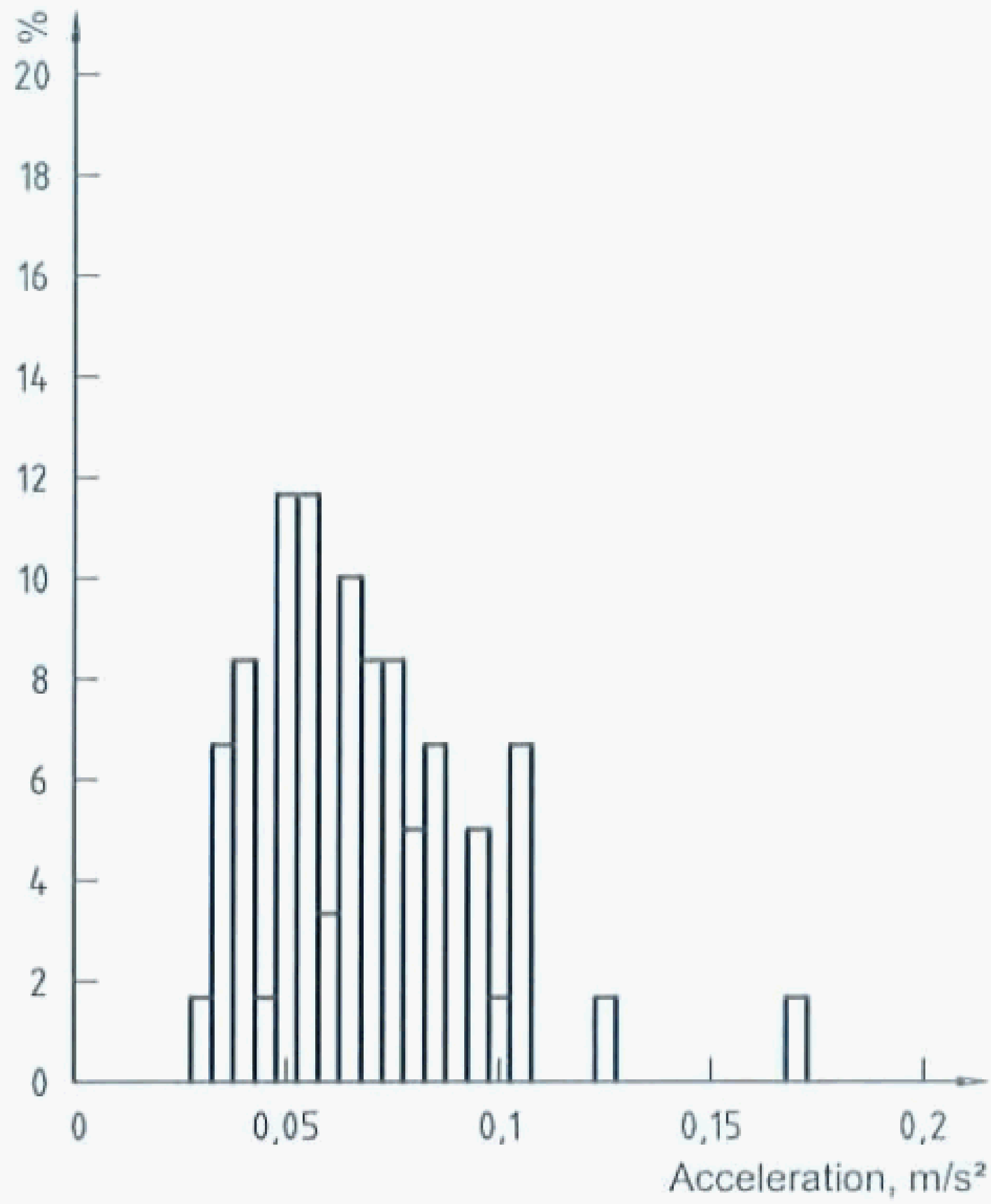
b) **Floor, *y*-direction**



c) **Floor, *z*-direction**

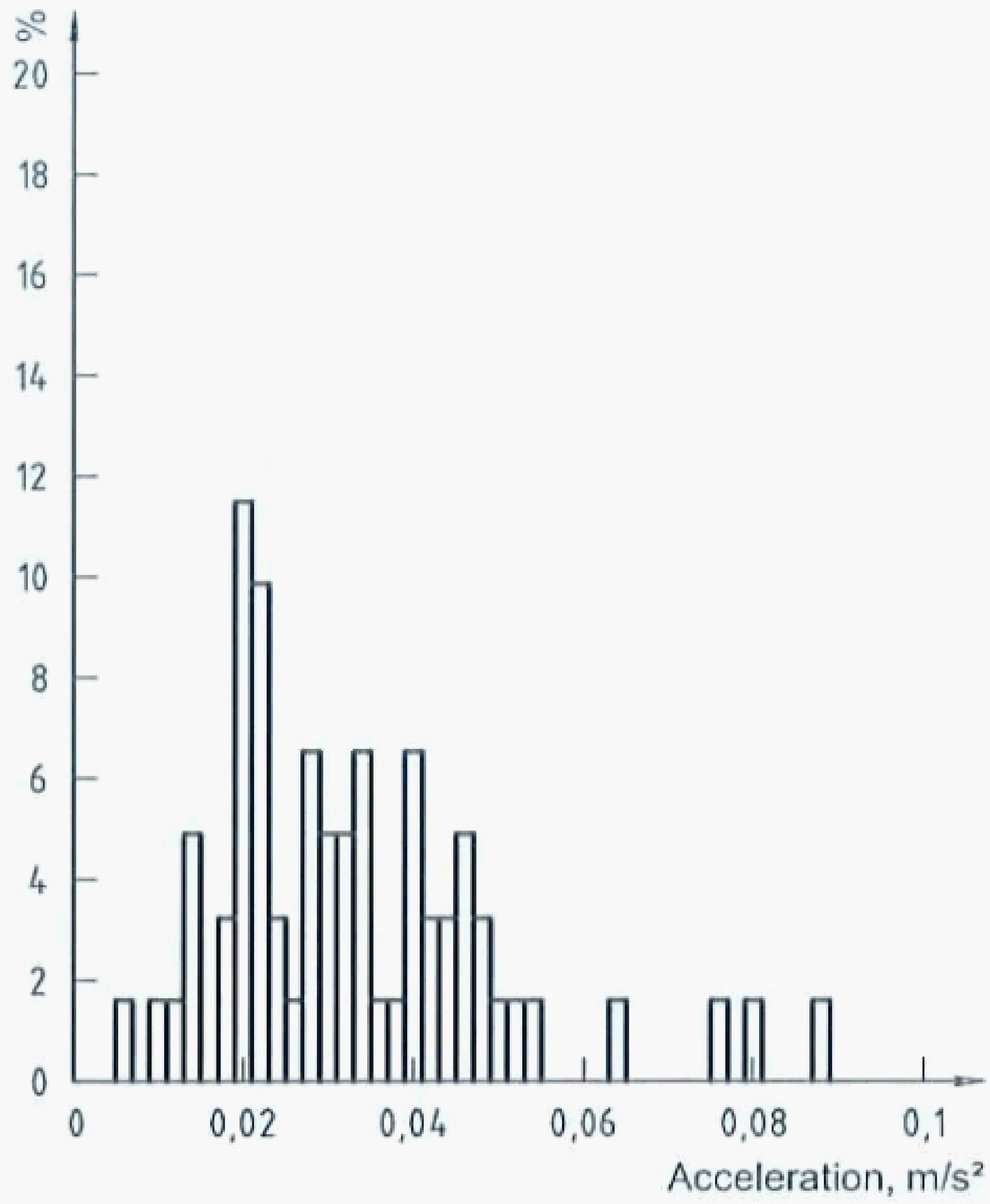
Figure A.3 — PSD at floor level measured in zone 1 (mean values over 5 min)

Number of samples: 60
Minimum value: 0,027 m/s^2
Maximum value: 0,172 m/s^2
Value of distribution function for
50 %: 0,062 m/s^2
95 %: 0,103 m/s^2
Standard deviation: 0,025 m/s^2
Width of class: 0,005 m/s^2



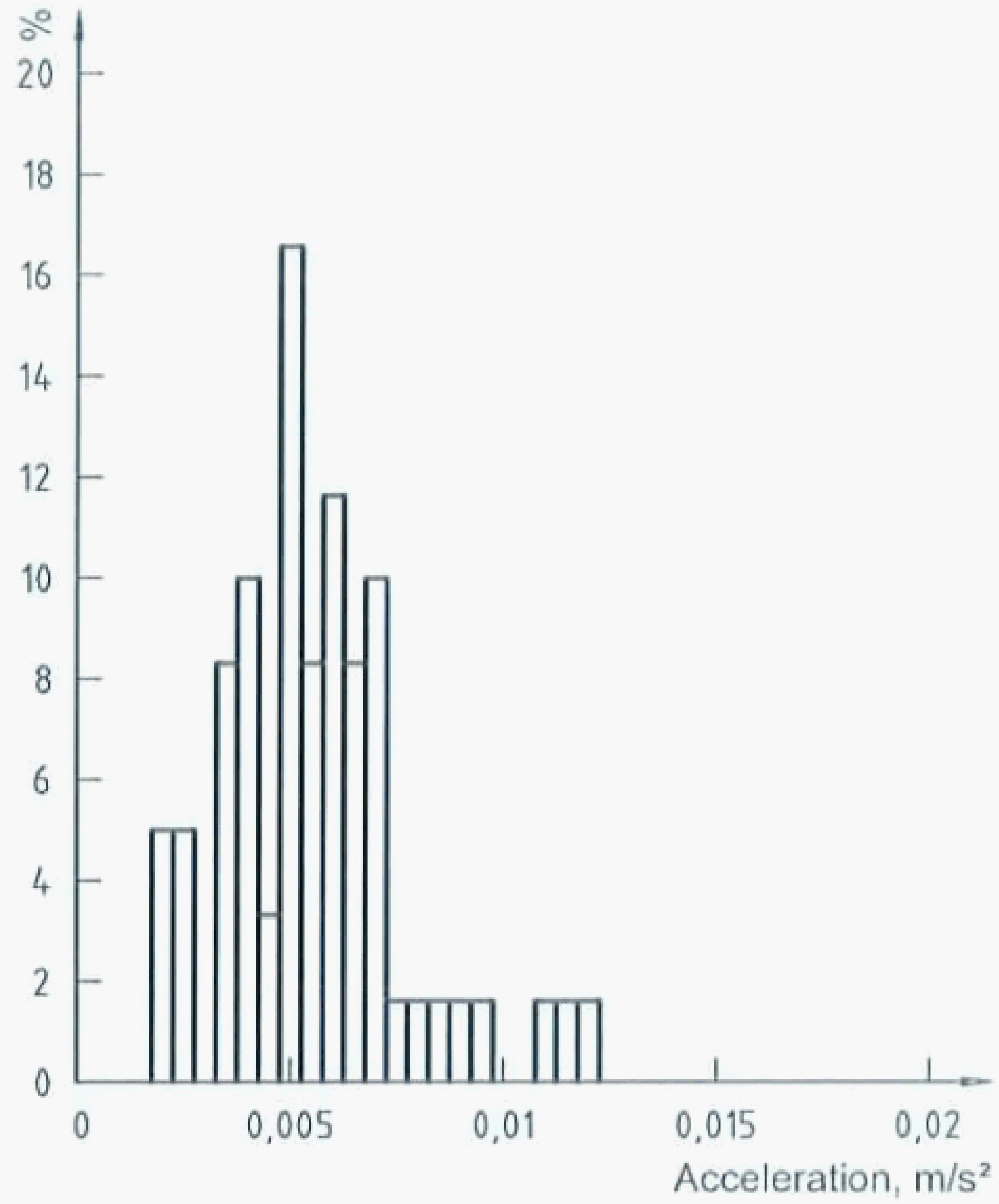
a) **Seat pan, x-direction**

Number of samples: 60
Minimum value: 0,005 m/s^2
Maximum value: 0,089 m/s^2
Value of distribution function for
50 %: 0,029 m/s^2
95 %: 0,059 m/s^2
Standard deviation: 0,016 m/s^2
Width of class: 0,002 m/s^2



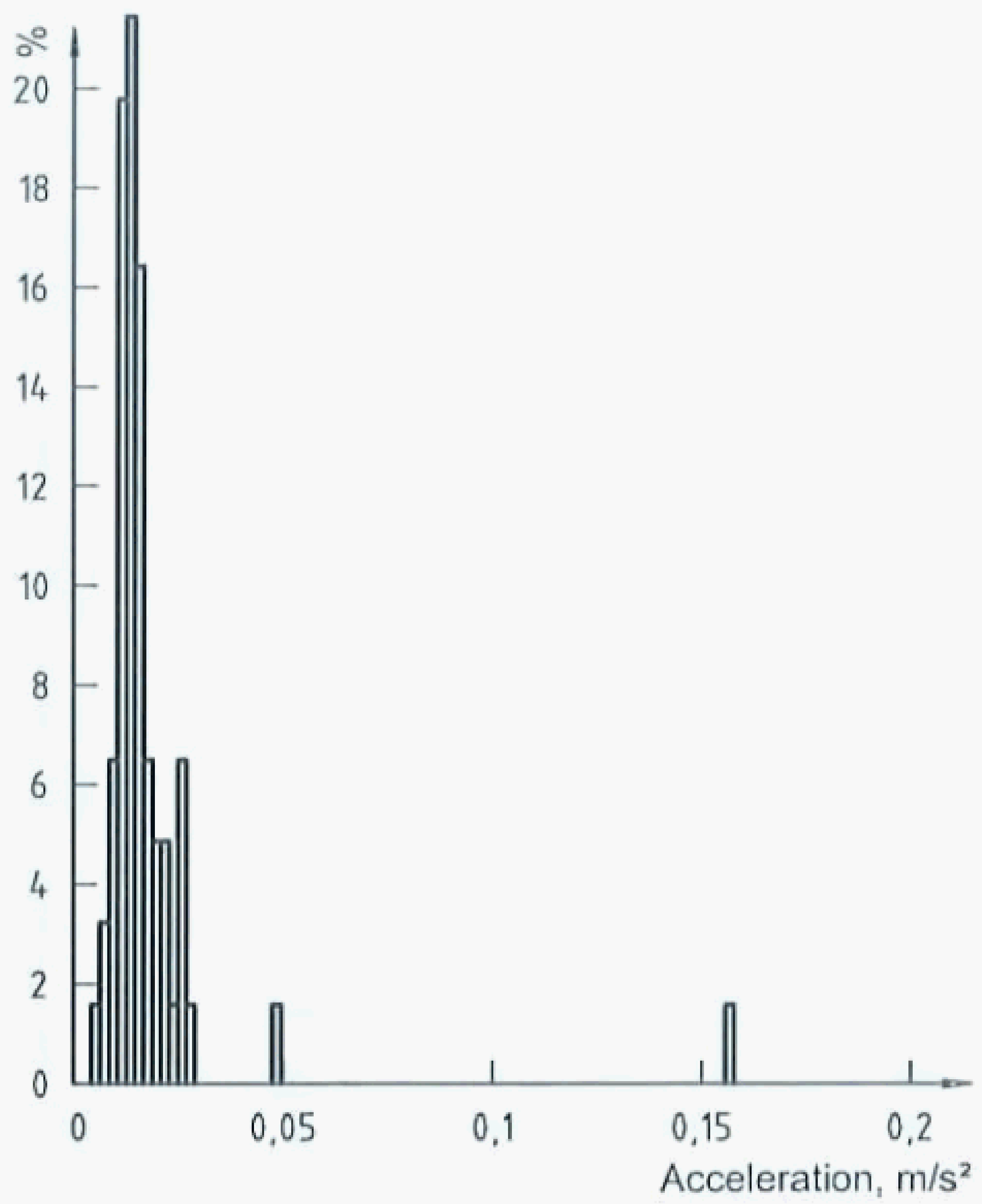
b) **Seat pan, y-direction**

Number of samples: 60
Minimum value: 0,002 m/s²
Maximum value: 0,012 m/s²
Value of distribution function for
50 %: 0,005 m/s²
95 %: 0,010 m/s²
Standard deviation: 0,002 m/s²
Width of class: 0,0005 m/s²



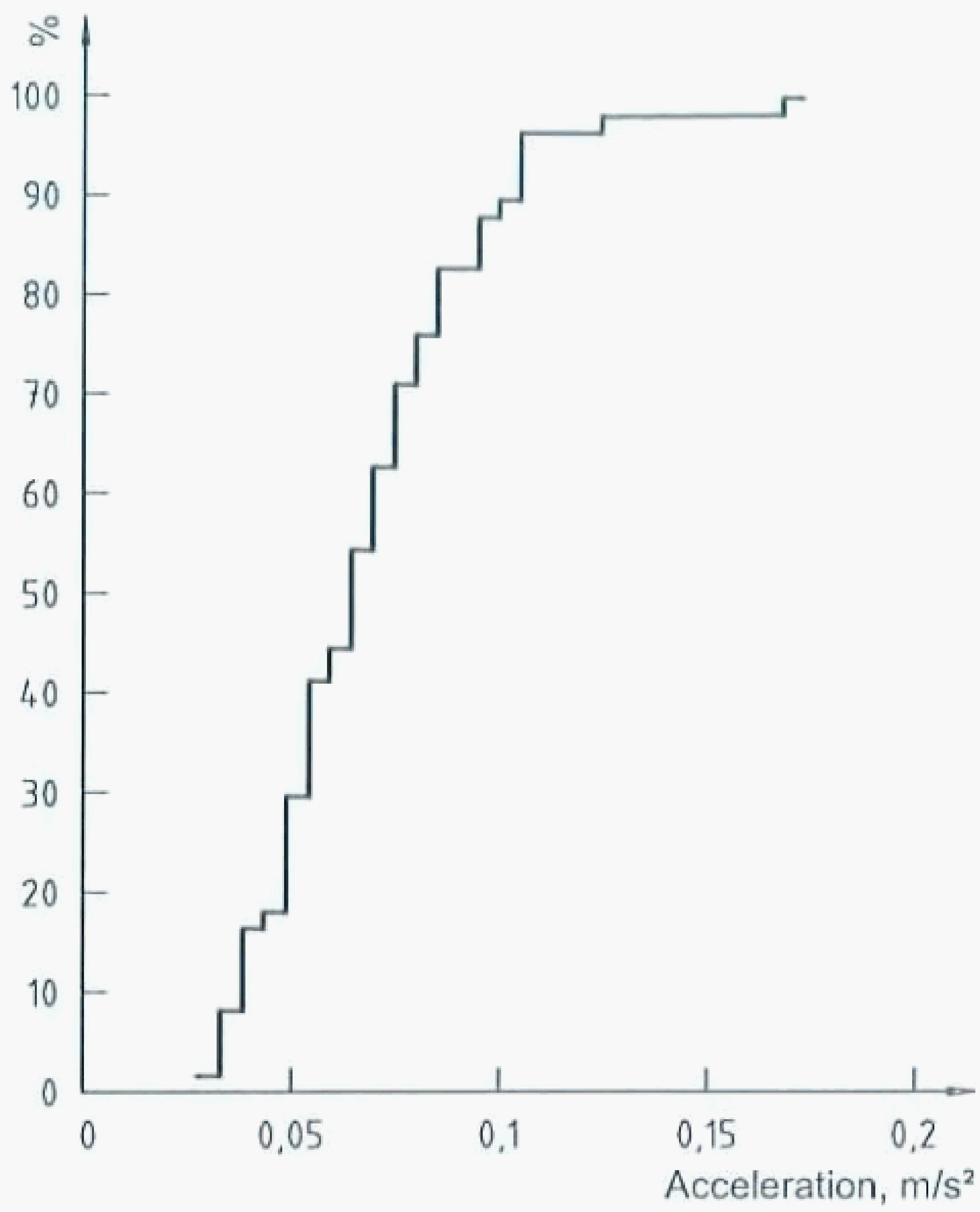
c) **Seat pan, *z*-direction**

Number of samples: 60
Minimum value: 0,002 m/s²
Maximum value: 0,162 m/s²
Value of distribution function for
50 %: 0,013 m/s²
95 %: 0,026 m/s²
Standard deviation: 0,020 m/s²
Width of class: 0,002 m/s²

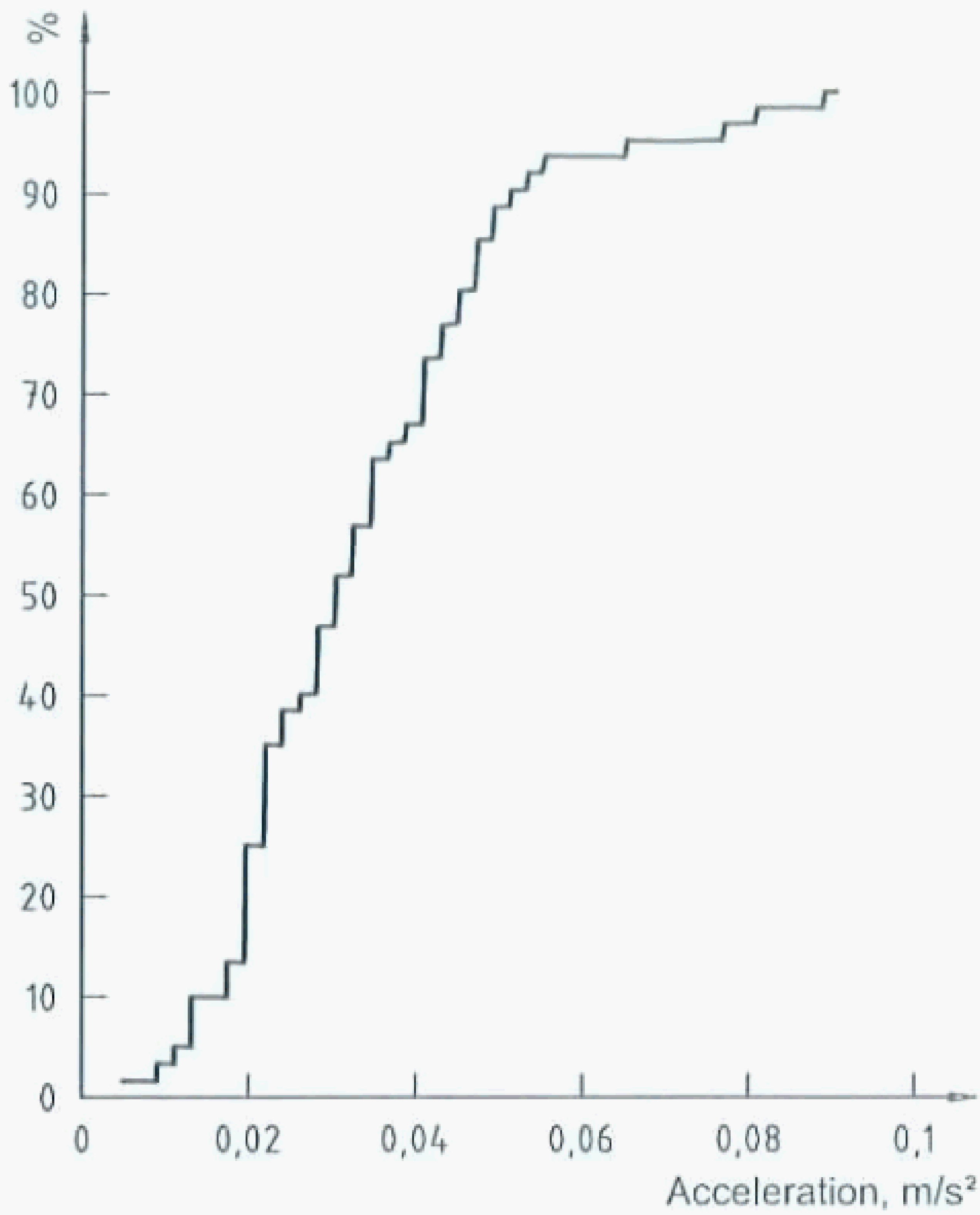


d) **Backrest, *x*-direction**

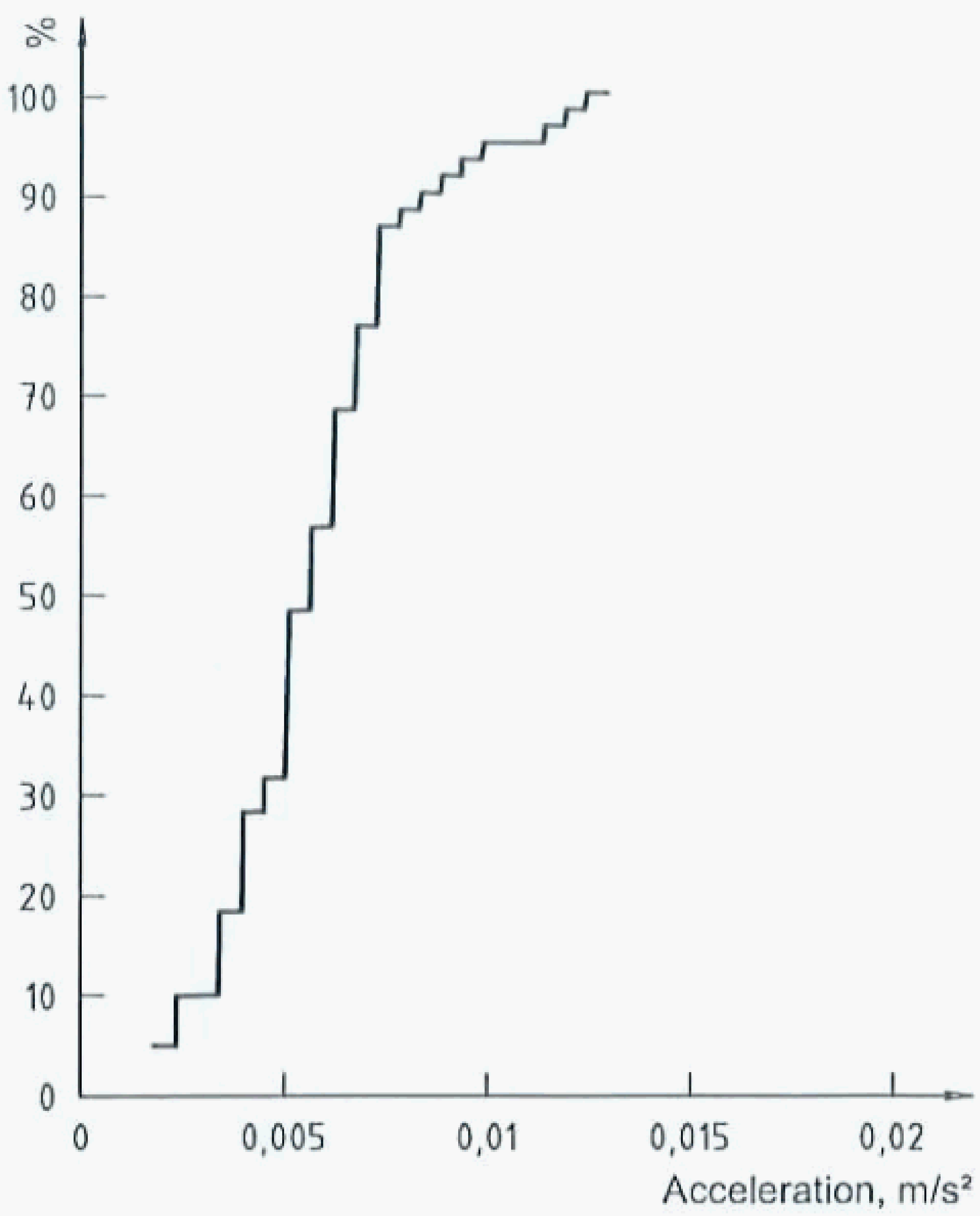
Figure A.4 — R.m.s. acceleration distribution histograms over 5 min



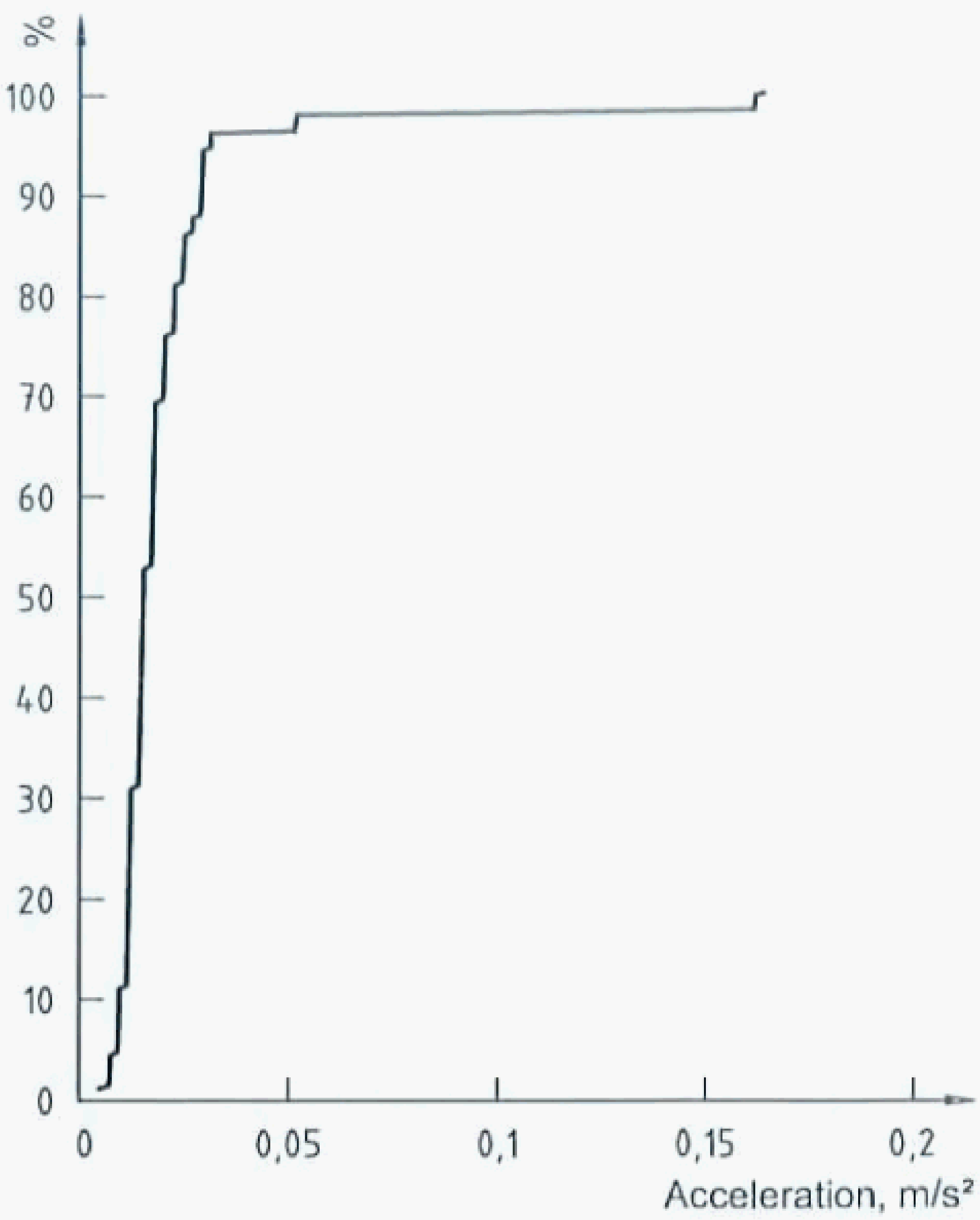
a) **Seat pan, *x*-direction**



b) **Seat pan, *y*-direction**



c) **Seat pan, *z*-direction**



d) **Backrest, *x*-direction**

Figure A.5 — R.m.s. acceleration cumulative distribution histograms over 5 min

Bibliography

[1] ISO 5348, *Mechanical vibration and shock — Mechanical mounting of accelerometers.*

[2] ISO 8041, *Human response to vibration — Measuring instrumentation.*

[3] ENV 12299, *Railway applications — Ride comfort for passengers — Measurement and evaluation.*