INTERNATIONAL STANDARD

ISO 16750-3

Third edition
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Road vehicles — Environmental conditions and testing for electrical and electronic equipment —

Part 3:
Mechanical loads

Véhicules routiers — Spécifications d'environnement et essais de l'équipement électrique et électronique —

Partie 3: Contraintes mécaniques

Reference number
ISO 16750-3:2012(E)

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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 2.

The main task of technical committees is to prepare International Standards. 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 document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 16750-3 was prepared by Technical Committee ISO/TC 22, *Road vehicle*, Subcommittee SC 3, *Electrical and electronical equipment*.

This third edition cancels and replaces the second edition (ISO 16750-3:2007), which has been technically revised.

ISO 16750 consists of the following parts, under the general title *Road vehicles — Environmental conditions and testing for electrical and electronic equipment*:

— *Part 1: General*

— *Part 2: Electrical loads*

— *Part 3: Mechanical loads*

— *Part 4: Climatic loads*

— *Part 5: Chemical loads*

Road vehicles — Environmental conditions and testing for electrical and electronic equipment —

Part 3: **Mechanical loads**

1 Scope

This part of ISO 16750 applies to electric and electronic systems/components for road vehicles. It describes the potential environmental stresses and specifies tests and requirements recommended for the specific mounting location on/in the vehicle.

This part of ISO 16750 describes mechanical loads.

2 Normative references

The following referenced documents are indispensable for the application 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 16750-1, *Road vehicles — Environmental conditions and testing for electrical and electronic equipment — Part 1: General*

IEC 60068-2, 6, *Environmental testing — Part 2-6: Testing, Test Fc: Vibration (Sinusoidal)*

IEC 60068-2, 14, *Basic environmental testing procedures — Part 2-14: Tests — Test Nb: Change of temperature*

IEC 60068-2, 64, *Environmental testing — Part 2-64: Test methods — Test Fh — Vibration, broad-band random (digital control) and guidance*

IEC 60068-2, 80, *Environmental testing — Part 2-80: Tests — Test Fi: Vibration — Mixed mode testing*

IEC 60068-2-31, *Environmental testing procedures — Part 2: Tests; Test Ec: Free fall, Clause 5.2*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 16750-1 apply.

4 Tests and requirements

4.1 Vibration

4.1.1 General

The vibration test methods specified consider various levels of vibration severities applicable to on-board electrical and electronic equipment. It is recommended that the vehicle manufacturer and supplier choose the test method, the environmental temperature and vibration parameters depending on the specific mounting location.

Following the expressions in MIL-STD please notice:

When applied properly, the environmental management and engineering processes described in this part of ISO 16750 can be of enormous value in generating confidence in the environmental worthiness and overall durability. However, it is important to recognize that there are limitations inherent in laboratory testing that make it imperative to use proper caution and engineering judgement when extrapolating these laboratory results to results that may be obtained under actual service conditions. In many cases, real-world environmental stresses (singularly or in combination) cannot be duplicated practically or reliably in test laboratories. Therefore, users of this part of ISO 16750 should not assume that a system or component that passes laboratory tests of this part of ISO 16750 would also pass field/fleet verification trials.

— “The specified values are the best estimation one can get up to the moment when results from measurements in the car are received – but they do not replace a car measurement!”

The specified values apply to direct mounting in defined mounting locations. Using a bracket for mounting can result in higher or lower loads. If the device under test (DUT) is used in the vehicle with a bracket then all vibration and mechanical shock test shall be done with this bracket.

Carry out the vibration with the DUT suitably mounted on a vibration table. The mounting method(s) used shall be noted in the test report. Carry out the frequency variation by logarithmic sweeping of 0,5 octave/minute for sinusoidal tests and the sinusoidal part of sine on random tests. The scope of the recommended vibration tests is to avoid malfunctions and breakage mainly due to fatigue in the field. Testing for wear has special requirements and is not covered in this part of ISO 16750.

Loads outside of the designated test frequency ranges are to be considered separately.

NOTE Deviations from the load on the DUT can result, should vibration testing be carried out according to this part of ISO 16750 on a heavy and bulky DUT, as mounting rigidity and dynamic reaction on the vibrator table excitation are different compared to the situation in the vehicle. This deviation can be minimized by applying the average control method (see Annex A).

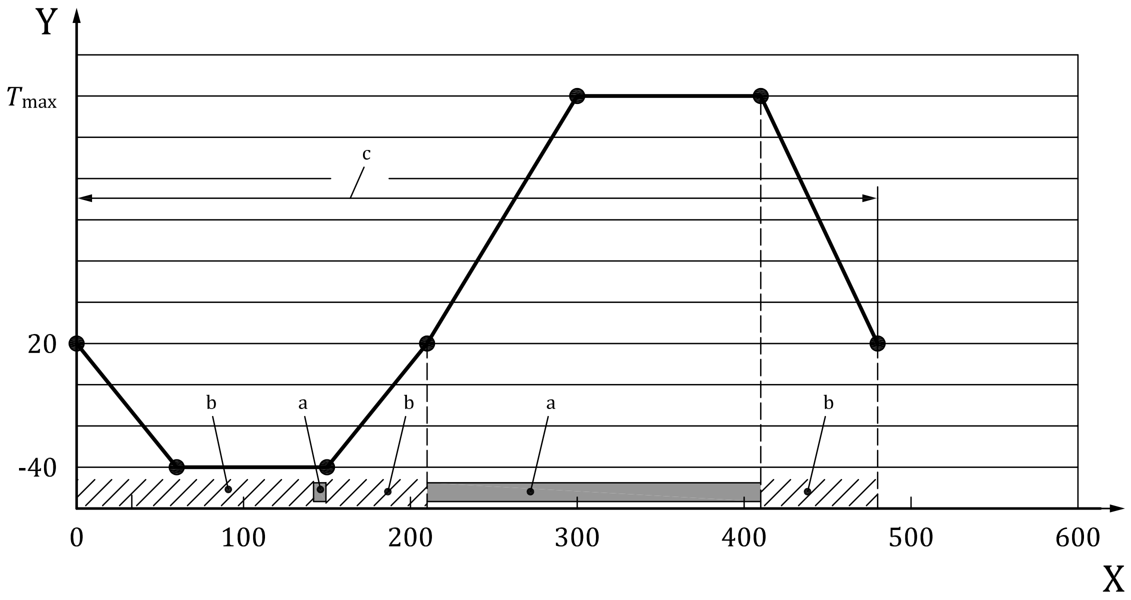
Application of the weighted average control method according to IEC 60068-2, 64 is to be agreed upon.

Subject the DUT during the vibration test to the temperature cycle according to IEC 60068-2, 14, with electric operation according to diagram 1. Alternatively, a test at constant temperature may be agreed on.

Operate the DUT electrically as indicated in Figure 1 at T_{min} (short functional test after the DUT completely reached T_{min}). This functional test shall be as short as possible — only long enough to check the proper performance of the DUT. This minimizes self-heating of the DUT. Additional electrical operation of the DUT between 210 min and 410 min of the cycle (see Figure 1).

Additional drying of test chamber air is not permitted.

In the vehicle, vibration stress can occur together with extremely low or high temperatures; for this reason, this interaction between mechanical and temperature stress is simulated in the test, too. A failure mechanism is, for example, a plastic part of a system/component, which mellows due to the high temperature and cannot withstand the acceleration under this condition.



Key

Y temperature [°C]
X time [min]

a Operating mode 3.2 according to ISO 16750-1.
b Operating mode 2.1 according to ISO 16750-1.
c One cycle.

Figure 1 — Temperature profile for the vibration test

Table 1 — Temperature versus time for the vibration test

Time min	**Temperature** °C
0	20
60	-40
150	-40
210	20
300	T_{max}[a]
410	T_{max}[a]
480	20

a See ISO 16750-4.

4.1.2 Tests

4.1.2.1 Test I — Passenger car, engine

4.1.2.1.1 Purpose

This test checks the DUT for malfunctions and breakage caused by vibration.

The vibrations of a piston engine can be split up into two kinds: Sinusoidal vibration which results from the unbalanced mass forces in the cylinders and random noise due to all other vibration-schemes of an engine, e.g. closing of valves. In the lowest frequency range from 10 Hz to 100 Hz the influence of rough-road conditions is taken into account. The main failure to be identified by this test is breakage due to fatigue.

NOTE 1 Road profile usually has negligible impact on engine-mounted components. Shock inputs are effectively isolated by suspension, and engine-mounting systems.

The test profiles specified in the following clauses apply to loads generated by (four stroke) reciprocating engines.

NOTE 2 If the DUT is to be tested for a specific resonance effect, then a resonance dwell test according to 8.3.2 of IEC 60068-2, 6:2007 can also be applied.

4.1.2.1.2 Test

4.1.2.1.2.1 General

It is required to perform this test as a mixed mode vibration test according to IEC 60068-2, 80.

NOTE The test duration is based on A.4. The temperature in the chamber is above room temperature (RT) at the end of the test (2 3/4 temperature cycles).

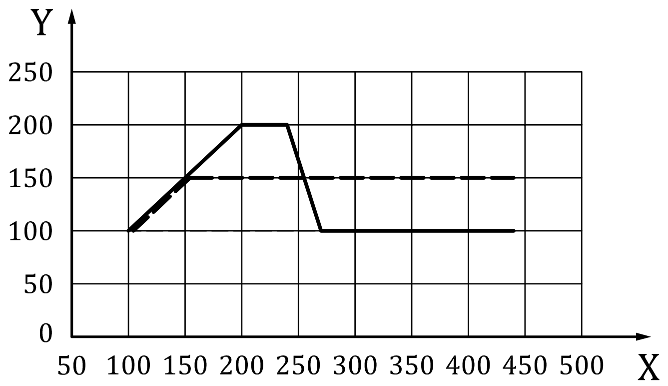
4.1.2.1.2.2 Sinusoidal vibration

Perform the test according to IEC 60068-2, 6, but using a sweep rate of ≤ 0,5 octave/minute. Use a test duration of 22 h for each plane of the DUT.

Use curve 1 in Table 2/Figure 2 for DUT intended for mounting on engines with 5 cylinders or fewer.

Use curve 2 in Table 2/Figure 2 for DUT test intended for mounting on engines with 6 cylinders or more.

Both curves may be combined to cover all engine types in one test.



Key

Y	amplitude of acceleration [m/s²]
X	frequency [Hz]
———	curve 1 (≤5 cylinders)
— —	curve 2 (>5 cylinders)

Figure 2 — Vibration severity curves

Table 2 — Values for max. acceleration versus frequency

Curve 1 (see Figure 2)	
Frequency Hz	**Amplitude of acceleration** m/s^2
100	100
200	200
240	200
270	100
440	100
Curve 2 (see Figure 2)	
Frequency Hz	**Amplitude of acceleration** m/s^2
100	100
150	150
440	150
Combination	
Frequency Hz	**Amplitude of acceleration** m/s^2
100	100
150	150
200	200
240	200
255	150
440	150

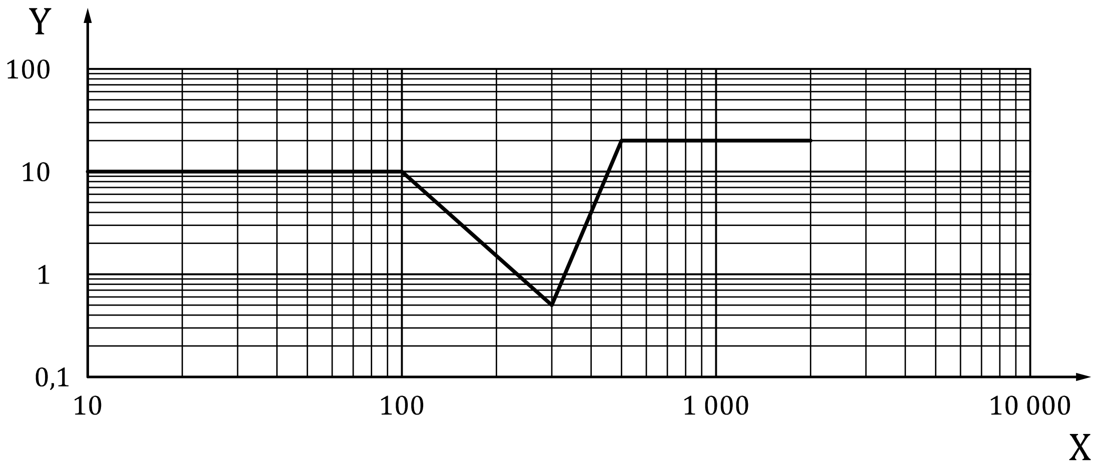
4.1.2.1.2.3 Random vibration

Perform the test according to IEC 60068-2, 64. Use a test duration of 22 h for each plane of the DUT.

The r.m.s. acceleration value shall be 181 m/s^2.

The PSD versus frequency are referred to in Figure 3 and Table 3

NOTE The Power Spectral Density (PSD) values (random vibration) are reduced in the frequency range of the sinusoidal vibration test.



Key

Y PSD [(m/s²)²/Hz]

X frequency [Hz]

Figure 3 — PSD of acceleration versus frequency

Table 3 — Values for frequency and PSD

Frequency Hz	**PSD** $(m/s^2)^2/Hz$
10	10
100	10
300	0,51
500	20
2 000	20

4.1.2.1.3 Requirement

Breakage shall not occur.

Functional status A (see ISO 16750-1) is required during operating mode 3.2 as defined in ISO 16750-1, and functional status C during periods with other operating modes.

4.1.2.2 Test II — Passenger car, gearbox

4.1.2.2.1 Purpose

This test checks the DUT for malfunctions and breakage caused by vibration.

The vibrations of a gearbox can be split up into two kinds which result partly from sinusoidal vibration from unbalanced mass forces of the engine (e.g. dominating orders) in the frequency range from 100 Hz to 440 Hz and vibration from the friction of the gear wheels and other schemes, which are tested in the random part. In the lowest frequency range from 10 Hz to 100 Hz the influence of rough-road conditions is taken into account. The main failure to be identified by this test is breakage due to fatigue.

The test profiles specified in the following subclauses apply to loads generated by gearbox vibrations. Changing the gears can create additional mechanical shock and shall be considered separately.

4.1.2.2.2 Test

4.1.2.2.2.1 General

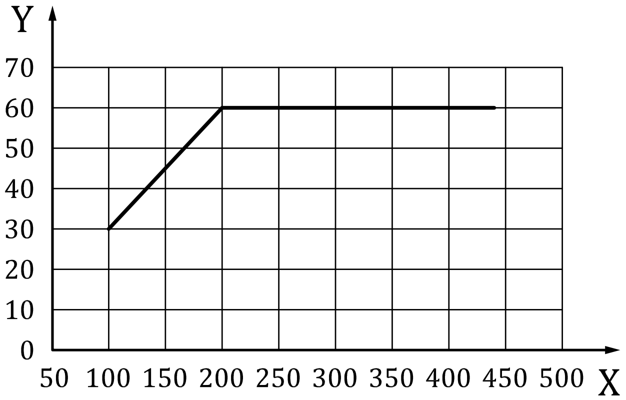
It is required to perform this test as a mixed mode vibration test according to IEC 60068-2, 80.

NOTE The test duration is based on A.4. The temperature in the chamber is above RT at the end of the test (2 3/4 temperature cycles).

4.1.2.2.2.2 Sinusoidal vibration

Perform the test according to IEC 60068-2, 6, but using a sweep rate of ≤ 0,5 octave/minute. Use a test duration of 22 h for each plane of the DUT.

The amplitude versus frequency are referred to in Figure 4 and Table 4.



Key

Y amplitude of acceleration [m/s^2]

X frequency [Hz]

Figure 4 — Acceleration versus frequency

Table 4 — Values for frequency and acceleration

Frequency Hz	**PSD** m/s^2
100	30
200	60
440	60

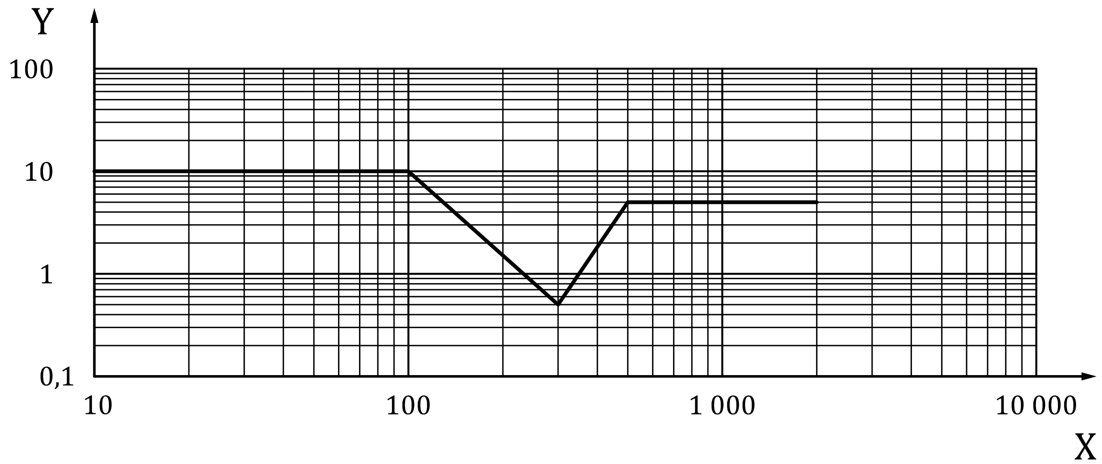
4.1.2.2.2.3 Random vibration

Perform the test according to IEC 60068-2, 64. Use a test duration of 22 h for each plane of the DUT.

The r.m.s. acceleration value shall be 96,6 m/s^2.

NOTE The PSD values (random vibration) are reduced in the frequency range of the sinusoidal vibration test.

The PSD versus frequency are referred to in Figure 5 and Table 5.



Key

Y PSD [(m/s²)²/Hz]

X frequency [Hz]

Figure 5 — PSD of acceleration versus frequency

Table 5 — Values for frequency and PSD

Frequency Hz	**PSD** [(m/s²)²/Hz]
10	10
100	10
300	0,51
500	5
2 000	5

4.1.2.2.3 Requirement

Breakage shall not occur.

Functional status A (see ISO 16750-1) is required during operating mode 3.2 as defined in ISO 16750-1, and functional status C during periods with other operating modes.

4.1.2.3 Test III — Passenger car, flexible plenum chamber

4.1.2.3.1 Purpose

This test checks the DUT for malfunctions and breakage caused by vibration.

This test is applicable to equipment to be mounted on flexible plenum chamber and/or connected to a source of air pulsations (e.g. intake manifold could be a source of air pulsations).

The vibrations are sinusoidal and mainly induced by the pulsation of the intake air.

NOTE This means even in case the DUT is mounted in another area (e.g. car body), connecting the DUT with a tube to the intake manifold leads to vibration load resulting out of air pulsation.

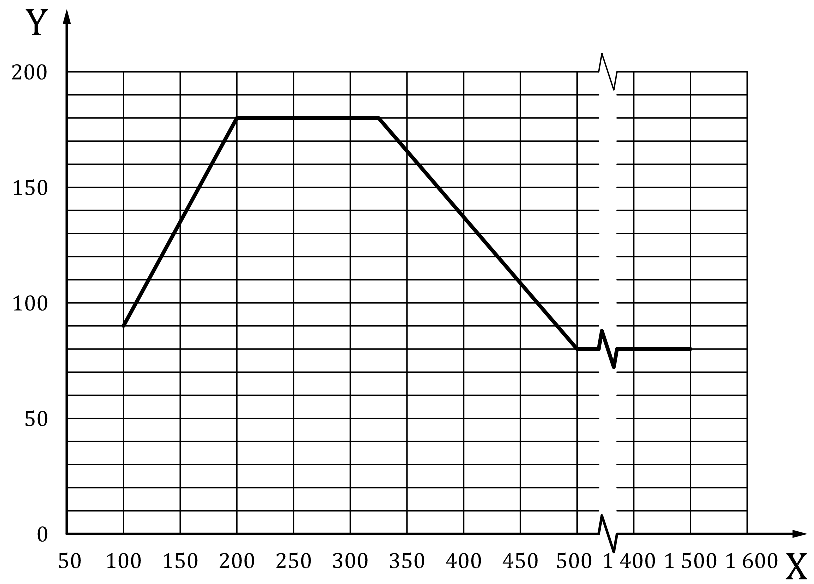
The main failure to be identified by this test is breakage due to fatigue.

4.1.2.3.2 Test

Perform the test according to IEC 60068-2, 6 sinusoidal vibration, but a sweep rate of ≤ 0,5 octave/minute shall be used. Use a test duration of 22 h for each plane of the DUT.

NOTE The test duration is based on A.4. The temperature in the chamber is above RT at the end of the test (2 3/4 temperature cycles).

The amplitude versus frequency are referred to in Figure 6 and Table 6.



Key

Y PSD [(m/s^2)^2/Hz]

X frequency [Hz]

Figure 6 — Max. acceleration versus frequency

Table 6 — Values for acceleration and frequency

Frequency Hz	**Amplitude of acceleration** (m/s^2)
100	90
200	180
325	180
500	80
1 500	80

4.1.2.3.3 Requirement

Breakage shall not occur.

Functional status A (see ISO 16750-1) is required during operating mode 3.2 as defined in ISO 16750-1, and functional status C during periods with other operating modes

4.1.2.4 Test IV — Passenger car, sprung masses (vehicle body)

4.1.2.4.1 Purpose

This test checks the DUT for malfunctions and breakage caused by vibration.

Vibration of the body is random vibration induced by rough-road driving. The main failure to be identified by this test is breakage due to fatigue.

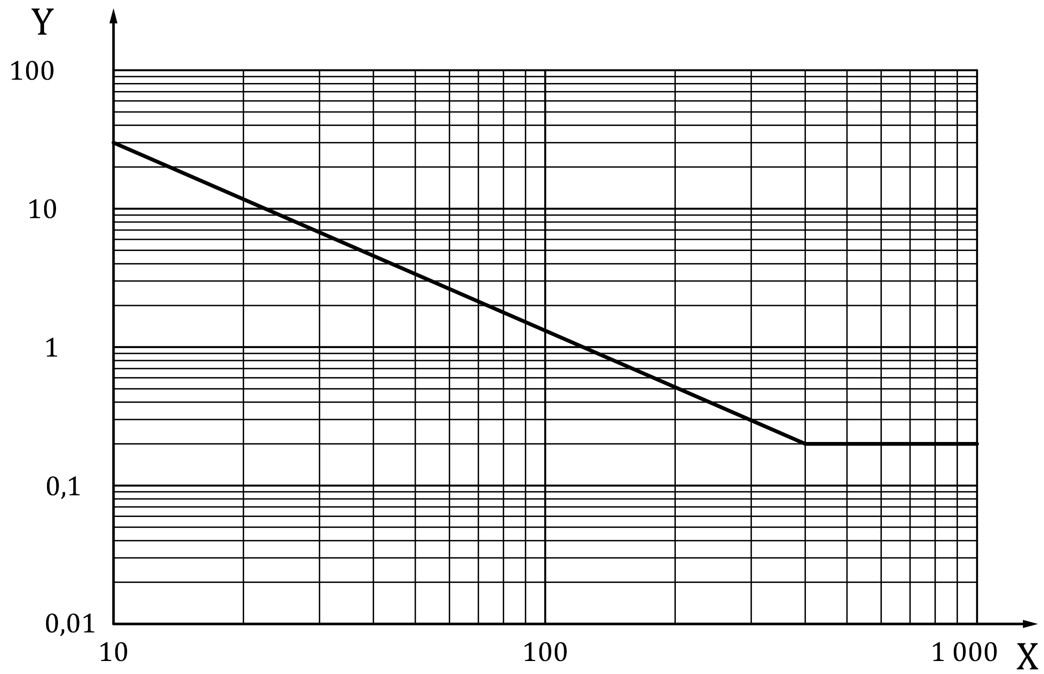
4.1.2.4.2 Test

Perform the test according to IEC 60068-2, 64 random vibration. Use a test duration of 8 h for each plane of the DUT.

The r.m.s. acceleration value shall be 27,1 m/s^2.

The PSD versus frequency are referred to in Figure 7 and Table 7.

NOTE The test duration is based on A.5.



Key

Y PSD [(m/s^2)^2/Hz]

X frequency [Hz]

Figure 7 — PSD of acceleration versus frequency

Table 7 — Values for PSD and frequency

Frequency Hz	**PSD** [(m/s^2)^2/Hz]
10	30
400	0,2
1 000	0,2

4.1.2.4.3 Requirement

Breakage shall not occur.

Functional status A (see ISO 16750-1) is required during operating mode 3.2 as defined in ISO 16750-1, and functional status C during periods with other operating modes.

4.1.2.5 Test V — Passenger car, unsprung masses (wheel, wheel suspension)

4.1.2.5.1 Purpose

This test checks the DUT for malfunctions and breakage caused by vibration.

Vibration of unsprung masses is random vibration induced by rough-road driving. The main failure to be identified by this test is breakage due to fatigue.

Loads with frequencies lower than 20 Hz are not covered by the test profile specified here. In practice high amplitudes can occur below 20 Hz; therefore, loads acting on the DUT in this frequency range shall be considered separately.

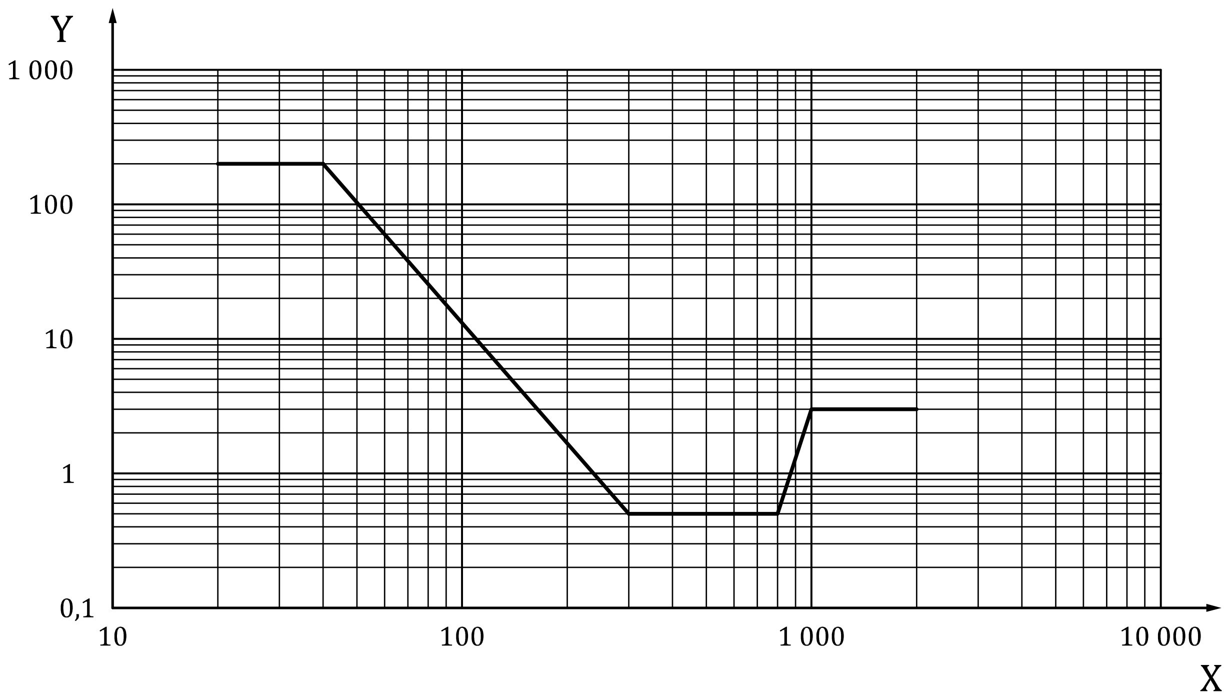
4.1.2.5.2 Test

Perform the test according to IEC 60068-2, 64 random vibration. Use a test duration of 8 h for each plane of the DUT.

The r.m.s. acceleration is 107,3 m/s^2.

The PSD versus frequency are referred to in Figure 8 and Table 8.

NOTE The test duration is based on A.5.



Key

Y PSD [(m/s^2)^2/Hz]

X frequency [Hz]

Figure 8 — PSD of acceleration versus frequency

Table 8 — Values for PSD and frequency

Frequency Hz	PSD [(m/s^2)^2/Hz]
20	200
40	200
300	0,5
800	0,5
1 000	3
2 000	3

4.1.2.5.3 Requirement

Breakage shall not occur.

Functional status A (see ISO 16750-1) is required during operating mode 3.2 as defined in ISO 16750-1, and functional status C during periods with other operating modes.

4.1.2.6 Test VI — Commercial vehicle, engine, gearbox

4.1.2.6.1 Purpose

This test checks the DUT for malfunctions and breakage caused by vibration.

The vibrations of a piston-engine can be split up into two kinds: sinusoidal vibration which results from unbalanced mass forces and random noise due to all other vibration sources of an engine, e.g. closing of valves.

Because the gearbox is rigidly attached to the engine, this test can also be used for systems/components mounted at the gearbox. But there is no sufficient number of measurements on gearbox-mounted systems/components performed up to now.

The main failure to be identified by this test is breakage due to fatigue.

If the DUT has natural frequencies below 30 Hz, an additional test is to be carried out with a duration of 32 h in all critical planes of the DUT.

4.1.2.6.2 Test

4.1.2.6.2.1 General

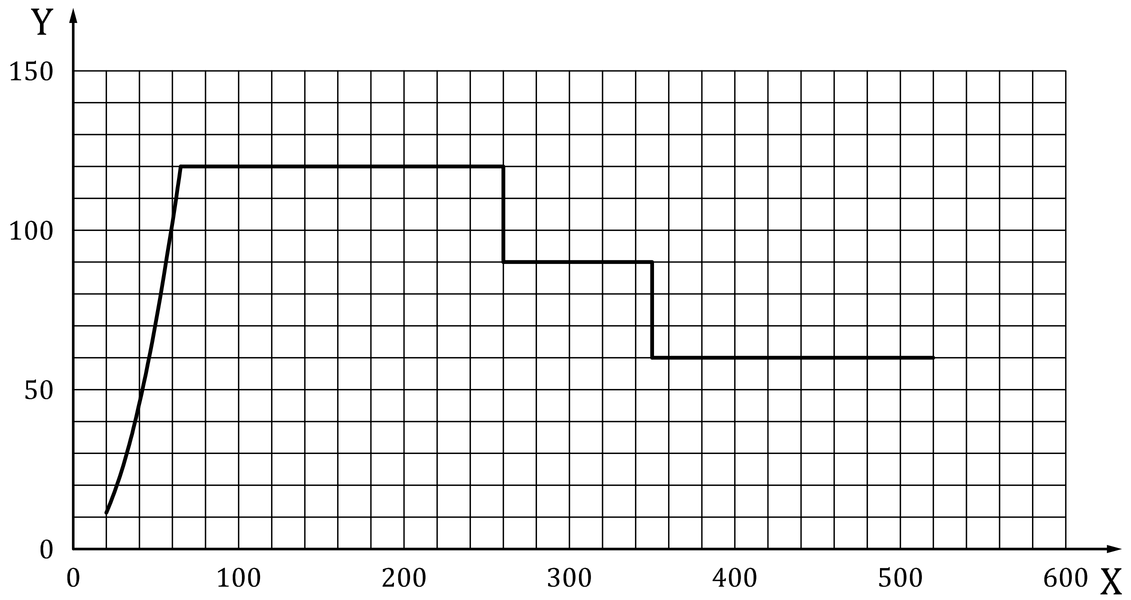
It is required to perform this test as a mixed mode vibration test according to IEC 60068-2, 80.

NOTE The temperature in the chamber is above RT at the end of the test (11 3/4 cycles).

4.1.2.6.2.2 Sinusoidal vibration

Perform the test according to IEC 60068-2, 6, but using a sweep rate of ≤ 0,5 octave/minute. Use a test duration of 94 h for each plane of the DUT (equivalent to approx. 20 h per octave). This is equivalent to 10^7 cycles in resonance in case of resonance bandwidth of 100 Hz or more. See Table A.2.

The amplitude versus frequency are referred to in Figure 9 and Table 9.



Key

Y amplitude of acceleration [m/s2]

X frequency [Hz]

Figure 9 — Max. acceleration versus frequency

Table 9 — Values for max. acceleration and frequency

Frequency Hz	**Amplitude of displacement** (mm)	**Amplitude of acceleration** (m/s2)
20	0,72	(11,4)
65	0,72	120
260		120
260		90
350		90
350		60
520		60

4.1.2.6.2.3 Random vibration

Perform the test according to IEC 60068-2, 64.

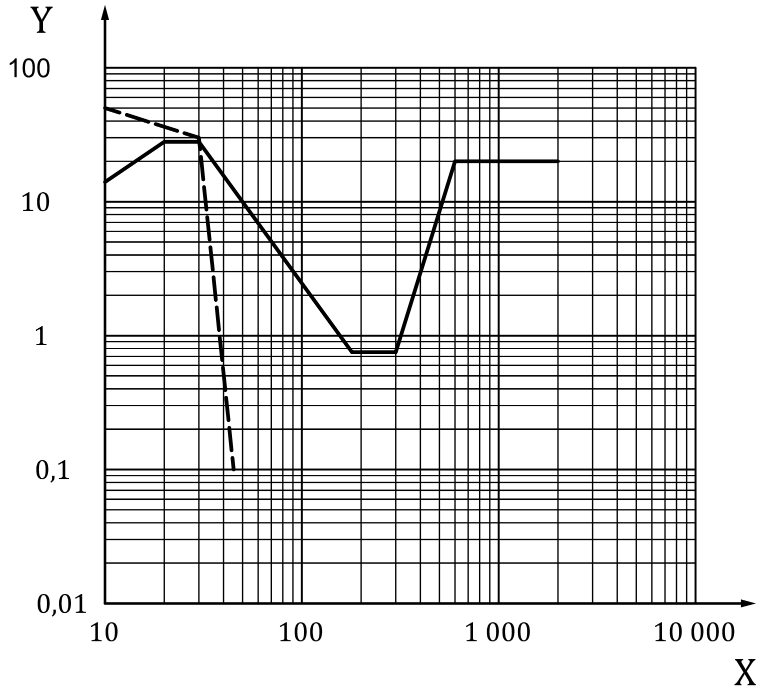
Test duration:

— 94 h for each plane of the DUT (standard) (see Figure 10 and Table 10),

— 32 h additionally for each critical plane of the DUT (for natural frequencies below 30 Hz) (see Table 11).

NOTE The PSD values (random vibration) are reduced in the frequency range of the sinusoidal vibration test.

The PSD versus frequency are referred to in Figure 10 and Tables 10 and 11.



Key

Y	PSD [(m/s²)²/Hz]
X	frequency [Hz]
———	standard random test profile
— —	additional profile in case of f_n < 30 Hz

Figure 10 — PSD of acceleration versus frequency

Table 10 — Values for PSD and frequency

Frequency Hz	**PSD** [(m/s²)²/Hz]
10	14
20	28
30	28
180	0,75
300	0,75
600	20
2 000	20
r.m.s. acceleration value = 177 m/s²	

Table 11 — Values for PSD and frequency, additional test in case of natural frequencies f_n of DUT below 30 Hz

Frequency Hz	**PSD** [(m/s^2)^2/Hz]
10	50
30	30
45	0,1
r.m.s. acceleration value = 28,6 m/s^2	

4.1.2.6.3 Requirement

Breakage shall not occur.

Functional status A (see ISO 16750-1) is required during operating mode 3.2 as defined in ISO 16750-1, and functional status C during periods with other operating modes.

4.1.2.7 Test VII — Commercial vehicle, sprung masses

4.1.2.7.1 Purpose

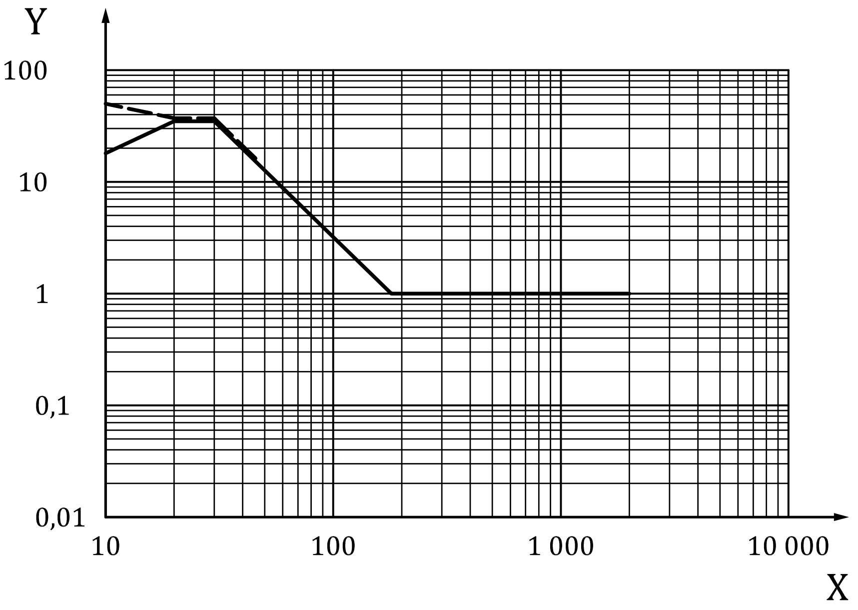
This test checks the DUT for malfunctions and breakage caused by vibration.

Vibration on sprung masses is random vibration induced by rough-road driving. The main failure to be identified by this test is breakage due to fatigue.

4.1.2.7.2 Test

Perform the test according to IEC 60068-2, 64, random vibration. Use a test duration of 32 h for each plane of the DUT.

The PSD versus frequency are referred to in Figure 11 and Tables 12 and 13.



Key

Y PSD [(m/s²)²/Hz]

X frequency [Hz]

——— standard random test profile

— — additional profile in case of f_n < 30 Hz

Figure 11 — PSD of acceleration versus frequency

Table 12 — Values for PSD and frequency

Frequency Hz	**PSD** [(m/s²)²/Hz]
10	18
20	36
30	36
180	1
2 000	1
r.m.s. acceleration value = 57,9 m/s²	

Table 13 — Values for PSD and frequency, additional test in case of natural frequencies f_n of DUT below 30 Hz

Frequency Hz	**PSD** [(m/s²)²/Hz]
10	50
20	36
30	36
45	16
r.m.s. acceleration value = 33,7 m/s²	

4.1.2.7.3 Requirement

Breakage shall not occur.

Functional status A (see ISO 16750-1) is required during operating mode 3.2 as defined in ISO 16750-1, and functional status C during periods with other operating modes.

4.1.2.8 Test VIII — Commercial vehicle, decoupled cab

4.1.2.8.1 Purpose

This test checks the DUT for malfunctions and breakage caused by vibration.

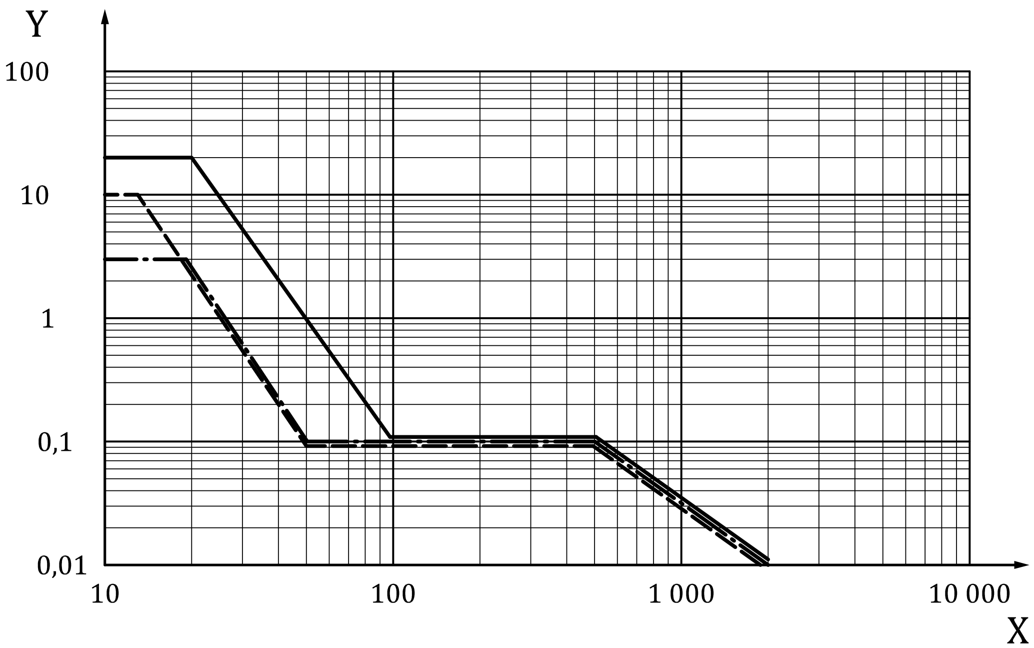
Vibration on a decoupled commercial vehicle cab is random vibration induced by rough-road driving. The main failure to be identified by this test is breakage due to fatigue.

4.1.2.8.2 Test

Perform the test according to IEC 60068-2, 64, random vibration.

Test duration: 32 h for each plane of the DUT.

The PSD versus frequency are referred to in Figure 12 and Table 14.



Key

Y PSD [$(m/s^2)^2$/Hz]

X frequency [Hz]

——— vertical

— — lateral

—·— longitudinal

Figure 12 — PSD of acceleration versus frequency

Table 14 — Values for PSD and frequency

Frequency [Hz]	**PSD** $[(m/s^2)^2/Hz]$		
	vertical	**longitudinal**	**lateral**
10	20	3	10
13	-	-	10
19	-	3	-
20	20	-	-
50	-	0,1	0,1
100	0,1	-	-
500	0,1	0,1	0,1
2 000	0,01	0,01	0,01
r.m.s. acceleration value	21,3 m/s^2	11,8 m/s^2	13,1 m/s^2

4.1.2.8.3 Requirement

Breakage shall not occur.

Functional status A (see ISO 16750-1) is required during operating mode 3.2 as defined in ISO 16750-1, and functional status C during periods with other operating modes.

4.1.2.9 Test IX — Commercial vehicle, unsprung masses

4.1.2.9.1 Purpose

This test checks the DUT for malfunctions and breakage caused by vibration.

Vibration on unsprung masses is vibration induced by rough-road driving. The main failure to be identified by this test is breakage due to fatigue.

4.1.2.9.2 Test

Perform the random vibration test VII as in 4.1.2.7.2 and in addition the sinusoidal vibration test described below.

Carry out the sinusoidal vibration test at RT.

The sinusoidal vibration test according to Table 15 describes the maximum amplitudes of acceleration on wheels and wheel suspension and the respective frequencies. If natural frequencies of the DUT below 40 Hz can be ruled out, the test can be carried out with a test frequency of 35 Hz (see Figure 16) so that it can be performed on an electro-mechanical test stand.

Table 15 — Values for max. acceleration and frequency in case of lowest natural frequency of a DUT < 40 Hz

Plane as mounted in vehicle	Frequency [Hz]	Amplitude of acceleration [m/s²]	Duration [min]	No. of cycles (approx.)
longitudinal, lateral	8 to 16	150	4	2 800
	8 to 16	120	10	7 000
	8 to 32	100	20	21 000
vertical	8 to 16	300	4	2 800
	8 to 16	250	10	7 000
	8 to 32	200	20	21 000

Table 16 — Values for max. acceleration and frequency in case of lowest natural frequency of a DUT ≥ 40 Hz

Plane as mounted in vehicle	Frequency [Hz]	Amplitude of acceleration [m/s²]	No. of cycles (approx.)
longitudinal, lateral	35	150	2 800
	35	120	7 000
	35	100	21 000
vertical	35	300	2 800
	35	250	7 000
	35	200	21 000

4.1.2.9.3 Requirement

Breakage shall not occur.

Functional status A (see ISO 16750-1) is required during operating mode 3.2 as defined in ISO 16750-1, and functional status C during periods with other operating modes.

4.1.2.10 Test X — Passenger car, fuel rail (gasoline engine with GDI-system)

4.1.2.10.1 Purpose

This test checks the DUT for malfunctions and breakage caused by vibration.

Vibration load on rail-mounted components is mainly influenced by rail resonances. Depending on design and mounting the rail resonance frequency will occur between approximately 700 Hz and 2000 Hz. The main failure to be identified by this test is breakage due to fatigue.

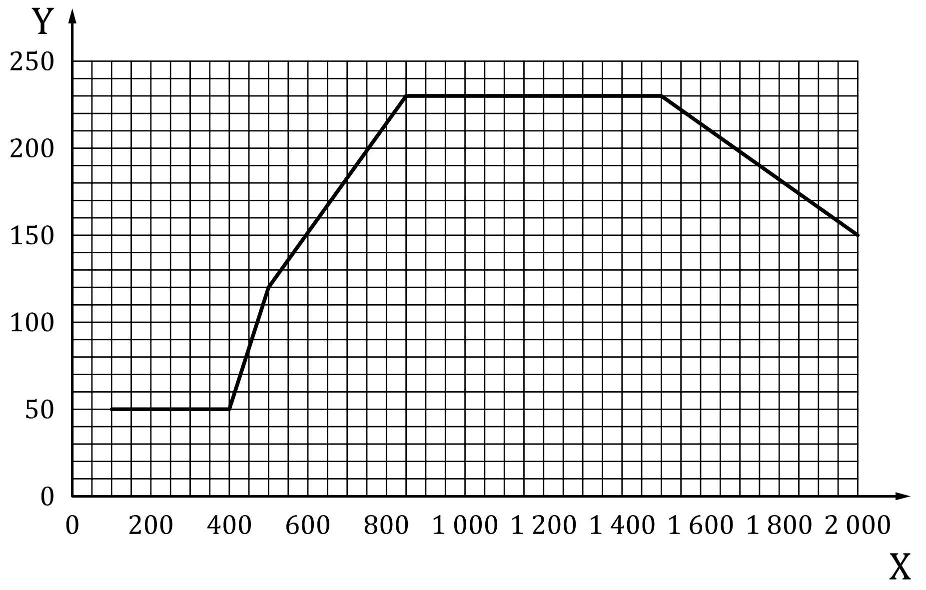
4.1.2.10.2 Test

4.1.2.10.2.1 General

It is required to perform this test as a mixed mode vibration test according to IEC 60068-2, 80.

4.1.2.10.2.2 Sinusoidal vibration

Perform the test according to IEC 60068-2, 6, but using a sweep rate of ≤ 0,5 octave/minute. Use a test duration of 40 h for each plane of the DUT. The amplitude versus frequency are referred to in Figure 13 and Table 17.



Key

Y amplitude of acceleration [m/s^2]

X frequency [Hz]

Figure 13 — Acceleration versus frequency

Table 17 — Values for frequency and acceleration

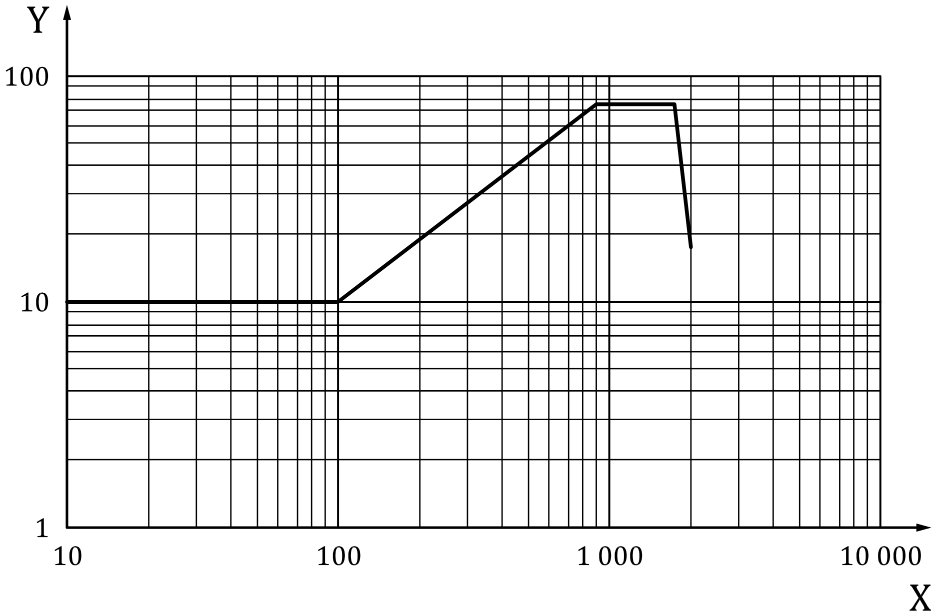
Frequency Hz	**Amplitude of acceleration** m/s^2
100	50
400	50
500	120
850	230
1 500	230
2 000	150

4.1.2.10.2.3 Random vibration

Perform the test according to IEC 60068-2, 64. Use a test duration of 40 h for each plane of the DUT.

The r.m.s. acceleration value shall be 331 m/s^2.

The PSD versus frequency are referred to in Figure 14 and Table 18.



Key

Y PSD [(m/s^2)^2/Hz]

X frequency [Hz]

Figure 14 — PSD of acceleration versus frequency

Table 18 — Values for frequency and PSD

Frequency Hz	**PSD** [(m/s^2)^2/Hz]
10	10
100	10
900	75
1 750	75
2 000	18

4.1.2.10.2.4 Requirement

Breakage shall not occur.

Functional status A (see ISO 16750-1) is required during operating mode 3.2 as defined in ISO 16750-1, and functional status C during periods with other operating modes.

4.1.2.11 Test XI — Passenger car, solid intake manifold

4.1.2.11.1 Purpose

This test checks the DUT for malfunctions and breakage caused by vibration.

Vibration on intake manifold components is influenced by resonances of the manifold and air pulsation. Out of this there is a difference between the conditions on engine and manifold.

This test is applicable for manifolds made of plastics and for those made of metal.

The main failure to be identified by this test is breakage due to fatigue.

4.1.2.11.2 Test

4.1.2.11.2.1 General

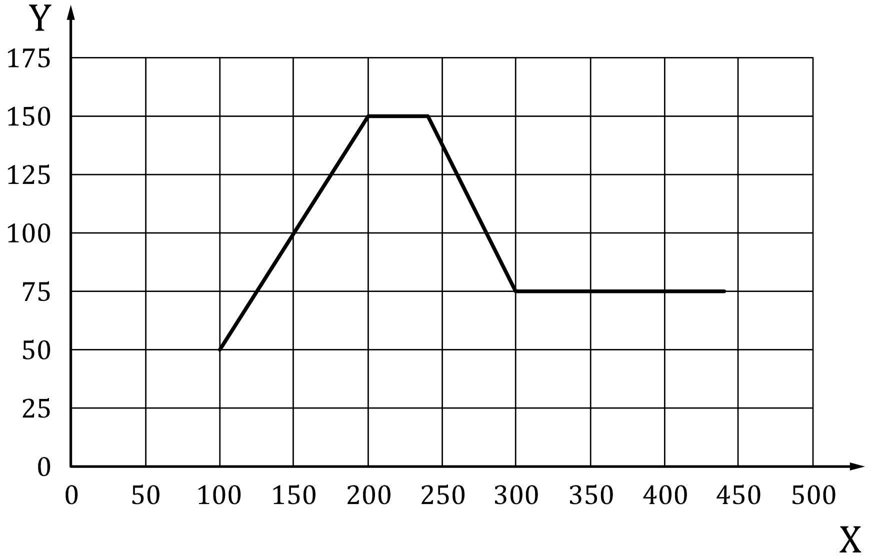
It is required to perform this test as a mixed mode vibration test according to IEC 60068-2, 80.

NOTE The test duration is based on A.4. The temperature in the chamber is above RT at the end of the test (2 3/4 temperature cycles).

4.1.2.11.2.2 Sinusoidal vibration

Perform the test according to IEC 60068-2, 6, but using a sweep rate of ≤ 0,5 octave/minute. Use a test duration of 22 h for each plane of the DUT.

The amplitude versus frequency are referred to in Figure 15 and Table 19.



Key

Y amplitude of acceleration [m/s2]

X frequency [Hz]

Figure 15 — Acceleration versus frequency

Table 19 — Values for frequency and acceleration

Frequency Hz	Amplitude of acceleration (m/s2)
100	50
150	100
200	150
240	150
300	75
440	75

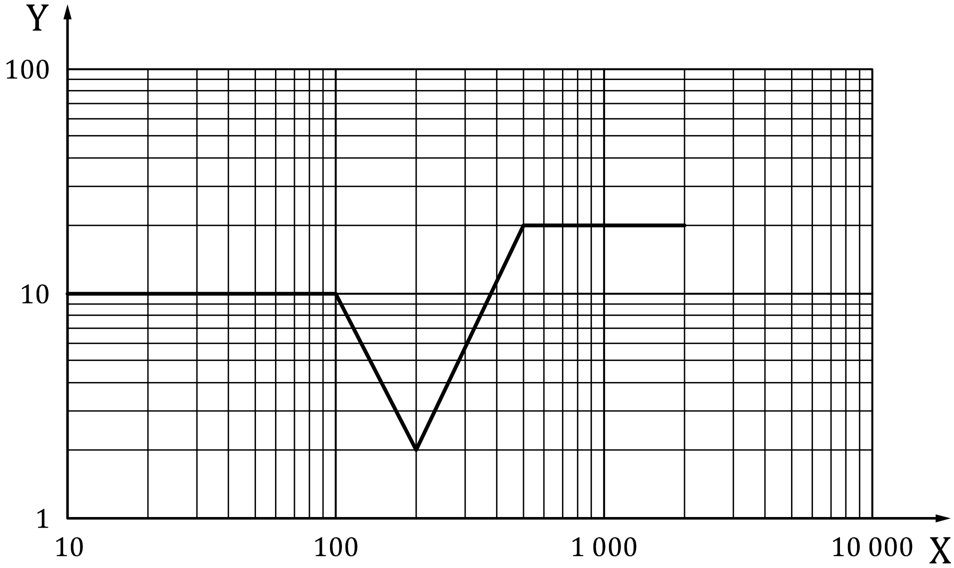
4.1.2.11.2.3 Random vibration

Perform the test according to IEC 60068-2, 64. Use a test duration of 22 h for each plane of the DUT.

The r.m.s. acceleration value shall be 184,5 m/s^2.

NOTE The PSD values (random vibration) are reduced in the frequency range of the sinusoidal vibration test.

The PSD versus frequency are referred to in Figure 16 and Table 20.



Key

Y PSD [(m/s^2)^2/Hz]

X frequency [Hz]

Figure 16 — PSD of acceleration versus frequency

Table 20 — Values for frequency and PSD

Frequency Hz	**PSD** [(m/s^2)^2/Hz]
10	10
100	10
200	2
500	20
2 000	20

4.1.2.11.3 Requirement

Breakage shall not occur.

Functional status A (see ISO 16750-1) is required during operating mode 3.2 as defined in ISO 16750-1, and functional status C during periods with other operating modes.

4.1.2.12 Test XII — Passenger car, exhaust pipe

4.1.2.12.1 Purpose

This test checks the DUT for malfunctions and breakage caused by vibration.

Vibration on exhaust pipe mounted components is influenced by resonances of the pipe and exhaust pulsation. Out of this there may be a difference between the conditions on engine and exhaust pipe, depending, for example, on the distance between the engine and application area.

The main failure to be identified by this test is breakage due to fatigue.

There are three tests to be defined:

XIIa valid for sensors with natural frequencies > 1 000 Hz;

XIIb valid for modules, mounted before the decoupling element;

XIIc valid for modules, mounted behind the decoupling element.

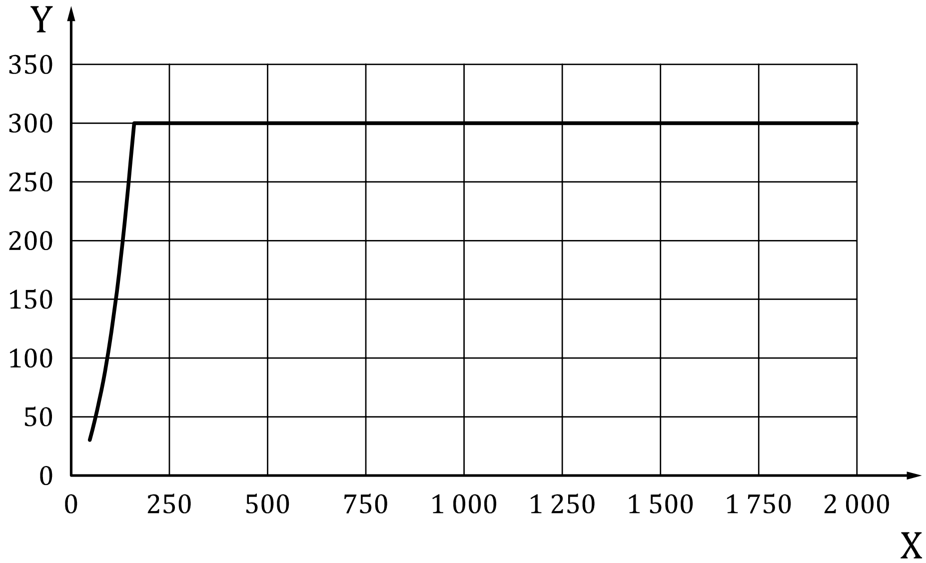
4.1.2.12.2 Test conditions

Test conditions XIIa: valid for sensors with natural frequencies > 1000 Hz

Perform the test according to IEC 60068-2, 6, but using a sweep rate of ≤ 0,5 octave/minute. Use a test duration of 50 h for each plane of the DUT. This is equivalent to 5 x 10^6 cycles in resonance in case of resonance bandwidth of 100 Hz or more. See Table A.2.

The amplitude versus frequency are referred to in Figure 17 and Table 21.

Ambient temperature: as measured in the car, e.g. 600 °C on the mounting position.



Key

Y amplitude of acceleration [m/s^2]

X frequency [Hz]

Figure 17 — Acceleration versus frequency

Table 21 — Frequency and amplitude

Frequency Hz	**Amplitude**
50 to 160	0,3 mm
160 to 2 000	300 m/s^2

Test conditions for XIIb: valid for modules, mounted before the decoupling element

The DUT has to be tested following to the conditions as defined for engine mounted components.

The temperature in the chamber shall be defined between customer and supplier.

Test conditions for XIIc: valid for modules, mounted behind the decoupling element

This test checks the DUT for malfunctions and breakage caused by vibration.

Test – General, for XIIc

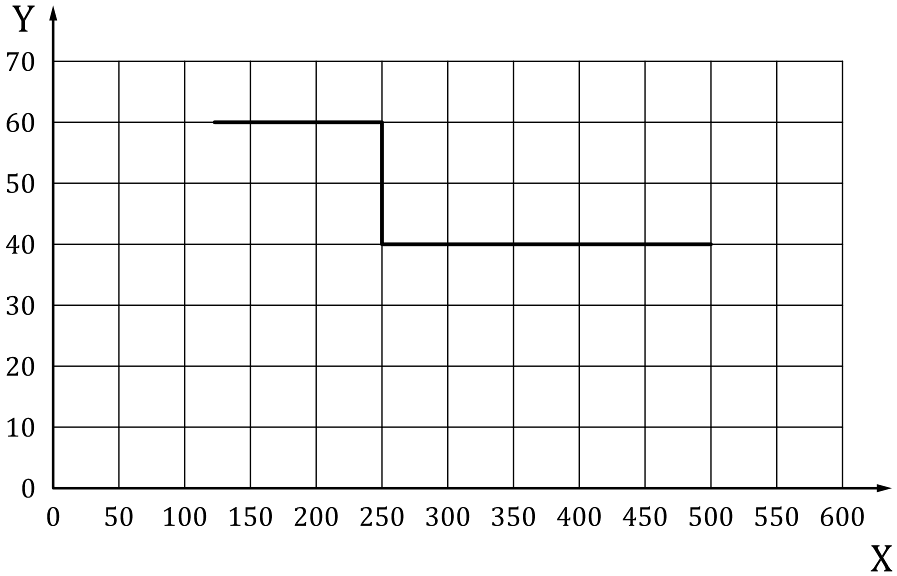
It is required to perform this test as a mixed mode vibration test according to IEC 60068-2, 80.

The temperature in the chamber shall be defined between customer and supplier.

Sinusoidal vibration for XIIc

Perform the test according to IEC 60068-2, 6, but a sweep rate of ≤ 0,5 octave/minute shall be used. Use a test duration of 40 h for each plane of the DUT.

The amplitude versus frequency are referred to Figure 18 and Table 22.



Key

Y amplitude of acceleration [m/s²]

X frequency [Hz]

Figure 18 — Acceleration versus frequency

Table 22 — Values for frequency and acceleration

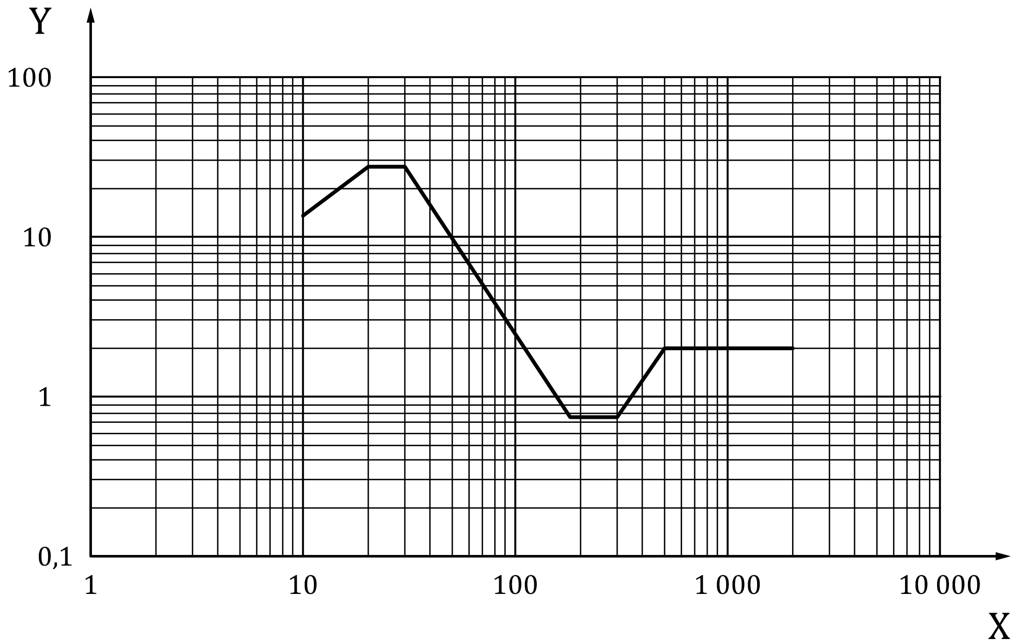
Frequency Hz	**Amplitude of acceleration** (m/s²)
125 to 250	60
250 to 500	40

Random vibration for XIIc

Perform the test according to IEC 60068-2, 64. Use a test duration of 40 h for each plane of the DUT.

The r.m.s. acceleration value shall be 67,4 m/s2.

The PSD versus frequency are referred to Figure 19 and Table 23.



Key

Y PSD [(m/s2)2/Hz]

X frequency [Hz]

Figure 19 — PSD of acceleration versus frequency

Table 23 — Values for frequency and PSD

Frequency Hz	**PSD** [(m/s2)2/Hz]
10	14
20	28
30	28
180	0,75
300	0,75
500	2
2 000	2

4.1.2.12.3 Requirement

Breakage shall not occur.

Functional status A (see ISO 16750-1) is required during operating mode 3.2 as defined in ISO 16750-1, and functional status C during periods with other operating modes.

4.2 Mechanical shock

4.2.1 Test for devices in or on doors and flaps

4.2.1.1 Purpose

This test checks the DUT for malfunctions and breakage caused by shock of door slamming.

The load occurs on closures when slammed shut. Failure mode is mechanical damage (e.g. a detached capacitor inside the housing of electronic control module due to the high accelerations caused by door slamming).

4.2.1.2 Test

Choose one of the profiles indicated in Table 24 and perform the test according to IEC 60068-2, 27:

— operating mode of the DUT: 1.2 (see ISO 16750-1);

— shock form (pulse shapes): half-sinusoidal.

The DUT shall be fixed on the shaker in a direction to generate the effect of acceleration in the same direction as it occurs in vehicle use.

Table 24 — Number of shocks

	Shock profile 1	**Shock profile 2**
	500 m/s^2; 11 ms	300 m/s^2; 6 ms
Driver’s door, cargo door	13 000	100 000
Passenger’s doors	6 000	50 000
Trunk lid, tailgate	2 400	30 000
Engine hood	720	3 000

4.2.1.3 Requirement

Breakage shall not occur. Functional status shall be class C as defined in ISO 16750-1.

4.2.2 Test for devices on rigid points on the body and on the frame

4.2.2.1 Purpose

This test checks the DUT for malfunctions and breakage caused by shock to body and frame.

The load occurs when driving over a curb stone at high speed, etc. Failure mode is mechanical damage (e.g. a detached capacitor inside the housing of an electronic control module due to the occurring high accelerations).

4.2.2.2 Test

Perform the test according to IEC 60068-2, 27:

operating mode of the DUT: 3.2 (see ISO 16750-1);

pulse shape: half-sinusoidal;

acceleration: 500 m/s^2;

duration: 6 ms;

— number of shocks: 10 per test direction.

Acceleration due to the shock in the test shall be applied in the same direction in which the acceleration of the shock occurs in the vehicle. If the direction of the effect is not known, the DUT shall be tested in all six spatial directions.

4.2.2.3 Requirement

Breakage shall not occur. Functional status shall be class A as defined in ISO 16750-1.

4.2.3 Test for devices in or on the gearbox

4.2.3.1 Purpose

This test checks the DUT for malfunctions and breakage caused by shock of gear shifting.

This test is applicable to DUT intended for mounting in or on the gearbox.

The loads occur during pneumatic powered gear-shifting operations. Failure mode is mechanical damage (e.g. a detached capacitor inside the housing of an electronic control module due to the high accelerations caused by pneumatically powered gear-shifting operations).

4.2.3.2 Test

Perform the test according to IEC 60068-2, 27:

— operating mode of the DUT: 3.2 (see ISO 16750-1);

— pulse shape: half-sinusoidal;

— typical max. acceleration:

  — for commercial vehicles: 3 000 m/s^2 (in single cases measured up to 50 000 m/s^2),

  — for passenger cars: to be agreed between customer and supplier;

— typical duration: < 1 ms;

temperature: to be agreed between customer and supplier;

number of shocks: to be agreed between customer and supplier.

The aforementioned values for commercial vehicles occur primarily during pneumatically supported gear-shifting operations (150 000 gear-shifting operations are typical if a range-change system is fitted).

The actual shock stresses depend both on the installation position of the gearbox and also on the design features of the gearbox and shall in individual cases be ascertained by means of suitable measurements (recommended sampling frequency: at least 25 kHz). A test shall be arranged between the manufacturer and the user.

The acceleration due to the shock in the test shall be applied in the same direction in which the acceleration of the shock occurs in the vehicle. If the direction of the effect is not known, the DUT shall be tested in all six spatial directions.

4.2.3.3 Requirement

Breakage shall not occur. Functional status shall be class A as defined in ISO 16750-1.

4.3 Free fall

4.3.1 Purpose

This test checks the DUT for malfunctions and breakage caused by free fall.

A system/component may drop down to the floor during handling (e.g. at the manufacturing line of the car manufacturer). If a system/component is visibly damaged after a fall, it will be replaced. But if it is not visibly damaged, it will be installed in the car and then it shall work correctly. Failure mode is mechanical damage (e.g. a detached capacitor inside the housing of an electronic control module due to the high accelerations when the DUT hits the ground).

4.3.2 Test

Parts that obviously will be damaged by the fall shall not be checked (e.g. headlights). Parts that may withstand falling without visible damage shall be checked as follows:

Perform the test sequence according to IEC 60068-2, 31 using the following test parameters:

number of DUT:	3;
falls per DUT:	2;
drop height:	1 m free fall or the height of handling according to agreement;
impact surface:	concrete ground or steel plate;
orientation of the DUT:	1st fall of each DUT at a different dimensional axis, 2nd fall with the given DUT at the same dimensional axis but on the opposite side of the housing;
operating mode of the DUT:	1.1 (see ISO 16750-1;)
temperature:	has to be agreed between customer and supplier.

The DUT shall be visually examined after the falls.

4.3.3 Requirement

Hidden damage is not permitted. Minor damage of the housing is permitted as long as this does not affect the performance of the DUT. Proper performance shall be proven following the test.

Functional status shall be class C as defined in ISO 16750-1.

4.4 Surface strength/scratch and abrasion resistance

Tests and requirements shall be agreed upon between manufacturer and customer (e.g. marking and labelling on control elements and keys shall remain visible).

4.5 Gravel bombardment

This test checks the resistance against gravel bombardment (in exposed mounting locations, e.g. front end).

5 Code letters for mechanical loads

See Table 25.

6 Documentation

For documentation the designations outlined in ISO 16750-1 shall be used.

Table 25 — Coding in relation to tests and requirements

	Requirement according to																
Section	4.1.2.1.2.2	4.1.2.1.2.3	4.1.2.2	4.1.2.3	4.1.2.4	4.1.2.5	4.1.2.6.2.2	4.1.2.6.2.3	4.1.2.7	4.1.2.8	4.1.2.9	4.1.2.10	4.1.2.11	4.1.2.12	5.2.1	5.2.1	4.2.2	5.3
Code letter	**Test I sinusoidal**	**Test I random**	**Test II**	**Test III**	**Test IV**	**Test V**	**Test VI sinusoidal**	**Test VI random**	**Test VII**	**Test VIII**	**Test IX**	**Test X**	**Test XI**	**Test XII**	**Mecha-nical shock Sever-ity 1**	**Mecha-nical shock Sever-ity 2**	**Mecha-nical shock**	**Free fall**
A	Curve 1	yes	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	yes
B	Curve 2	yes	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	yes
C	-	-	-	yes	-	-	-	-	-	-	-	-	-	-	-	-	-	yes
D	-	-	-	-	yes	-	-	-	-	-	-	-	-	-	-	-	-	yes
E	-	-	-	-	yes	-	-	-	-	-	-	-	-	-	-	-	yes	yes
F	-	-	-	-	yes	-	-	-	-	-	-	-	-	-	yes	-	-	yes
G	-	-	-	-	yes	-	-	-	-	-	-	-	-	-	-	yes	-	yes
H	-	-	-	-	-	yes	-	-	-	-	-	-	-	-	-	-	-	yes
I	-	-	-	-	-	yes	-	-	-	-	-	-	-	-	-	-	yes	yes
J	-	-	-	-	-	-	yes	yes	-	-	-	-	-	-	-	-	-	yes
K	-	-	-	-	-	-	-	-	yes	-	-	-	-	-	-	-	-	yes
L	-	-	-	-	-	-	-	-	yes	-	-	-	-	-	-	-	yes	yes
M	-	-	-	-	-	-	-	-	yes	-	-	-	-	-	yes	-	-	yes
N	-	-	-	-	-	-	-	-	yes	-	-	-	-	-	-	yes	-	yes
O	-	-	-	-	-	-	-	-	-	-	yes	-	-	-	-	-	-	yes
P	-	-	-	-	-	-	-	-	-	yes	-	-	-	-	-	-	-	yes
Q	-	-	-	-	-	-	-	-	-	yes	-	-	-	-	-	-	yes	yes
R	-	-	-	-	-	-	-	-	-	yes	-	-	-	-	yes	-	-	yes
S	-	-	-	-	-	-	-	-	-	yes	-	-	-	-	-	yes	-	yes
T	-	-	-	-	-	-	-	-	-	-	yes	-	-	-	-	-	yes	yes
U	-	-	yes	-	-	-	-	-	-	-	-	-	-	-	-	-	-	yes
V	-	-	-	-	-	-	-	yes	-	-	-	-	-	-	-	-	-	yes
W	-	-	-	-	-	-	-	-	-	-	-	yes	-	-	–	-	-	yes
X	-	-	-	-	-	-	-	-	-	-	-	-	yes	-	-	-	-	yes
Y	-	-	-	-	-	-	-	-	-	-	-	-	-	yes	-	-	-	yes
Z	**Upon agreement**																	

Annex A
(informative)

Guideline for the development of test profiles for vibration tests

A.1 Scope

The aim of this guideline is to make sure that the user of this part of ISO 16750 is able to develop test profiles from vibration measurements in a reproducible way thus avoiding errors.

A.2 General

The process of creating test profiles should be clarified using the recommended documentation.

The process to create test profiles is described in Table A.1 and Table A.2.

Table A.1 — Test profile definition

<table>
<tr><th>Item</th><th>Description</th></tr>
<tr><td>Nominal speed</td><td>At nominal speed there is maximum output of the engine</td></tr>
<tr><td>Vehicle axis</td><td>X’: driving direction
Y’: perpendicular to driving direction and vertical axis
Z’: vertical axis</td></tr>
<tr><td>Engine axis</td><td>X: crankshaft direction
Y: perpendicular to crankshaft and piston direction
Z: piston direction</td></tr>
</table>

Table A.1 lists some basic definitions used for assessment of a vehicle measurement in order to create a test profile. The coordinate systems shown in Table A.1 are taken from DIN 70003, which also gives other valuable information regarding procedures for a vehicle measurement of vibrational loads.

Table A.2 — Development of test profiles for vibration tests

<table>
<tr><th>Item</th><th>Documentation</th><th>Recommended documentation/ parameters</th><th>Comments</th></tr>
<tr><td></td><td>Description of the vehicle</td><td>Technical data (e.g. power, max. min^{-1}, nominal speed, displacement, kind of engine, number of cylinders ...)</td><td></td></tr>
<tr><td>Engine mounted</td><td rowspan="5">Boundary conditions</td><td rowspan="2">Dynamometer and/or road</td><td rowspan="2">Full load
Note: there is some indication that higher values may occur at trailing throttle condition.</td></tr>
<tr><td>Gearbox mounted</td></tr>
<tr><td rowspan="3">Body mounted</td><td>Proving ground/ test track description</td><td>-</td></tr>
<tr><td>Road surfaces (e.g. Belgian block, washboard, hip hop, ...)</td><td>-</td></tr>
<tr><td>Driving speed</td><td>-</td></tr>
</table>

Table A.2 *(continued)*

Item	Documentation	Recommended documentation/ parameters	Comments
Vehicle data gathering	Sampling frequency	≥2,5 times of f_{max}	f_{max} = frequency limit for evaluation
	Block length b	≥ 2k	-
	Resolution	LSB <0,1 % of max. value	LSB = least significant bit
	Filtering techniques and methods	Anti-aliasing filter at f_{max} with >48 db/oct, high pass filter (f_{filter}<$f_{min.}$) to avoid offset	-
	Engine speed increase	engine speed increase rate, e.g. 3 000 min^{-1}/min	If the engine revolution increases too fast, existing resonances may not be detected.
	Frequency resolution, Delta *f*	make sure that the frequency resolution is higher than the difference of excitation frequency while ramping engine speed. Otherwise the FFT values will be wrong. example: Delta *f* = 1 Hz leads to window length of 1 second. But: ramping engine speed with 1 000 min^{-1}/min during 1 sec even the 4th order will sweep more than 1 Hz	Delta $f = f_{sampling} / b$ e.g. 12 500 Hz / 2 048 = 6,1 Hz
	Temperature	Cooling water temperature, oil temperature DUT temperature (DUT measuring point and mounting area)	Description of engine conditions and DUT conditions (esp. elastic suspensioned DUT)
Data analysis	Peak-hold FFT	Peak-hold	Reference for creating sine tests or the sinusoidal part of a sine on random test.
	Peak-hold and all other spectra	Give information: amplitude value or RMS value shown?	-
	Windowing	Hanning for stationary signals (no transient signal)	-
		No windowing for transient signals (crest factor > 6)	-
	RMS versus speed/ time	-	-
	Signal characteristic (sinusoidal/random part of signal)	Arithmetically averaged PSD from the time windows with the highest RMS-value	Reference for creating random tests or the random part of a sine on random test.
		Waterfall diagram	-
		Auto-correlation for stationary signals	-

Table A.2 *(continued)*

Item	Documentation	Recommended documentation/ parameters	Comments
Test profile development	Methods and processes used to develop the test profile	E.g. describe all key points including data reduction (averaging/enveloping)	-
	Methods and procedures used to determine or calculate the test duration	Explain assumptions and models used to correlate field stress and service life with test stress and duration, e.g. as in MIL-standard 810 with *M*-value based on most critical material.	*M*-value = gradient of the S/N curve The calculation of the test duration should be done according to the engine speed distribution as shown in principle in A.4. If it is necessary to cover fatigue strength with sinusoidal vibration load, the sinusoidal test will perform this by a test duration of 20 h per octave under the condition of resonance bandwidth ≥ 100 Hz. Performing the test in mixed mode, the test duration has to be calculated for random load separately. In case of a natural frequency ≥ 500 Hz this will be equivalent to a test duration of 70 h. The test duration of the mixed mode test will be the higher value of both of these separately calculated values. For other values of the resonance bandwidth a separate calculation is necessary. A test duration of 20 h per octave was used (e.g.) in 4.1.2.6.2.2.
	For engine mounted components	Take the engine speed distribution into account.	-
	For body mounted components	Take the mileage of bad road conditions into account.	-
	Rationale for the methods — Processes and engineering judgement	-	-

NOTE In some cases it can be helpful to perform the excitation in so-called mixed mode with two or more sine tones (high intensity at single frequencies may fit better to the real stress than random excitation, e.g. to simulate chattering effects of a rotor, but this method also allows simultaneous excitation of more than one natural frequency).

A.3 Average control method

Generally the responses of a DUT (response level at the natural frequencies) mounted in the vehicle and mounted on the vibration table differ. The reason is the different mounting rigidity and the different dynamic feedback for both cases.

To be able to reproduce the vibration tests in the laboratory, it is required that the vibration fixture is as stiff as possible and therefore normally much stiffer than in the car.

It should also be taken into account that the mounting points of the DUT move normally in phase on the vibration fixture, whereas the mounting points in the vehicle might not move in phase at the specific natural frequencies of the DUT. The reason is the higher stiffness of the test fixture compared to the mounting situation in the vehicle.

Furthermore the dynamic feedback of the DUT during the vibration test (attenuation of the excitation) is minimized by the vibration control unit.

This leads to much higher response peaks in case of resonance during the shaker test compared to the response in the vehicle with similar excitation at least for heavy/bulky DUT.

To avoid over testing it might be necessary to apply the average control method according to IEC 60068-2, 64 Fh,

NOTE Separate rigidly two ways of average control methods (multipoint control strategies):

— weighted average control out of excitation and response of the DUT

Recommended weighting: Averaged control signal = 3 × excitation + 1 × response of the DUT.

— ("unweighted") average control out of several control point signals on the mounting of the DUT, each weighted with the same factor.

It shall be ensured that the DUT is not "undertested"; the stress in the lab shall be high enough to cover the field conditions (e.g. by measuring the response of the DUT and spectra comparison or fatigue calculation).

A.4 Engine rotational speed distribution

There is a general relation between the rotational speed (min^{-1}) and the vibration level. The vibration level increases with higher rotational speed (see Figure A.1 and Table A.3).

For fatigue testing it is sufficient to consider the speed range with the highest acceleration levels. This is normally the range between $0{,}9n_{nominal}$ and n_{max}.

To assess the test duration it is necessary to take into account different engine speed distributions and the vehicle lifetime. All available engine speed distributions show that the engine speed range from $0{,}9n_{nominal}$ to n_{max}. is normally not used very often.

For this part of ISO 16750 three distributions were chosen:

a) an engine speed distribution which has been published in SAE where 55 cars were investigated (70 000 km; 10 000 trips);

b) a "severe" engine speed distribution that was recorded during temperature measurements with the aim to reach very high temperatures. Therefore the vehicles were driven in a very high engine speed range;

c) weighted distribution, consisting of: distribution a) SAE publication = 80 %, and distribution b) severe = 20 %.

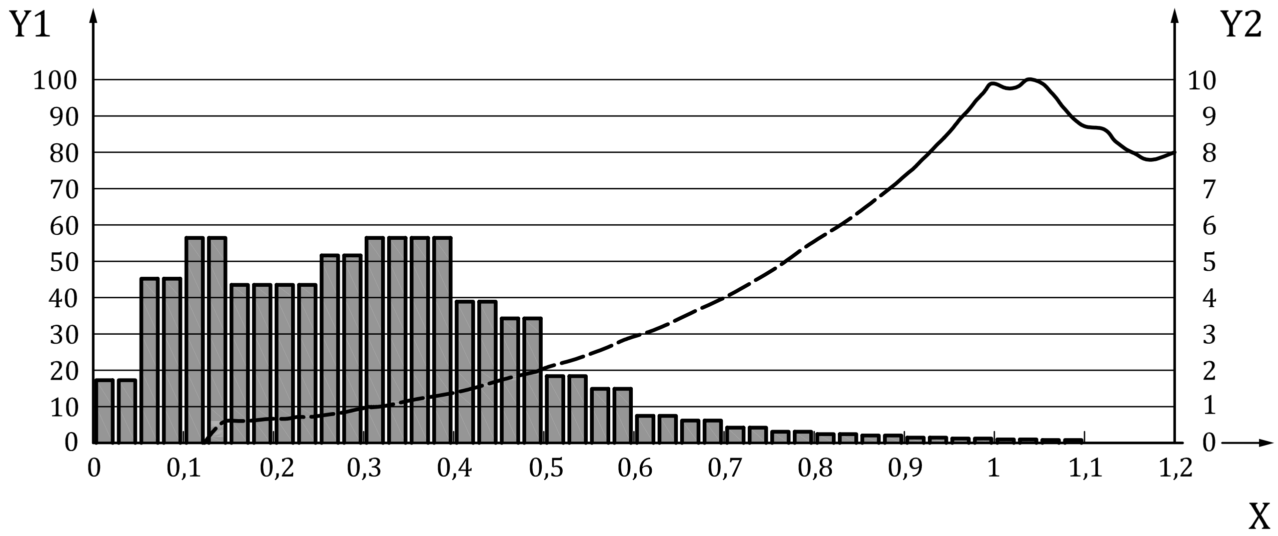
This leads to a relevant distribution of 0,5 % in the engine speed range from $0{,}9n_{nominal}$ to n_{max}. So testing 22 h along each axis is equal to approximately 4 400 h lifetime in the car. With an average speed of 40 km/h this represents a mileage of 176 000 km.

Taking into account other lifetimes/mileages/min^{-1} distributions the test engineer is allowed to change the test duration proportionally.

NOTE Depending on the required lifetime and the required engine speed distribution, the result of the calculation according to the shown method may lead to a very long test duration. The recommended maximum test duration for practical reasons is 100 h per axis. For most vibration environments, equivalent fatigue damage is easily accomplished within this duration. In general for commercial vehicle the fatigue limit has to be covered.

For passenger cars in most cases the shown method is usable.

A classification of car types and/or lifetime duration should follow up (t.b.d.).



Key

Y1	min⁻¹ normalized to $N_{nominal}$ in %
Y2	min⁻¹ probability (weighted engine speed distribution)
X	RMS-level normalized
—— (solid line)	RMS-level versus engine speed ≤ 0,9*n* nominal
— — (dashed line)	RMS-level versus engine speed > 0,9*n* nominal
$N_{nominal}$	engine speed with maximum power
N_{max}	maximum safe engine speed

Figure A.1 — RMS-acceleration level and weighted min^{-1} distribution versus engine speed

Table A.3 — RMS-acceleration level and engine speed distribution versus engine speed

$n/n_{nominal}$	**RMS-level versus min^{-1}**	**min^{-1} probability**	**min^{-1} probability**	**weighted min^{-1} probability**
	(normalized)	px_{severe}	px_{normal}	(20 px_{severe} + 80 px_{normal})/100[a]
0,050	-	0,56 %	2,14 %	1,82 %
0,075	-	0,56 %	2,14 %	1,82 %
0,100	-	0,02 %	5,69 %	4,56 %
0,125	-	0,02 %	5,69 %	4,56 %
0,150	7,0 %	8,00 %	5,09 %	5,67 %
0,175	6,3 %	8,00 %	5,09 %	5,67 %
0,200	6,1 %	5,75 %	4,04 %	4,38 %
0,225	7,2 %	5,75 %	4,04 %	4,38 %
0,250	7,4 %	3,06 %	4,73 %	4,40 %
0,275	8,4 %	3,06 %	4,73 %	4,40 %
0,300	10 %	4,70 %	5,31 %	5,19 %
0,325	11 %	4,70 %	5,31 %	5,19 %
0,350	12 %	5,69 %	5,61 %	5,62 %
0,375	13 %	5,69 %	5,61 %	5,62 %
0,400	14 %	5,06 %	5,72 %	5,59 %
0,425	15 %	5,06 %	5,72 %	5,59 %

[a] The cumulative weighted min^{-1}-distribution ($n > 0{,}9n_{nominal}$) is 0,5 %; a test duration of 22 h corresponds to 4 400 h in car.

Table A.3 *(continued)*

$n/n_{nominal}$	**RMS-level versus min^{-1}**	**min^{-1} probability**	**min^{-1} probability**	**weighted min^{-1} probability**
	(normalized)	px_{severe}	px_{normal}	$(20\ px_{severe} + 80\ px_{normal})/100$[a]
0,450	17 %	3,95 %	3,85 %	3,87 %
0,475	18 %	3,95 %	3,85 %	3,87 %
0,500	20 %	3,23 %	3,48 %	3,43 %
0,525	22 %	3,23 %	3,48 %	3,43 %
0,550	24 %	2,26 %	1,71 %	1,82 %
0,575	26 %	2,26 %	1,71 %	1,82 %
0,600	29 %	1,56 %	1,39 %	1,42 %
0,625	31 %	1,56 %	1,39 %	1,42 %
0,650	34 %	1,34 %	0,55 %	0,71 %
0,675	36 %	1,34 %	0,55 %	0,71 %
0,700	39 %	1,20 %	0,39 %	0,55 %
0,725	42 %	1,20 %	0,39 %	0,55 %
0,750	46 %	1,00 %	0,19 %	0,35 %
0,775	50 %	1,00 %	0,19 %	0,35 %
0,800	54 %	0,79 %	0,09 %	0,23 %
0,825	59 %	0,79 %	0,09 %	0,23 %
0,850	63 %	0,57 %	0,03 %	0,14 %
0,875	67 %	0,57 %	0,03 %	0,14 %
0,900	72 %	0,40 %	0,01 %	0,08 %
0,925	77 %	0,40 %	0,01 %	0,08 %
0,950	84 %	0,31 %	0,00 %	0,06 %
0,975	90 %	0,31 %	0,00 %	0,06 %
1,000	98 %	0,22 %	0,00 %	0,04 %
1,025	96 %	0,22 %	0,00 %	0,04 %
1,050	100 %	0,19 %	0,00 %	0,04 %
1,075	92 %	0,19 %	0,00 %	0,04 %
1,100	86 %	0,06 %	0,00 %	0,01 %
1,125	85 %	0,06 %	0,00 %	0,01 %
1,150	79 %	0,04 %	0,00 %	0,01 %
1,175	77 %	0,04 %	0,00 %	0,01 %
1,200	79 %	0,02 %	0,00 %	0,00 %
1,225	79 %	0,02 %	0,00 %	0,00 %

[a] The cumulative weighted min^{-1}-distribution ($n > 0{,}9 n_{nominal}$) is 0,5 %; a test duration of 22 h corresponds to 4 400 h in car.

A.5 Fatigue calculation

A.5.1 Example for passenger cars, body mounted (sprung masses)

Verification whether an 8 h random vibration test is sufficient to cover the stress in car which occurs during car lifetime.

NOTE The measurements and calculations were made on an electronic control unit (ECU). This is thought as an example. The presented methods are neither restricted to ECUs nor to body mounted components.

A.5.2 Procedure

1) Vibration measurement in the car on the test track (road bumps) and during the random vibration test on the ECU with at least two measurement points, one at the ECU mounting location (input or excitation) and one to measure the response on the printed circuit board (PCB);

2) determination of the load distribution on the PCB by means of a cycle counting method (see A.5.5, A.5.6 and Figure A.2) during the measuring time;

3) choosing the car lifetime and the “bad road percentage” (both are selectable parameters);

4) calculation of the expected PCB load distribution by multiplying the count result in each class with the factor:

— (test duration/measuring time during test);

— and (car lifetime x percentage of bad roads/measuring time in car);

5) The new load distributions are used to calculate the fatigue limit that corresponds to a damage of 1. These calculations are based on the

— Woehler curve — “Haibach” modification — and

— the “Palmgren-Miner hypotheses of linear damage accumulation”; for details see A.5.7 and Figure A3.

NOTE 1 According to current “state of the art” only the calculation in the form of the “Haibach modification” will be taken into account from now on. This means, that low acceleration levels have a contribution to the damage sum, too. As a conclusion, the results of the chosen example show that the stress (fatigue limits) which results from a test duration of 8 h is about 1,6 (1,23 – 2,02) times higher than the stress in car during 5 400 h on a test track. Measurements and calculations like this have been done for many years (>20) and in many applications. The results were always similar and confirmed that a test duration of 8 h is sufficient.

NOTE 2 Comparisons between the chosen test tracks and measurements on selected rough public roads show that these test tracks are much more severe than bad public roads.

NOTE 3 The selected parameters — car lifetime 6 000 h, rough road part = 90 % — are absolutely worst case. Normally it is calculated with less than 50 % rough road part.

A.5.3 Test parameters

— test equipment:	electro-dynamic shaker
— mounting assembly:	ECU firmly fixed on the shaker
— control point:	on the shaker
— direction:	C, perpendicular to PCB
— r.m.s. acceleration value	33 m/s^2
— test spectra:	see Table A.4

Table A.4 — Example of a random vibration test, parameters

Frequency [Hz]	PSD [(m/s^2)^2/Hz][a]
10	20
30	20
200	0,5
1 000	0,1

[a] The chosen spectrum is slightly different to the spectrum documented in 4.1.2.4.2. At the resonance of the ECU (about 600 Hz) the difference is negligible.

A.5.4 Result

— Load distribution from a measuring time of 19,91 s, calculated for a 8 h test,

— load distribution from a measuring time of 3,69 s on the rough road (road bumps, 50 km/h), calculated for 5 400 h (car lifetime 6 000 h, rough road part 90 %).

Acceleration classes a_i and number of cycles n_i in each class during the random vibration test of 8 h		Acceleration classes a_i and number of cycles n_i in each class during rough road driving for 5 400 h	
a_i [m/s^2]	n_i	a_i [m/s^2]	n_i
403,4	6 509	129,4	2 636 719
377,4	9 402	112,7	2 636 719
351,3	18 082	104,4	7 910 156
325,3	43 396	96,04	5 273 438
299,3	104 150	87,69	7 910 156
273,3	203 237	79,34	7 910 156
247,2	434 680	70,99	7 910 156
221,2	721 815	62,64	18 457 031
195,2	1 160 835	54,28	10 546 875
169,2	1 595 516	45,93	47 460 938
143,1	2 104 692	37,58	84 375 000
117,1	2 438 116	29,23	152 929 688
91,09	2 606 636	20,88	271 582 031
65,06	2 345 538	12,53	690 820 313

Table A.5 — Short result of the fatigue calculation for different models of stress versus number of load cycles (S/N)

Fatigue cycles of the S/N model	Slope "*k*" of S/N graph	Hypotheses	Calculated fatigue level for the random vibration test (12 "S/N models")	Needed fatigue level for 5400 h rough road driving (12 "S/N models")	Comparison
2 000 000	3,5	Haibach	250 m/s^2	165 m/s^2	OK
	5	Haibach	246 m/s^2	144 m/s^2	OK
	7	Haibach	252 m/s^2	136 m/s^2	OK
	10	Haibach	267 m/s^2	132 m/s^2	OK
10 000 000	3,5	Haibach	173 m/s^2	126 m/s^2	OK
	5	Haibach	187 m/s^2	118 m/s^2	OK
	7	Haibach	205 m/s^2	116 m/s^2	OK
	10	Haibach	229 m/s^2	117 m/s^2	OK
50 000 000	3,5	Haibach	112 m/s^2	91 m/s^2	OK
	5	Haibach	137 m/s^2	93 m/s^2	OK
	7	Haibach	164 m/s^2	97 m/s^2	OK
	10	Haibach	196 m/s^2	102 m/s^2	OK

A.5.5 Determination of the load distribution from the measured time history

There is one maximum between two zero crossings.

In each class (acceleration level) the number of maxima during the measuring time is counted.

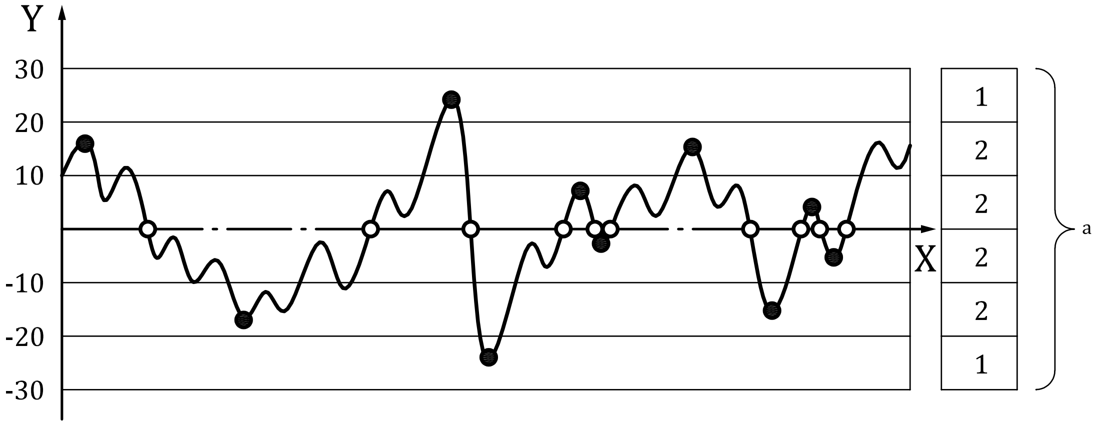
The result of this counting method gives the number of half cycles for each class or in other words the load distribution from the measured time history.

The load distribution for the test duration is achieved by using a factor of (test time/measuring time) for each class (for instance 8 h × 3 600 s/h / 19,9 s = 1 446).

The load distribution for the car lifetime is achieved by using a factor of (car lifetime × percentage of rough roads/measuring time) for each class (for instance 6 000 h × 0,9 × 3 600 s/h / 3,69 s = 5 268 293).

NOTE Determination of the load distribution is done for measuring points on the DUT.

This simple method is usable only in case of one dominant DUT-resonance mode. Otherwise the time signal has to be prepared before counting is started. For example, filtering has to be done for each mode corresponding to a weak point of the DUT separately. Notice of weak points may, for example, be given out of step-stress-tests.



Key

Y class m/s^2

X *t*

a number of half cycles in each class

Figure A.2 — Counting method for the load distribution

A.5.6 Calculation of the fatigue limits

For the determination of the fatigue limit a_D one S/N model — described by the slope *k* and the fatigue number N_D — has to be chosen.

Afterwards any starting value for a_D is chosen.

From the chosen S/N model it is possible to calculate the number of cycles to failure $N_{(i)}$ for each acceleration level $a_{(i)}$ and the corresponding cycle number $n_{(i)}$.

According to Palmgren/Miners rule the partial damage at each level *a*(i) is:	$s_{(i)} = n_{(i)}/N_{(i)}$.
The whole damage is	$S = \Sigma s_{(i)}$.
Damage occurs per definition for	$S \geq 1$.

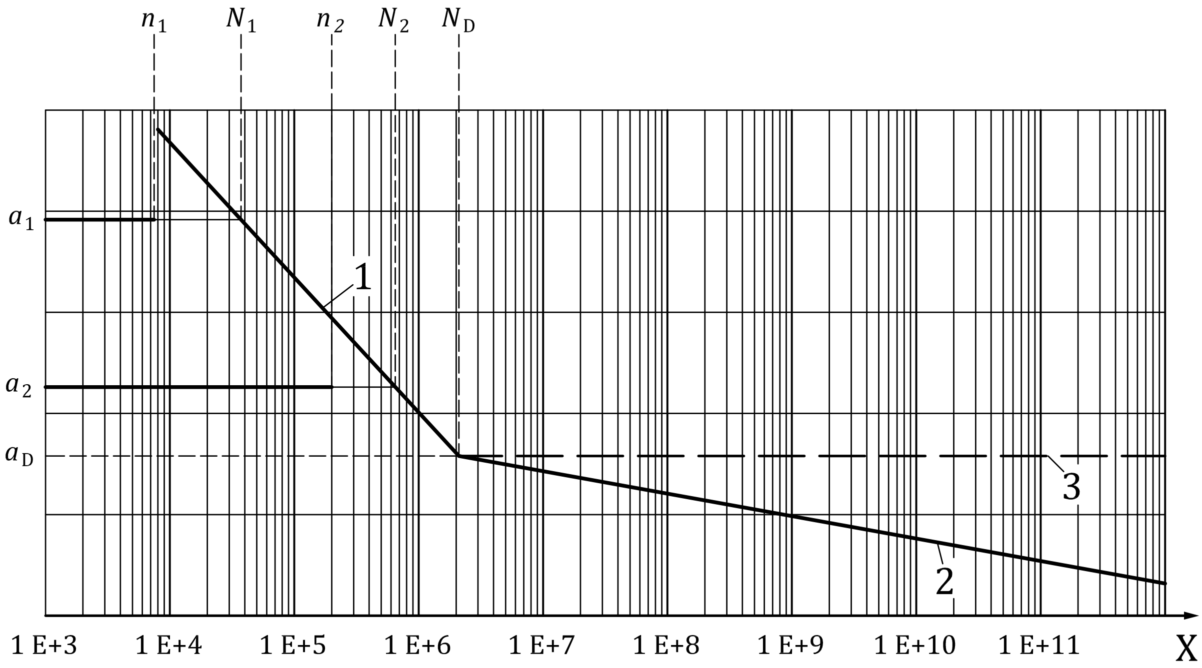
With the arbitrarily chosen starting value for a_D the damage will definitely be < 1.

By means of iteration the a_D value is varied until a damage of “1” occurs.

Without very extensive investigations and experiments it is impossible to know, whether the chosen S/N model is realistic. Therefore it makes sense to cover a wide range for each S/N parameter (e.g. from specialized literature). Twelve models are currently used (“Haibach hypothesis”, “4 slopes *k*” and “3 fatigue limit cycles N_D ”). Note: “Miner original” is no longer used because according to this acceleration, levels lower than a_D have no contribution to the whole damage. According to present knowledge use of “Haibach modification” is more realistic.

Some of these models are far from reality, others are more realistic. It is to be expected that at least one of these 12 models is relatively realistic. But even if this is not the case, the quality of the comparison is not influenced too much, as long as the same model is used or the same assumptions are made for both situations (car and test), because in a comparison some of the wrong assumptions are compensated.

If all 12 a_D values coming from the test are higher than the ones needed in the car, then the stress in car is permissible. The load distribution from the selected example and the corresponding S/N graph (one model) are shown in Table A.5 and Figure A.3.



Key

1 slope k

2 Haibach-modification Slope $2k$-1

3 Miner original

X number of cycles

S $= \sum(n_i/N_i) \leq 1$

Figure A.3 — Palmgren-Miner hypotheses — Linear damage accumulation "*S*"

An example for this methodology is given in Table A.6 and Figure A.4.

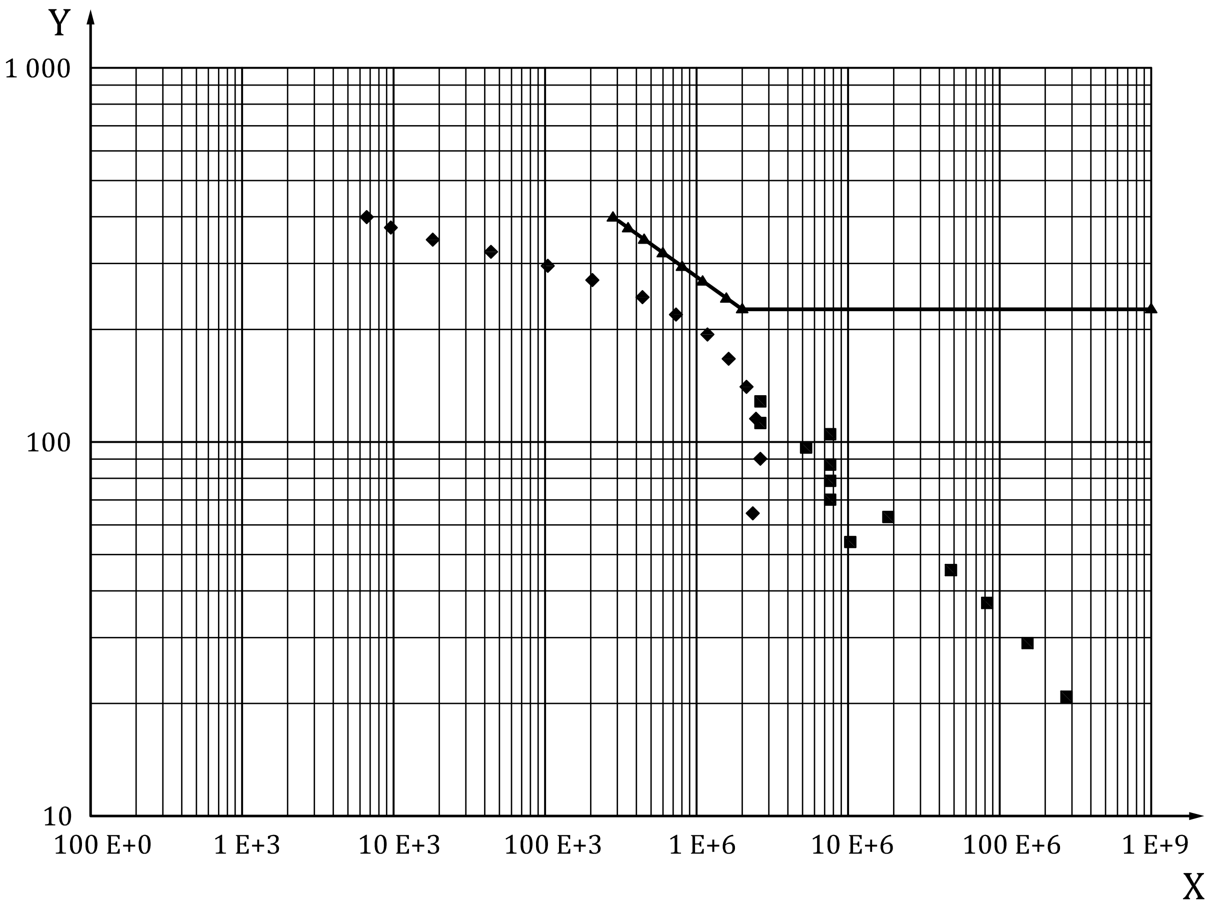
Table A.6 — Comparison of load distribution of random vibration test and one field measurement

Random vibration test (8 h)		**Corresponding "S/N graph"** ($2x10^6$; $k = 5$; $a_D = 229$ m/s²)		**Measurement in car; road bumps (5 400 h)**	
Acceleration [m/s²]	**Cycles** (n)	**Acceleration** [m/s²]	**Number of S/N cycles**	**Acceleration** [m/s²]	**Cycles** (n)
403,40	6 509	403,4	276 718	129,40	2 636 719
377,40	9 402	377,4	349 387	112,70	2 636 719
351,30	18 082	351,3	448 993	104,40	7 910 156
325,30	43 396	325,3	587 650	96,04	5 273 438
299,30	104 150	299,3	786 574	87,69	7 910 156
273,30	203 237	273,3	1 081 121	79,34	7 910 156
247,20	434 680	247,2	1 536 185	70,99	7 910 156
221,20	721 815	229,0	2 000 000	62,64	18 457 031
195,20	1 160 835	229,0	1 000 000 000	54,28	10 546 875
169,20	1 595 516	-	-	45,93	47 460 938
143,10	2 104 692	-	-	37,58	84 375 000
117,10	2 438 116	-	-	29,23	152 929 688
91,09	2 606 636	-	-	20,88	271 582 031

Table A.6 *(continued)*

Random vibration test (8 h)		Corresponding "S/N graph" ($2x10^6$; k = 5; a_D = 229 m/s²)		Measurement in car; road bumps (5 400 h)	
Acceleration [m/s²]	**Cycles** (n)	**Acceleration** [m/s²]	**Number of S/N cycles**	**Acceleration** [m/s²]	**Cycles** (n)
65,06	2 345 538	-	-	12,53	690 820 313
39,04	1 823 343	-	-	4,176	3 158 789 063

NOTE Modification of table and graph necessary; calculation shown for Miner curve (not for Haibach).



Key

Y acceleration

X cycles

◆ random vibration test (8 h)

■ measurement in car

▲ corresponding Woehler graph to random vibration test (2×10^6; k = 5; a_D = 229 m/s²)

Figure A.4 — Load distribution and S/N curve one model

Annex B
(informative)

Recommended mechanical requirements for equipment depending on the mounting location

Table B.1 — Mounting location

Mounting location	Recommended tests and requirements (Code letter; see Table 25)
	Passenger cars
Engine compartment	
to body	D, K
to frame	K, L
on the flexible plenum chamber, not rigidly attached	C
in the flexible plenum chamber, not rigidly attached	C
on the engine	A, B, J
in the engine	A, B, J
on the transmission/retarder	U,V
in the transmission/retarder	U,V
on the GDI fuel rail	W
on the solid intake manifold	X
Passenger compartment	
without special requirement	D, E, K, L,
exposed to direct solar radiation	D, E, K, L
exposed to radiated heat	D, E, K, L
Luggage compartment/load compartment	
luggage compartment/load compartment	D, E, K, L
Mounting on the exterior	
to body	D, E, K, L
to frame	K
Underbody/ wheel housing	
sprung masses	D, E, K, L
unsprung masses	H, I, O, T
in/on passenger compartment door	F, G, R, S
to engine compartment cover	F, G, R, S
to luggage compartment lid/door	F, G, R, S
to trunk lid/door	F, G, R, S
to exhaust pipe	Y
In cavity	
open towards interior	D, E, K, L

Table B.1 *(continued)*

Mounting location	Recommended tests and requirements (Code letter; see Table 25)
open towards exterior	D, E, K, L
in special compartments	D, E, K, L

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