INTERNATIONAL STANDARD

ISO 16750-3

Second edition
2007-08-01

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

Part 3: Mechanical loads

Véhicules routiers — Spécifications d'environnement et essais des équipements électrique et électronique —

Partie 3: Contraintes mécaniques

Reference number
ISO 16750-3:2007(E)

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Published in Switzerland

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Foreword

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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 vehicles*, Subcommittee SC 3, *Electrical and electronic equipment*.

This second edition cancels and replaces the first edition (ISO 16750-3:2003), 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*

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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. This part of ISO 16750 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 the 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*

ISO 16750-4, *Road vehicles — Environmental conditions and testing for electrical and electronic equipment — Part 4: Climatic loads*

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

IEC 60068-2-14, *Environmental testing — Part 2: Tests — Test N: Change of temperature*

IEC 60068-2-29, *Environmental testing — Part 2: Tests — Test Eb and guidance: Bump*

IEC 60068-2-32, *Environmental testing — Part 2: Tests — Test Ed: Free fall*

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

3 Terms and definitions

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

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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 vehicle manufacturer and supplier choose the test method, the environmental temperature and vibration parameters depending on the specific mounting location.

The specified values apply to direct mounting in defined mounting locations. The use of 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 testing shall be done with this bracket.

Carry out the vibration test 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 objective 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 the designated test frequency ranges shall be considered separately.

NOTE Deviations from the load on the DUT can result if vibration testing is carried out in accordance with 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 in accordance with IEC 60068-2-64 shall be agreed upon.

Subject the DUT during the vibration test to the temperature cycle in accordance with IEC 60068-2-14, with electric operation in accordance with Figure 1. Alternatively, a test at constant temperature may be agreed between customer and supplier.

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

Additional drying of test chamber air is not permitted.

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

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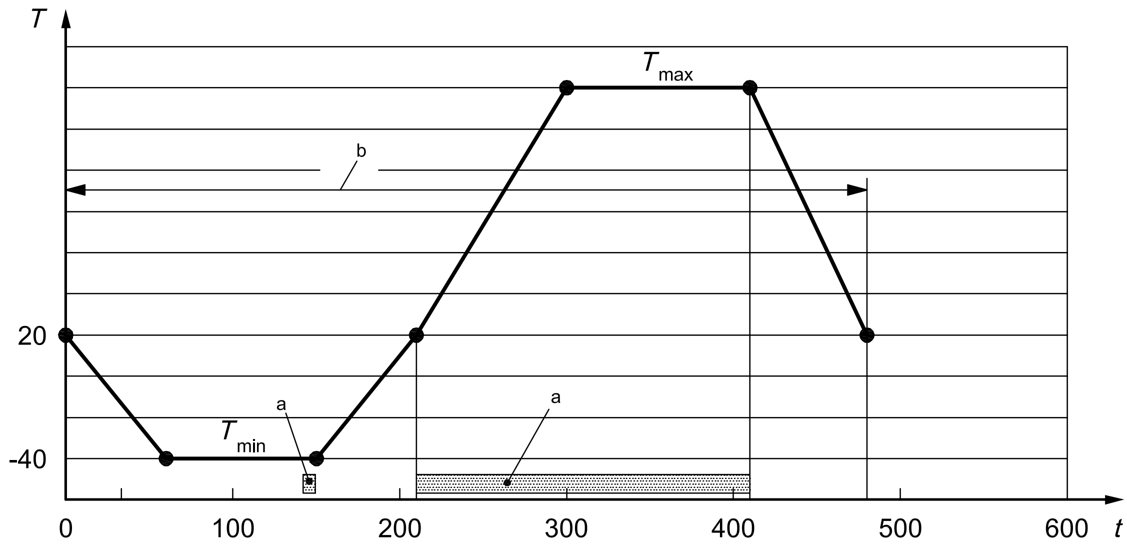

Key

T temperature, °C

t time, min

[a] Operating mode 3.2 in accordance with ISO 16750-1.

[b] One cycle.

Figure 1 — Temperature profile for the vibration test

Table 1 — Temperature versus time for the vibration test

Duration min	**Temperature** °C
0	20
60	–40
150	–40
210	20
300	T_{max} [a]
410	T_{max} [a]
480	20
[a] For T_{max}, 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 that 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.

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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 Road profile usually has negligible impact on engine mounted components. Shock inputs are effectively isolated by the suspension of motor mounting systems.

The test profiles specified in the following clauses (4.1.2.1.2 to 4.1.2.1.3) apply to loads generated by (four stroke) reciprocating engines.

It is recommended to perform this test as a mixed mode vibration test in accordance with IEC 60068-2-80. Alternatively these tests may be performed sequentially.

4.1.2.1.2 Test

4.1.2.1.2.1 Sinusoidal vibration

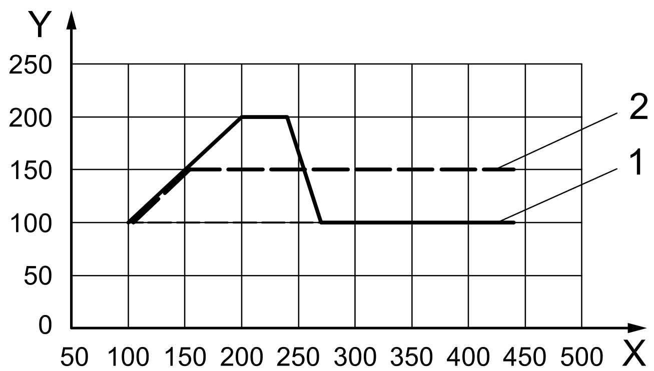
Perform the test in accordance with IEC 60068-2-6. Unlike in IEC 60068-2-6, a sweep rate of 0,5 octave/minute or less shall be used. Use a test duration of 22 h for each plane of the DUT.

NOTE The test duration is based on A.4. The temperature in the chamber is above room temperature (RT) at the end of the test (2,75 temperature cycles).

Use curve 1 in Table 2 and Figure 2 for DUT intended for mounting on engines with five cylinders or less.

Use curve 2 in Table 2 and Figure 2 for DUT test intended for mounting on engines more than five cylinders or more.

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



Key

X frequency, Hz

Y maximum acceleration, m/s^2

1 curve 1 ($\leqslant$ five cylinders)

2 curve 2 (> five cylinders)

Figure 2 — Vibration severity curves

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Table 2 — Values for maximum acceleration versus frequency

Curve 1 (see Figure 2)	
Frequency Hz	**Maximum acceleration** m/s^2
100	100
200	200
240	200
270	100
440	100

Curve 2 (see Figure 2)	
Frequency Hz	**Maximum acceleration** m/s^2
100	100
150	150
440	150

Combination	
Frequency Hz	**Maximum acceleration** m/s^2
100	100
150	150
200	200
240	200
255	150
440	150

4.1.2.1.2.2 Random vibration

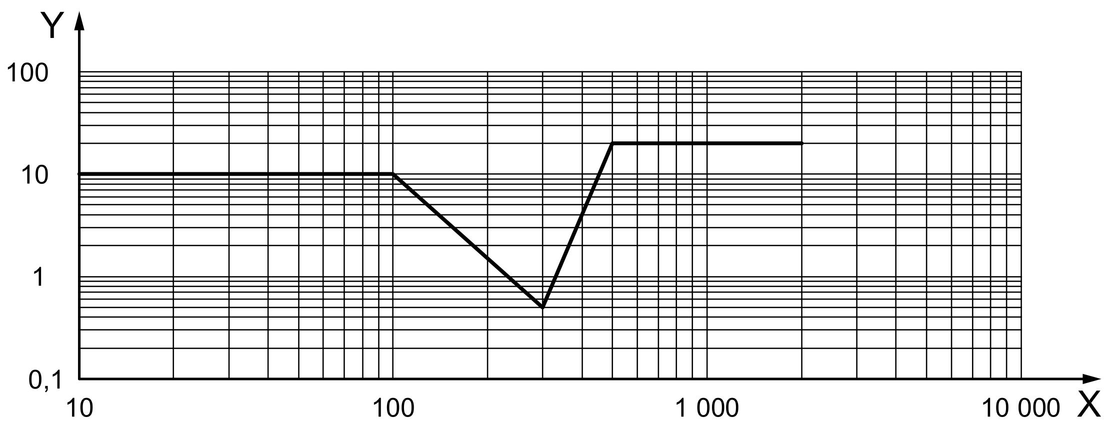
Perform the test in accordance with IEC 60068-2-64. Use a test duration of 22 h for each plane of the DUT.

NOTE The test duration is based on A.4. The temperature in the chamber is above RT at the end of the test (2,75 temperature cycles).

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

The power spectral density (PSD) versus frequency is illustrated in Figure 3 and Table 3.

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



Key

X frequency, Hz

Y power spectral density, $(m/s^2)^2/Hz$

Figure 3 — PSD of acceleration versus frequency

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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.

As defined in ISO 16750-1, functional status class A is required during operating mode 3.2, and functional status class 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 clauses apply to loads generated by gearbox vibrations. Changing the gears can create additional mechanical shock and shall be considered separately.

It is recommended to perform this test as a mixed mode vibration test in accordance with IEC 60068-2-80. Alternatively these tests may be performed sequentially.

4.1.2.2.2 Test

4.1.2.2.2.1 Sinusoidal vibration

Perform the test in accordance with IEC 60068-2-6. Unlike in IEC 60068-2-6, a sweep rate of 0,5 octave/minute or less 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 (2,75 temperature cycles).

The amplitude versus frequency is illustrated to in Figure 4 and Table 4.

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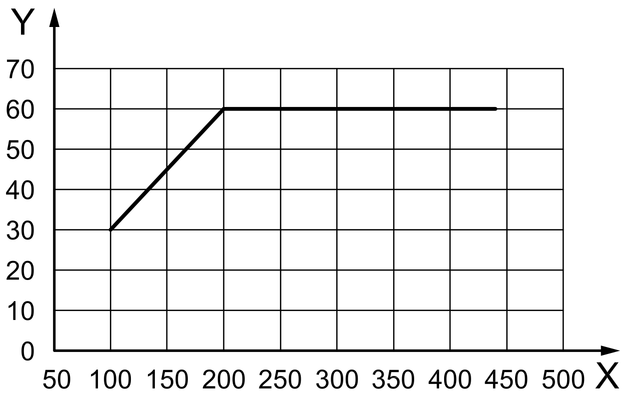


Key

X frequency, Hz

Y maximum acceleration, m/s²

Figure 4 — Maximum versus frequency

Table 4 — Values for maximum acceleration versus frequency

Frequency Hz	**Maximum acceleration** m/s²
100	30
200	60
440	60

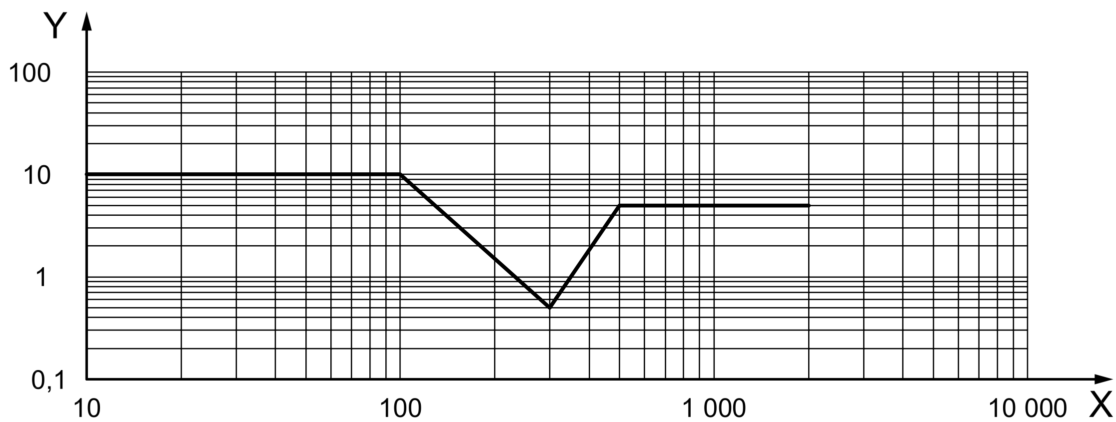
4.1.2.2.2.2 Random vibration

Perform the test in accordance with 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/s².

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

The PSD versus frequency is illustrated to in Figure 5 and Table 5.



Key

X frequency, Hz

Y power spectral density, (m/s²)²/Hz

Figure 5 — PSD of acceleration versus frequency

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Table 5 — Values for frequency and PSD

Frequency Hz	**PSD** $(m/s^2)^2/Hz$
10	10
100	10
300	0,51
500	5
2 000	5

4.1.2.2.3 Requirement

Breakage shall not occur.

As defined in ISO 16750-1, functional status class A is required during operating mode 3.2, and functional status class 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 a flexible plenum chamber but not rigidly attached.

The vibrations in this mounting location are sinusoidal and mainly induced by the pulsation of the intake air.

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

4.1.2.3.2 Test

Perform the test in accordance with IEC 60068-2-6. Unlike in IEC 60068-2-6, a sweep rate of 0,5 octave/minute or less 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 (2,75 temperature cycles).

The amplitude versus frequency is illustrated in Figure 6 and Table 6.

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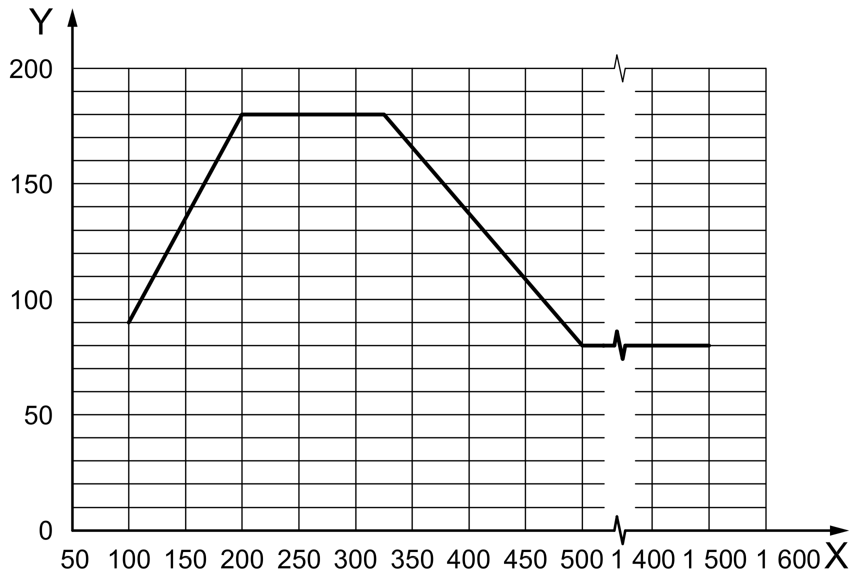

Key

X frequency, Hz

Y maximum acceleration, m/s²

Figure 6 — Maximum acceleration versus frequency

Table 6 — Values for maximum acceleration versus frequency

Frequency Hz	**Maximum acceleration** m/s²
100	90
200	180
325	180
500	80
1 500	80

4.1.2.3.3 Requirement

Breakage shall not occur.

As defined in ISO 16750-1, functional status class A is required during operating mode 3.2, and functional status class 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.

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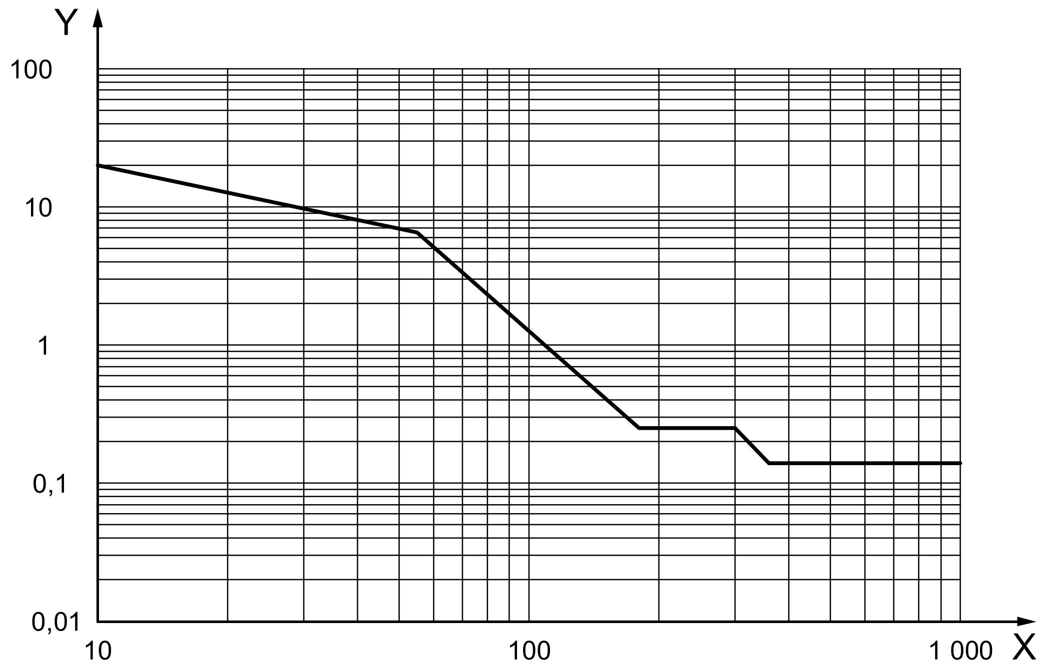
4.1.2.4.2 Test

Perform the test in accordance with 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 27,8 m/s^2.

The PSD versus frequency is illustrated in Figure 7 and Table 7.

NOTE The test duration is based on A.5.



Key

X frequency, Hz

Y power spectral density, (m/s^2)^2/Hz

Figure 7 — PSD of acceleration versus frequency

Table 7 — Values for PSD and frequency

Frequency Hz	**PSD** (m/s^2)^2/Hz
10	20
55	6,5
180	0,25
300	0,25
360	0,14
1 000	0,14

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4.1.2.4.3 Requirement

Breakage shall not occur.

As defined in ISO 16750-1, functional status class A is required during operating mode 3.2, and functional status class 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.

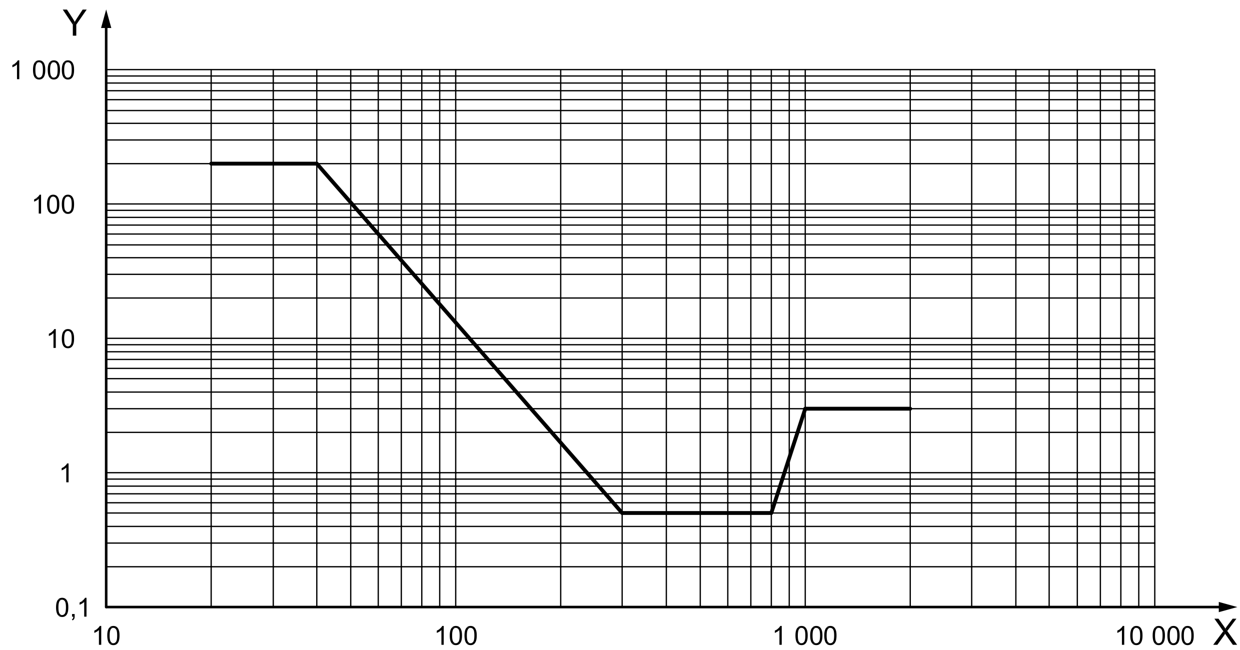
4.1.2.5.2 Test

Perform the test in accordance with 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 is illustrated in Figure 8 and Table 8.

NOTE The test duration is based on A5.



Key

X frequency, Hz

Y power spectral density, (m/s^2)^2/Hz

Figure 8 — PSD of acceleration versus frequency

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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.

As defined in ISO 16750-1, functional status class A is required during operating mode 3.2, and functional status class 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 (no sufficient number of measurements on gearbox-mounted systems/components has been performed up to now). The main failure to be identified by this test is breakage due to fatigue.

The test profiles specified in the following apply to loads generated by (four stroke) reciprocating engines. It is recommended to perform this test as a mixed mode vibration test in accordance with IEC 60068-2-80. Alternatively, these tests may be performed sequentially.

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

NOTE The temperature in the chamber is above RT at the end of the test (11,75 cycles).

4.1.2.6.2 Test

4.1.2.6.2.1 Sinusoidal vibration

Perform the test in accordance with IEC 60068-2-6. Unlike in IEC 60068-2-6, a sweep rate of 0,5 octave/minute or less shall be used. Use a test duration of 94 h for each plane of the DUT (equivalent to approximately 20 hours/octave).

The amplitude versus frequency is illustrated in Figure 9 and Table 9.

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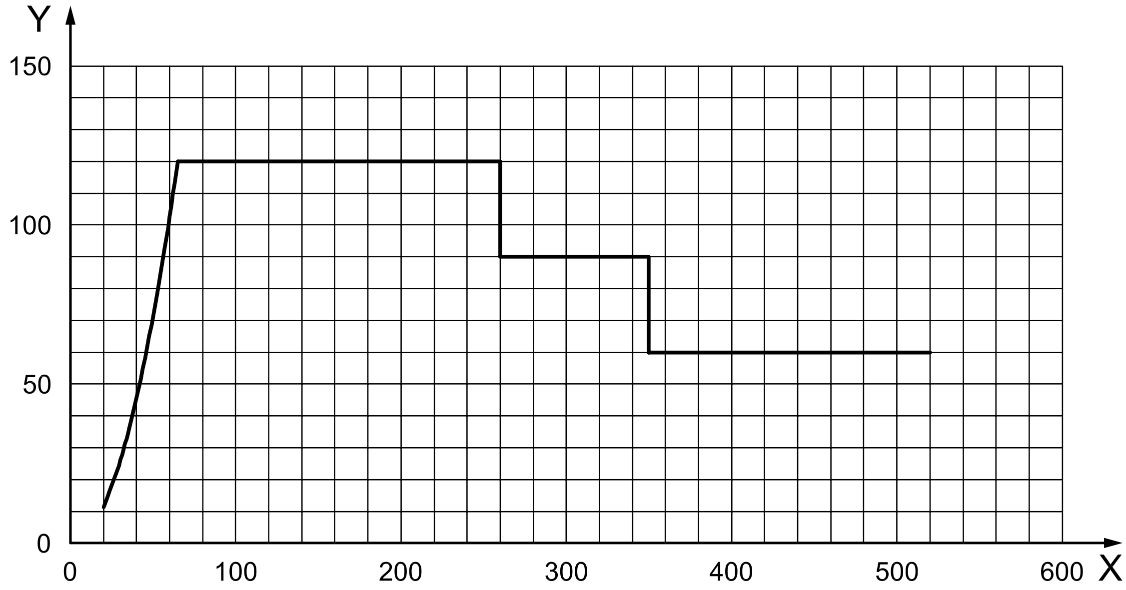

Key

X frequency, Hz

Y maximum acceleration, m/s²

Figure 9 — Maximum acceleration versus frequency

Table 9 — Values for maximum acceleration versus frequency

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

4.1.2.6.2.2 Random vibration

Perform the test in accordance with IEC 60068-2-64.

The test duration is as follows:

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

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

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

The PSD versus frequency is illustrated in Figure 10 and Tables 10 and 11.

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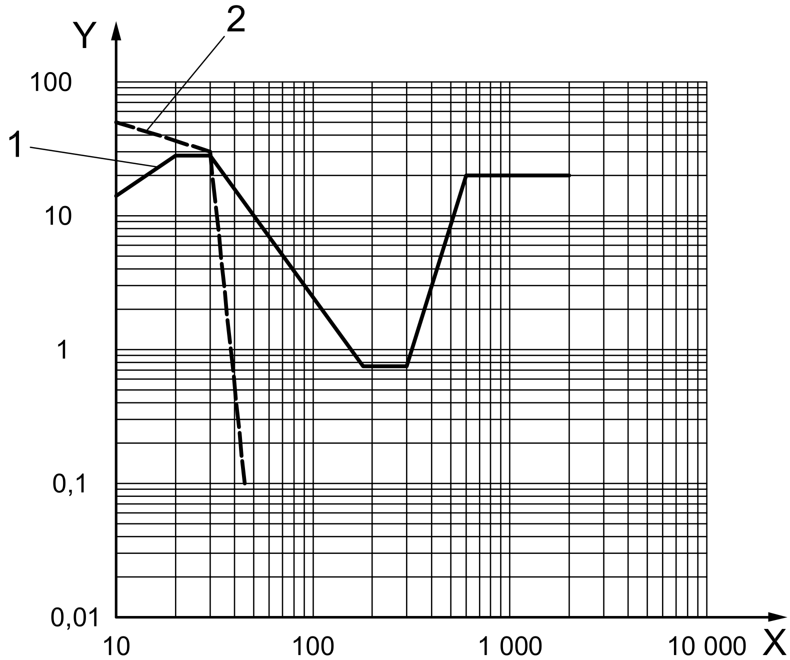

Key

X frequency, Hz

Y power spectral density, $(m/s^2)^2/Hz$

1 standard random test profile

2 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** $(m/s^2)^2/Hz$
10	14
20	28
30	28
180	0,75
300	0,75
600	20
2 000	20
NOTE r.m.s. acceleration value = 177 m/s^2.	

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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
NOTE r.m.s. acceleration value = 28,6 m/s^2.	

4.1.2.6.3 Requirement

Breakage shall not occur.

As defined in ISO 16750-1, functional status class A is required during operating mode 3.2, and functional status class C during periods with other operating modes.

4.1.2.7 Test VII — Commercial vehicle, sprung masses

4.1.2.7.1 Purpose

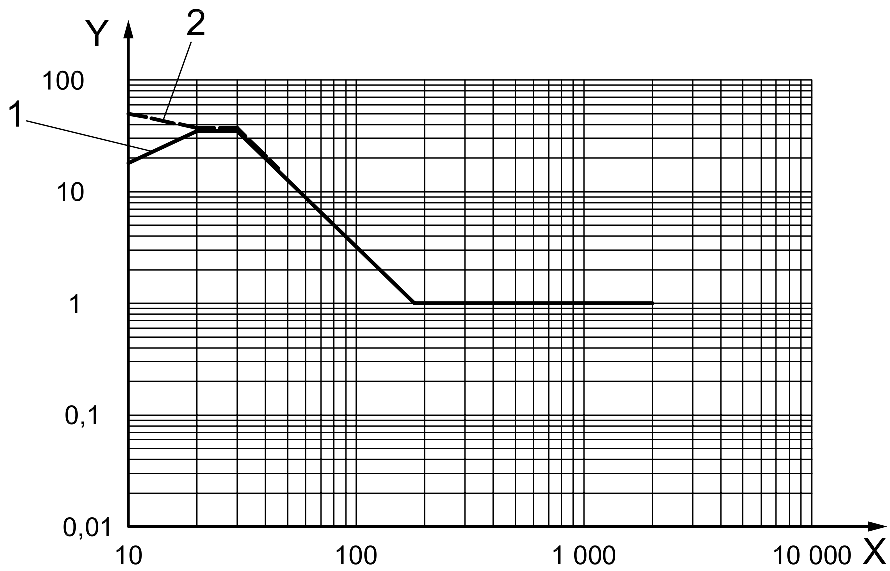
This test checks the DUT for malfunctions and breakage caused by vibration.

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 in accordance with IEC 60068-2-64, random vibration, using a test duration of 32 h for each plane of the DUT.

The PSD versus frequency is illustrated to in Figure 11 and Tables 12 and 13.



Key

X frequency, Hz

Y power spectral density, $(m/s^2)^2/Hz$

1 standard random test profile

2 additional profile in case of $f_n < 30$ Hz

Figure 11 — PSD of acceleration versus frequency

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Table 12 — Values for PSD and frequency

Frequency Hz	PSD $(m/s^2)^2/Hz$
10	18
20	36
30	36
180	1
2 000	1
NOTE r.m.s. acceleration value = 57,9 m/s^2.	

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

Frequency Hz	PSD $(m/s^2)^2/Hz$
10	50
20	36
30	36
45	16
NOTE r.m.s. acceleration value = 33,7 m/s^2.	

4.1.2.7.3 Requirement

Breakage shall not occur.

As defined in ISO 16750-1, functional status class A is required during operating mode 3.2, and functional status class 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 in accordance with IEC 60068-2-64, random vibration.

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

The PSD versus frequency is illustrated in Figure 12 and Table 14.

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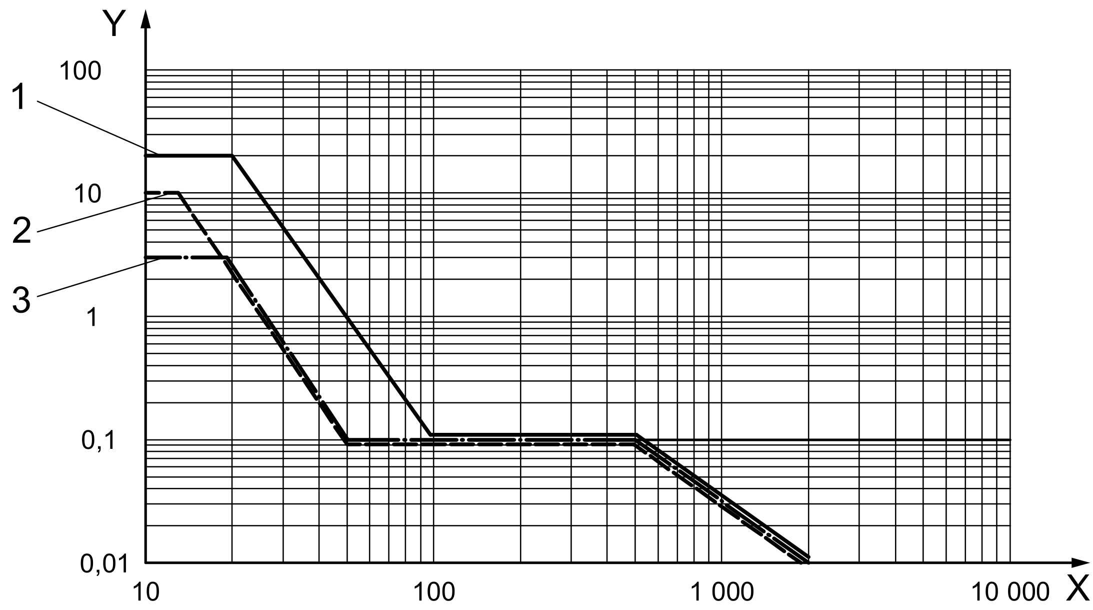

Key

X frequency, Hz

Y power spectral density, $(m/s^2)^2/Hz$

1 vertical

2 lateral

3 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.

As defined in ISO 16750-1, functional status class A is required during operating mode 3.2, and functional status class C during periods with other operating modes.

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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 in accordance with 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, so that it can be performed on an electro-mechanical test stand.

Table 15 — Values for maximum acceleration and frequency in case of lowest natural frequency, f_n, of a DUT $<$ 40 Hz

Plane in accordance with plane in vehicle	**Frequency** Hz	**Maximum acceleration** m/s^2	**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 maximum acceleration and frequency in case of lowest natural frequency, f_n, of a DUT $\geqslant$ 40 Hz

Plane in accordance with plane in vehicle	**Frequency** Hz	**Maximum acceleration** m/s^2	**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

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4.1.2.9.3 Requirement

Breakage shall not occur.

As defined in ISO 16750-1, functional status class A is required during operating mode 3.2, and functional status class 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 an 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 17 and perform the test in accordance with IEC 60068-2-29 using the following test parameters:

— 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 17 — Number of shocks

Location	Shock profile 1 500 m/s^2; 11 ms	Shock profile 2 300 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

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).

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4.2.2.2 Test

Perform the test in accordance with IEC 60068-2-29 using the following test parameters:

— 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 that 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

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 in accordance with IEC 60068-2-29 using the following test parameters:

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

— pulse shape: half-sinusoidal;

— typical maximum acceleration:

  — for commercial vehicles: 3 000 m/s^2 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).

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The actual shock stresses depend both on the installation position of the gearbox and also on the design features of the gearbox: in individual cases, it shall be ascertained by means of suitable measurements (recommended sampling frequency 25 kHz or more). 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 that 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

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 in accordance with IEC 60068-2-32 using the following test parameters:

- number of DUT: 3;
- falls per DUT: 2;
- drop height: 1 m free fall or the height of handling in accordance with 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: shall 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.

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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

For code letters for mechanical loads, see Table 18.

6 Documentation

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

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Table 18 — Coding in relation to tests and requirements

Code letter	Requirement in accordance with														
	4.1.2.1.2.1	4.1.2.1.2.2	4.1.2.2.2	4.1.2.3.2	4.1.2.4.2	4.1.2.5.2	4.1.2.6.2.1	4.1.2.6.2.2	4.1.2.7.2	4.1.2.8.2	4.1.2.9.2	4.2.1.2	4.2.2.2	4.2.3.2	4.3.2
	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**	**Mechanical shock Severity 1**	**Mechanical shock Severity 2**	**Mechanical 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
Z	upon agreement														

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Annex A
(informative)

Guideline for the development of test profiles for vibration tests

A.1 Purpose

The purpose of this guideline is to ensure that the user of this part of ISO 16750 is able to develop test profiles from vibration measurements in a reproducible way and thus avoid errors.

A.2 General

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

The process for creating test profiles is described in Table A.1.

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. This is because of the different mounting rigidity and the different dynamic feedback for both cases.

In order to be able to reproduce the vibration tests in the laboratory, it is necessary that the vibration fixture be 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. This is because of 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 overtesting, it might be necessary to apply the average control method in accordance with IEC 60068-2-64.

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

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Table A.1 — Development of test profiles for vibration tests

Item	**Documentation** Description of the vehicle	**Recommended documentation/parameters** Technical data (e.g. power, maximum r/min, nominal speed, volume, kind of engine, number of cylinders)	Comments
Engine-mounted	Boundary conditions	Dynamometer and/or road	Full load
Body-mounted		Proving ground/ test track description	
		Road surfaces (e.g. Belgian block, washboard, hip hop)	
		Driving speed	
Vehicle data gathering	Sampling frequency	$\geqslant$ 2,5 times of f_{max}	Df = 1/($f_{sample} \times b$)
	Block length, b	$\geqslant 2k$ (where k is the slope)	
	Resolution	LSB $<$ 0,1 % of maximum 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	
Data analysis	Peak-hold FFT	Peak-hold	Reference for creating sine tests or the sinusoidal part of a sine on random test
	Windowing	“Hanning” for stationary signals (no transient signal)	
		No windowing for transient signals (crest factor $>$ 6)	
	r.m.s. versus speed/time		
	Signal characteristic (sinusoidal/random part of signal)	Arithmetically averaged PSD from the time windows with the highest r.m.s. value	Reference for creating random tests or the random part of a sine on random test
		Waterfall diagram	
		Auto-correlation for stationary signals	
Test profile development	Methods and processes used to develop the test profile	For example, describe all key points including data reduction (averaging/enveloping)	
	Methods and procedures used to determine 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 (stress versus number) curve
	For engine mounted components	Take the r/min distribution into account	
	For body mounted components	Take the mileage of bad road conditions into account	
	Rationale for the methods — Processes and engineering judgement		
	Test parameters	For example, the tests in 4.1.3	

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A.4 Engine rotational speed distribution

There is a general relation between the rotational speed (r/min) and the vibration level. The vibration level increases with higher rotational speed (see Figure A.1 and Table A.2).

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

To assess the test duration, it is necessary to take into account different r/min distributions and the vehicle life time. All available r/min distributions show that the r/min range from $0{,}9 \times n_{nominal}$ to n_{max} is normally not used very often.

For this part of ISO 16750, three distributions were chosen:

a) an r/min distribution published in SAE [2], in which 55 cars were investigated (70 000 km; 10 000 trips)

b) a “worst case” r/min distribution recorded during temperature measurements with the aim of reaching very high temperatures, the vehicles therefore being driven in a very high r/min range;

c) a weighted distribution, consisting of:

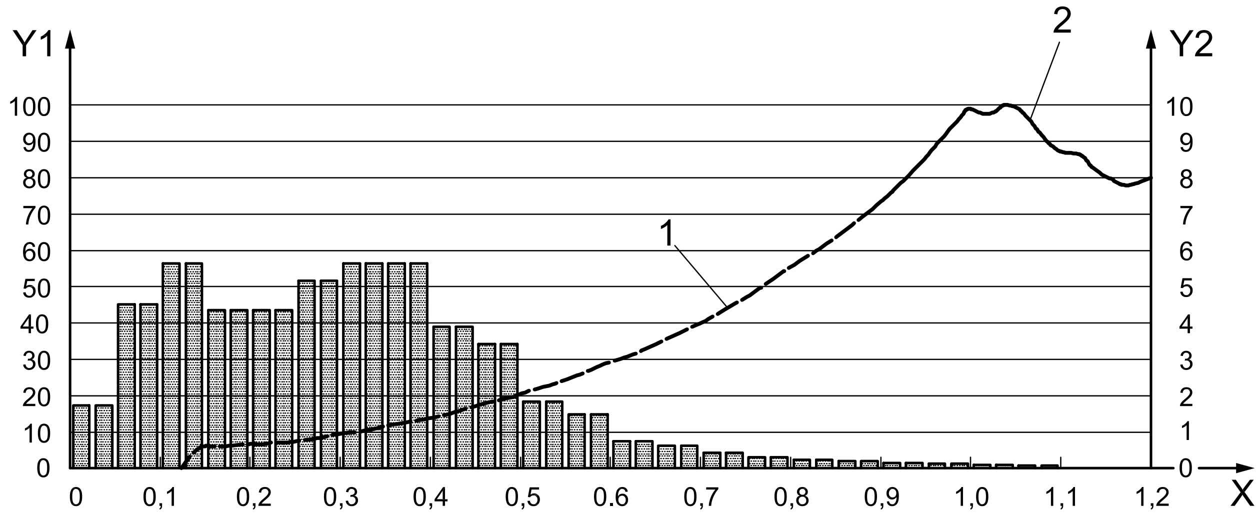
   1) SAE publication = 80 %,

   2) “worst case” = 20 %.

This leads to a relevant distribution of 0,5 % in the r/min range from $0{,}9 \times n_{nominal}$ to n_{max}. Thus, 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 and r/min distributions, the test engineer is allowed to change the test duration proportionally.

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.



Key

X r/min — normalized to $n_{nominal}$

Y1 r.m.s. — normalized, %

Y2 r/min — probability (weighted distribution), %

1 r.m.s. level versus engine speed, $n \leqslant 0{,}9 \times n_{nominal}$

2 r.m.s. level versus engine speed, $n > 0{,}9 \times n_{nominal}$

Figure A.1 — r.m.s. acceleration level and weighted r/min distribution versus engine speed

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Table A.2 — r.m.s. acceleration level and r/min distribution versus engine speed

$n/n_{nominal}$	r.m.s. level versus r/min (normalized) %	r/min probability [a] (p_x) %	r/min probability [b] (p_x') %	Weighted r/min distribution [c] ($20p_x + 80p_x'$)/100
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
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] "Worst case" distribution.

[b] SAE distribution.

[c] Cumulative weighted r/min distribution ($n > 0{,}9\ n_{nominal}$) is 0,5 %; test duration of 22 h corresponds to 4 400 h in the vehicle.

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A.5 Fatigue calculation

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

A verification is made as to whether a 8 h random vibration test is sufficient to cover the stress in the vehicle which occurs during the vehicle's lifetime.

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

A.5.2 Procedure

A.5.2.1 Carry out 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).

A.5.2.2 Determine 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.

A.5.2.3 Choose the car lifetime and the “bad road percentage” (both are selectable parameters).

A.5.2.4 Calculate the expected PCB load distribution by multiplying the count result in each class with the factors:

- test duration/measuring time during test;
- car lifetime × percentage of bad roads/measuring time in car.

A.5.2.5 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 hypothesis” and modifications (“Haibach”), and
- the “Palmgren–Miner hypotheses of linear damage accumulation” (for details, see A.5.7 and Figure A.3).
- Table A.5 shows the short result of the fatigue calculation for different models of stress versus number of load cycles (S/N model).

A.5.3 Conclusions

A.5.3.1 General

The results of the chosen example show that the stress (fatigue limits) which results from a test duration of 8 h is about 1,7 (1,37–2,06) times higher than the stress in the vehicle during 5 400 h on a test track.

Measurements and calculations like this have been done for more than 20 years and in many applications. The results are always similar and confirm that a test duration of 8 h is sufficient.

A.5.3.2 Additional confirmations

From field experience, there have been no failures known to be caused by vibration in more than 20 years.

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

The selected parameters (car lifetime of 6 000 h, 90 % rough road part) are absolutely worst case. Normally, the calculation is done with less than 50 % rough road part.

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A.5.4 Test parameters

The test parameters are as follows:

- 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 below.

Table A.3 — Example of a random vibration test, parameters

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

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

A.5.5 Results

The test results shown in Table A.4 are based on the following parameters:

- load distribution from a measuring time of 19,91 s, calculated for an 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 %).

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Table A.4 — Test results

8 h random vibration test		5 400 h rough road driving	
Acceleration class a_i m/s^2	No. of cycles per class n_i	Acceleration class a_i m/s^2	No. of cycles per class 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 model)

Fatigue cycles of the S/N model	Slope, k, of S/N model graph	Hypotheses	Calculated fatigue level for the random vibration test (24 “S/N models”) m/s^2	Needed fatigue level for 5400 h rough road driving (24 “S/N models”) m/s^2	Comparison
2 000 000	3,5	Haibach	250	165	OK
		Miner	229	133	OK
	5	Haibach	246	144	OK
		Miner	236	131	OK
	7	Haibach	252	136	OK
		Miner	249	130	OK
	10	Haibach	267	132	OK
		Miner	266	130	OK
10 000 000	3,5	Haibach	173	126	OK
		Miner	169	112	OK
	5	Haibach	187	118	OK
		Miner	184	112	OK
	7	Haibach	205	116	OK
		Miner	203	113	OK
	10	Haibach	229	117	OK
		Miner	229	115	OK
50 000 000	3,5	Haibach	112	91	OK
		Miner	112	87	OK
	5	Haibach	137	93	OK
		Miner	137	91	OK
	7	Haibach	164	97	OK
		Miner	164	96	OK
	10	Haibach	196	102	OK
		Miner	196	101	OK

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A.5.6 Determination of the load distribution from the measured time history

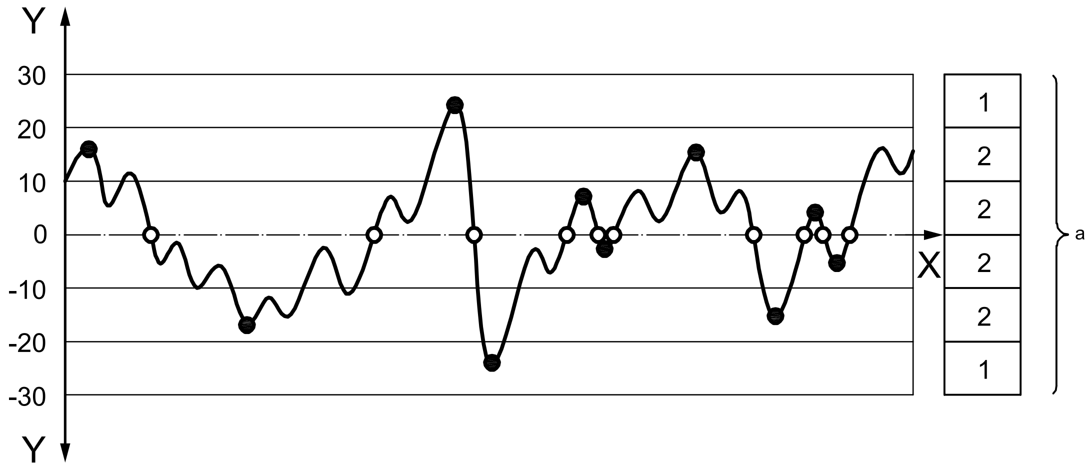
There is one maximum between two zero crossings.

In each class (acceleration level), the number of maxima during the measuring time are 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, e.g. (8 h × 3 600 s/h) / 19,9 s = 1 447.

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, e.g. (6 000 h × 0,9 × 3 600 s/h) / 3,69 s = 5 268 293.



Key

X time

Y class, m/s²

a Number of half cycles in each class.

Figure A.2 — Counting method for the load distribution

A.5.7 Calculation of the fatigue limits

For the determination of the fatigue limit, a_D, one S/N model shall be chosen. The S/N model is described by the slope, k, and the fatigue number, N_D.

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.

In accordance with Palmgren–Miners hypothesis, the partial damage, s_i, at each level, a_i, is defined by the following equation:

$$s_i = \frac{n_i}{N_i}$$

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The whole damage, S, is defined by the following equation:

$$S = \sum s_i$$

Damage occurs per definition for $S \geqslant 1$.

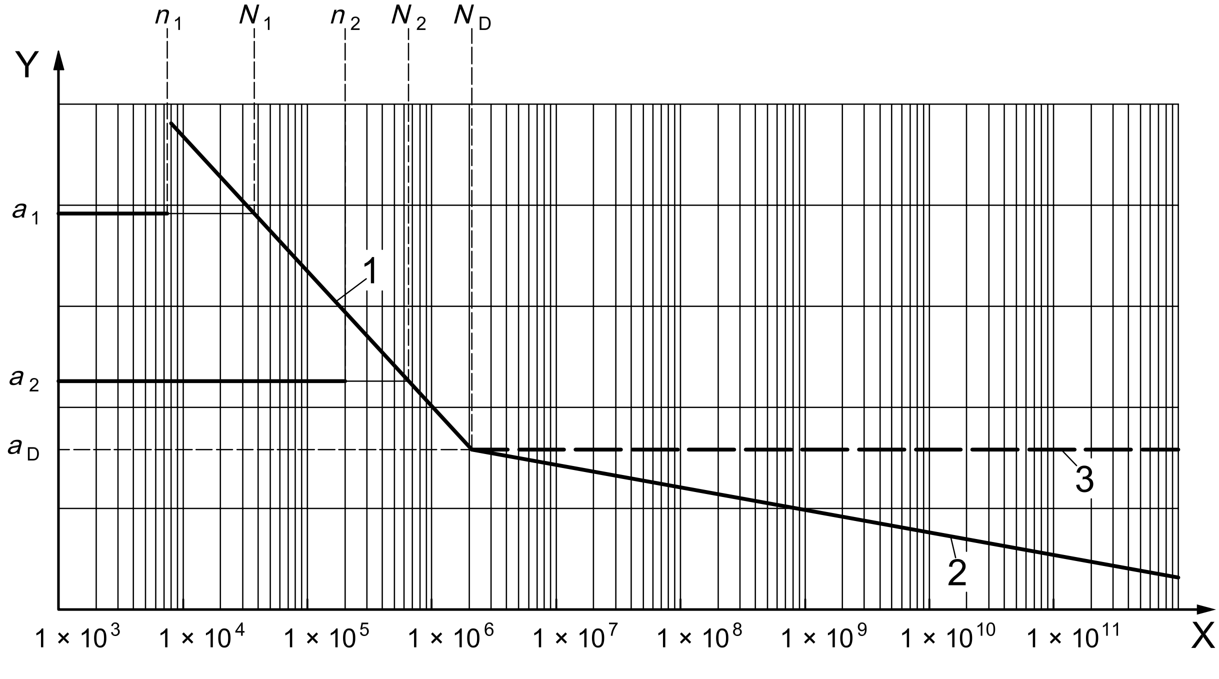
With the arbitrarily chosen starting value for a_D, the damage will definitely be either < 1 or > 1.

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 specialised literature). 24 models are currently used (e.g. "2 separate hypothesis", "4 slopes k" and "3 fatigue limit cycles N_D").

Even if some of these models are unrealistic, others have more potential and it is hoped that at least one of the 24 models is sufficiently realistic. However, even if this is not the case, the quality of the comparison is not influenced too much, so long as the same model is used or the same assumptions are made for both situations (car and test), because in a comparison some false assumptions are compensated.

If all 24 a_D values produced by the test are higher than the ones needed in the car, then the stress in the car is permissible. The load distribution from the selected example and the corresponding S/N graph (one model) are shown in Table A.6 and Figure A.3.



Key

X number of cycles

Y acceleration level

1 slope, k

2 Haibach modification slope, $2k–1$

3 Palmgren–Miner

$$S = \sum \left(\frac{n_i}{N_i} \right) \leqslant 1$$

Figure A.3 — Palmgren–Miner hypotheses — Linear damage accumulation, S

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

Random vibration test (8 h)		Corresponding S/N model graph (2×10^6; k = 5; a_D = 229 m/s²)		Measurement in car; road bumps (5 400 h)	
acceleration m/s²	**No. of cycles,** n	**acceleration** m/s²	**No. of S/N cycles**	**acceleration** m/s²	**No. of 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
65,06	2 345 538	—	—	12,53	690 820 313
39,04	1 823 343	—	—	4,176	3 158 789 063

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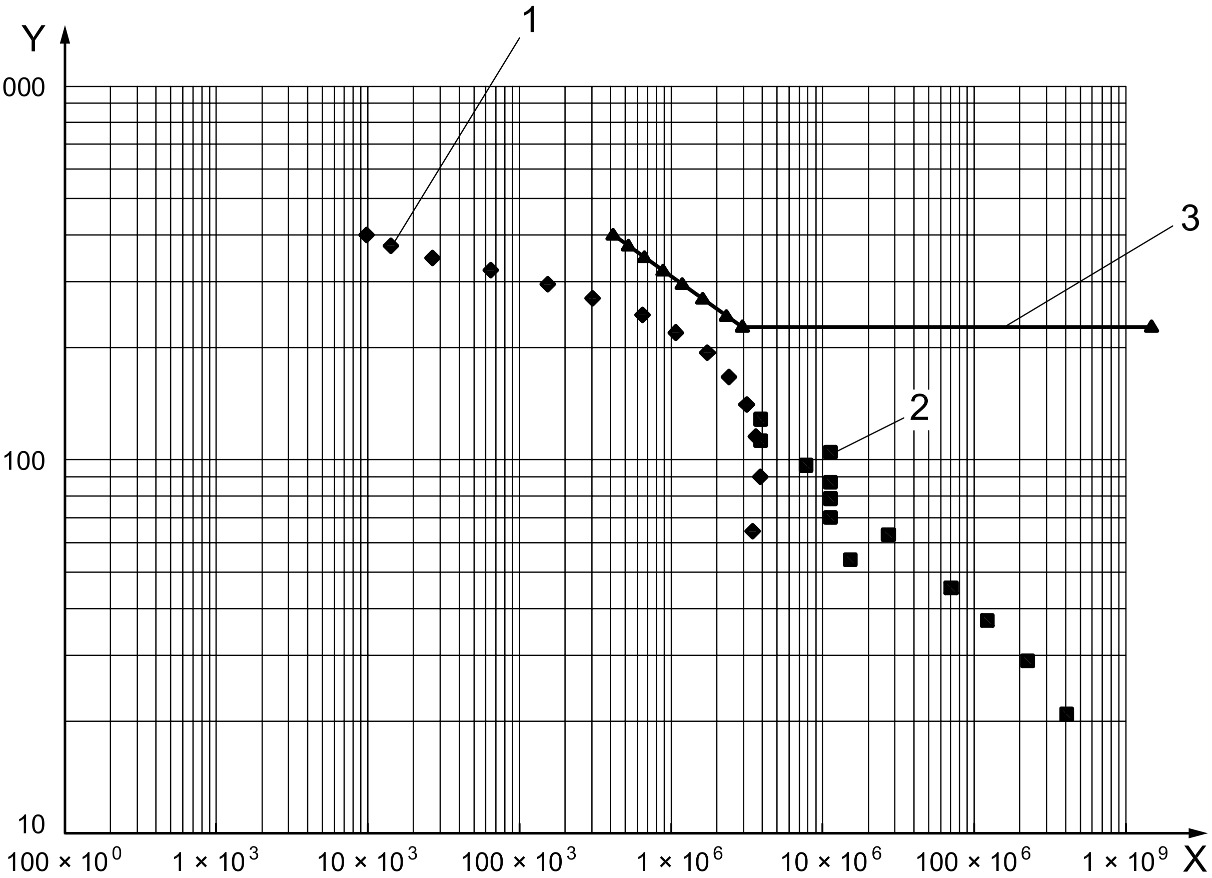

Key

X number of cycles

Y acceleration, m/s^2

1 random vibration test (8 h)

2 measurement in car

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

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

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Annex B
(informative)

Recommended mechanical requirements for equipment depending on the mounting location

Table B.1 indicates recommended mechanical requirements for equipment depending on the mounting location.

Table B.1 — Mounting location

<table>
<tr><th colspan="3" rowspan="2">Mounting location</th><th colspan="2">Recommended tests and requirements (Code letter see ISO 16750-1)</th></tr>
<tr><th>passenger cars</th><th>commercial vehicle</th></tr>
<tr><td rowspan="8">Engine compartment</td><td colspan="2">to body</td><td>D, K</td><td></td></tr>
<tr><td colspan="2">to frame</td><td>K, L</td><td></td></tr>
<tr><td colspan="2">on the flexible plenum chamber, not rigidly attached</td><td>C</td><td></td></tr>
<tr><td colspan="2">in the flexible plenum chamber, not rigidly attached</td><td>C</td><td></td></tr>
<tr><td colspan="2">on the engine</td><td>A, B, J</td><td></td></tr>
<tr><td colspan="2">in the engine</td><td>A, B, J</td><td></td></tr>
<tr><td colspan="2">on the transmission/retarder</td><td>U,V</td><td></td></tr>
<tr><td colspan="2">in the transmission/retarder</td><td>U,V</td><td></td></tr>
<tr><td rowspan="3">Passenger compartment</td><td colspan="2">without special requirement</td><td>D, E, K, L</td><td></td></tr>
<tr><td colspan="2">exposed to direct solar radiation</td><td>D, E, K, L</td><td></td></tr>
<tr><td colspan="2">exposed to radiated heat</td><td>D, E, K, L</td><td></td></tr>
<tr><td>Luggage compartment/
load compartment</td><td colspan="2">luggage compartment/load compartment</td><td>D, E, K, L</td><td></td></tr>
<tr><td rowspan="11">Mounting on the exterior</td><td colspan="2">to body</td><td>D, E, K, L</td><td></td></tr>
<tr><td colspan="2">to frame</td><td>K</td><td></td></tr>
<tr><td rowspan="2">underbody/
wheel housing</td><td>sprung masses</td><td>D, E, K, L</td><td></td></tr>
<tr><td>unsprung masses</td><td>H, I, O, T</td><td></td></tr>
<tr><td colspan="2">in/on passenger compartment door</td><td>F, G, R, S</td><td></td></tr>
<tr><td colspan="2">to engine compartment cover</td><td>F, G, R, S</td><td></td></tr>
<tr><td colspan="2">to luggage compartment lid/door</td><td>F, G, R, S</td><td></td></tr>
<tr><td colspan="2">to trunk lid/door</td><td>F, G, R, S</td><td></td></tr>
<tr><td rowspan="2">in cavity</td><td>open towards interior</td><td>D, E, K, L</td><td></td></tr>
<tr><td>open towards exterior</td><td>D, E, K, L</td><td></td></tr>
<tr><td colspan="2">in special compartments</td><td>D, E, K, L</td><td></td></tr>
</table>

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ICS 43.040.10
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