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Fourth edition
2023-07

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

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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.

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

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

This document was prepared by Technical Committee ISO/TC 22, *Road vehicles*, Subcommittee SC 32, *Electrical and electronic components and general system aspects*.

This fourth edition cancels and replaces the third edition (ISO 16750-3:2012), which has been technically revised.

The main changes are as follows:

- integrating and harmonizing content from ISO 19453-3:2018;
- distinction between small and lightweight versus large and heavy DUTs;
- revising vibration profiles where necessary due to extended datasets of and experience from vehicle measurements;
- addition of vibration test for rotating machines on combustion engines and Annex C;
- addition of vibration tests for hybrid-electric/fully-electric commercial vehicles;
- addition of guided fall test description and Annex D;
- addition of Annex E as guidance for 3D shaker testing;
- test order appearing in the document has been changed for a logical grouping depending on test type, however test numbers have been kept for backwards compatibility.

A list of all parts in the ISO 16750 series can be found on the ISO website.

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

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

Part 3:
Mechanical loads

1 Scope

This document applies to electric and electronic systems and components for vehicles including electric propulsion systems and components with maximum working voltages according to voltage class B. It describes the potential environmental stresses and specifies tests and requirements recommended for the specific mounting location on/in the vehicle.

This document describes mechanical loads.

This document is not intended to apply to environmental requirements or testing for systems and components of motorcycles and mopeds.

Systems and their components released for production, or systems and their components already under development prior to the publication date of this document, can be exempted from fulfilling the changes in this edition compared to the previous one.

2 Normative references

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

ISO 16750-1:2023, *Road vehicles — Environmental conditions and testing for electrical and electronic equipment — Part 1: General*

ISO 16750-4:2023, *Road vehicles — Environmental conditions and testing for electrical and electronic equipment— Part 4: Climatic loads*

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

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

IEC 60068-2-27, *Environmental testing — Part 2-27: Tests — Test Ea and guidance: Shock*

IEC 60068-2-31, *Environmental testing — Part 2-31: Tests — Test Ec: Rough handling shocks, primarily for equipment-type specimens*

IEC 60068-2-64, *Environmental testing — Part 2-64: Tests — Test Fh: Vibration, broadband random and guidance*

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

UL 969:2017, *Standard for Marking and Labeling Systems*

ISO 20567-1:2017, *Paints and varnishes — Determination of stone-chip resistance of coatings — Part 1: Multi-impact testing*

3 Terms and definitions

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

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

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

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

4 Tests and requirements

4.1 Vibration

4.1.1 Testing conditions during the vibration test

4.1.1.1 General

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

A clear dependence of the typical vibration load on the size and mass of the DUT is evident from vehicle measurements. This applies to all mounting locations due to dynamic system coupling. That is why in this document a distinction is made between small and lightweight E/E components (typically <2 kg, unless stated otherwise in the individual test description, e.g. sensors, ECUs or fuel injection equipment), mostly belonging but not limited to ICE vehicles, and much larger and heavier components (typically ≥2 kg, unless stated otherwise in the individual test description, e.g. electric motors, inverters, DC/DC converters or alternators), mostly belonging but not limited to electric powertrains in electric propulsion vehicles. In each application the applicability of the intended vibration profile should be verified with a vehicle measurement. See a mass classification example in ISO 16750-1:2023, Annex C. For further information and guidance please refer to Tables 38-40 (code letters).

The following basic idea of environmental test methods is expressed in the Foreword of Reference [7].

When applied properly, the environmental management and engineering processes described in this document can be of enormous value in generating confidence in the environmental worthiness and overall durability of the tested equipment. However, it is important to recognize that limitations inherent in laboratory testing make it imperative to use proper caution and engineering judgment when extrapolating these laboratory results to results that can 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 document should not assume that a system or component that passes laboratory tests of this document would also pass field/fleet verification trials.

The specified values are the best estimation that can be obtained up to the moment when results from measurements in the vehicle are received, but they do not replace a vehicle measurement.

The specified values apply to direct mounting in defined mounting locations. The specified vibration profiles apply to direct mounting in defined mounting locations. Since the use of an installation support (e.g. mounting bracket) can influence test vibration loads on the shaker to be much higher or much lower than actual vehicle loads, in principle, each vibration test should be carried out with only DUT itself. If using an installation support, the applied loads on the shaker should be checked to reproduce the actual vehicle loads as realistically as possible.

Carry out the vibration with the DUT rigidly mounted on a vibration table for reasons of comparability and reproducibility (see also IEC 60068-2-47:2005, Clauses 5 and 6). If using a bracket is technically unavoidable in order to fix the DUT to the shaker instead of a rigid mounting, then the transfer functions from the excitation to the DUT compared to vehicle measurements as well as a proper control strategy shall be considered. For further information refer to A.3. The mounting method(s) used shall be noted in the test report. 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 document.

If active operation and/or signal monitoring is applied during the test, extra care shall be taken with respect to the fixation of the power cables and the wiring harnesses. This aims at avoiding signal disturbances and negative mechanical impact on the connector, caused by dynamic motion of the harness itself. The routing, rigidity, mass and fixation of wire harness in vehicle installation should also be considered when deciding on the fixation of wire harness in a test setup in order to avoid a wrong testing load for the DUT.

Loads outside the designated test frequency ranges can be considered separately if agreed between the customer and the supplier. If it is known that resonance frequencies of the DUT are present that are critical for fatigue and are not covered by the test frequency ranges, then it is recommended to perform separate durability tests, such as resonance dwell testing.

NOTE Deviations from the load on the DUT can occur if vibration testing is carried out according to this document on a large and heavy DUT, as mounting rigidity and dynamic reaction on the vibrator table excitation are different compared to the situation in the vehicle. Such deviations can be minimized by applying the average control method (see A.3).

The application of the weighted average control method in accordance with IEC 60068-2-64 may be agreed upon.

4.1.1.2 Overlaid temperature cycles during vibration testing

4.1.1.2.1 General

Vibration tests are typically run with an overlaid temperature cycle. The intention is not to create additional aging of the DUTs, but to induce a temperature-dependent dynamic response of or within the DUT that might otherwise not occur if only tested at room temperature.

In the vehicle, vibration stress can occur together at low or high temperatures; for this reason, this interaction between mechanical and temperature stress is simulated in the test, too. A failure mechanism occurs when material characteristics of components change and cannot withstand the acceleration under this condition. For example, a plastic part may mellow due to the high temperature.

The mass of the DUT as well as the installation area are the main influence factors that determine the design of the temperature cycle which is why in the following clauses the different use cases are distinguished.

For longer test durations of the vibration test the test cycles can be either repeated for a sufficient number of times or stretched to fit the test duration. None of the following temperature cycles shall be further compressed in their duration, otherwise a temperature equilibrium within the DUT might not be ensured.

Depending on the failure mode of the DUT, a deviating temperature profile may be used if agreed between the customer and the supplier.

Intentional humidity control is not permitted even if water condensation on the DUT occurs during temperature cycles.

4.1.1.2.2 Temperature profile for small and lightweight components not mounted on the combustion engine

During the vibration test, for small and lightweight DUT not mounted on the combustion engine, perform the temperature cycling in accordance with IEC 60068-2-14, Test Nb, not using its specified temperature changing rates, but using the variant given in Figure 1 and Table 1.

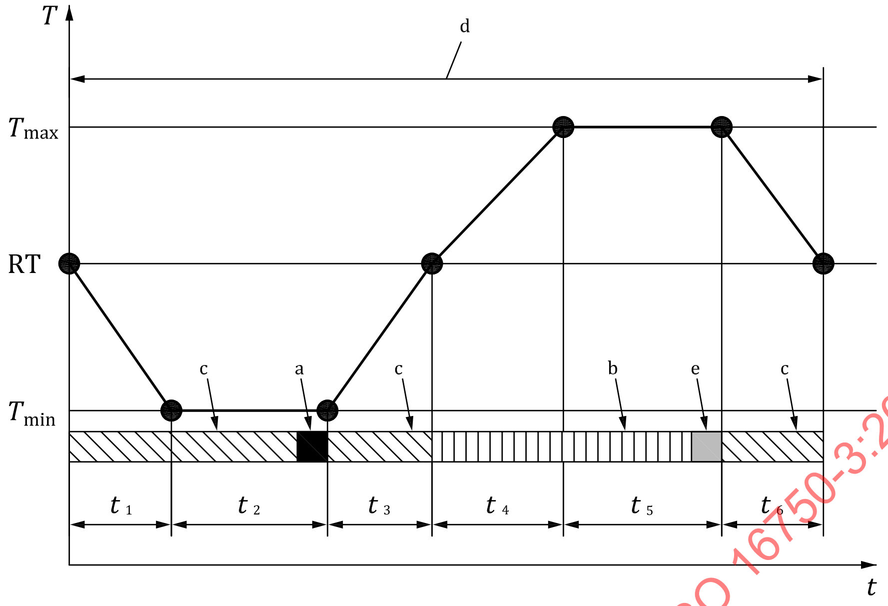
NOTE 1 This temperature profile can also be applied to small and lightweight components mounted on electric drive systems or components.

Perform temperature cycling with the following as one cycle. Decrease ambient temperature from RT to T_{min}, expose the DUT at T_{min}, increase ambient temperature from T_{min} to T_{max}, expose the DUT at T_{max} and then decrease ambient temperature from T_{max} to RT (see Figure 1).

Perform a functional test at the end of T_{min} and T_{max} as short as possible with operating mode 3.3 or 4.3 as defined in ISO 16750-1 (see key a in Figure 1). In addition, operate with operating mode 3.4 or 4.4 as defined in ISO 16750-1 (see key b in Figure 1) during the section from room temperature (RT) to T_{max}. During the other sections, operate with operating mode 2.1 as defined in ISO 16750-1 (see key c in Figure 1). If operating mode 4.3/4.4 is not technically feasible, operating mode 3.3/3.4 may be used if agreed between the customer and the supplier.

NOTE 2 A permanent operation starting at T_{min} prevents possible condensation of humidity on DUT because the self-heating of the DUT occurs. An electrical operation starting at RT allows this phenomenon.

NOTE 3 Condensation can lead to swelling of plastic sub-components of the DUT and therefore, influence the dynamic behaviour under vibrational load.



Key

T	temperature [°C]
t	time
T_{min}	minimum operating temperature as defined in ISO 16750-4
T_{max}	maximum operating temperature as defined in ISO 16750-4
RT	room temperature as defined in ISO 16750-1
t_1, t_2, t_3, t_4, t_5, t_6	time parameter as defined in Table 1
a	Functional test with operating mode 3.3 or 4.3 as defined in ISO 16750-1.
b	Operating mode 3.4 or 4.4 as defined in ISO 16750-1.
c	Operating mode 2.1 as defined in ISO 16750-1.
d	One cycle.
e	Functional test with operating mode 3.4 or 4.4 as defined in ISO 16750-1.

Figure 1 — Temperature cycle with specified change rate for the vibration test of a small and lightweight DUT

Table 1 — Temperatures versus time duration for temperature cycling for the vibration test of a small and lightweight DUT

Parameter	Duration [min]	Temperature [°C]
t_1	60	From RT to T_{min}
t_2	90	Exposure time at T_{min}
t_3	60	From T_{min} to RT
t_4	90	From RT to T_{max}
t_5	110	Exposure time at T_{max}
t_6	70	From T_{max} to RT
NOTE T_{min} and T_{max} are defined in ISO 16750-4:2023, Table 1.		

4.1.1.2.3 Temperature profile for large and heavy components not mounted on the combustion engine

During the vibration test, for large and heavy DUT not mounted on the combustion engine, perform the temperature cycling in accordance with IEC 60068-2-14, Test Nb, not using its specified temperature changing rates, but using the variant given in Figure 2 and Table 2.

Perform temperature cycling with the following as one cycle. Decrease ambient temperature from RT to T_{min}, expose the DUT at T_{min}, increase ambient temperature from T_{min} to T_{max}, expose the DUT at T_{max} and then decrease ambient temperature from T_{max} to RT (see Figure 2).

Before performing this test, a separate temperature measurement (with DUT in operating mode 2.1 as defined in ISO 16750-1) shall be performed to determine what exposure time at T_{max}, T_{min} (see Figure 2) is necessary to warrant that this desired temperature is also reached in DUT temperature. The measuring point of the DUT shall be agreed between the customer and the supplier, considering a target device (e.g. microprocessor, motor coil) which is temperature-influenced in functionality or performance.

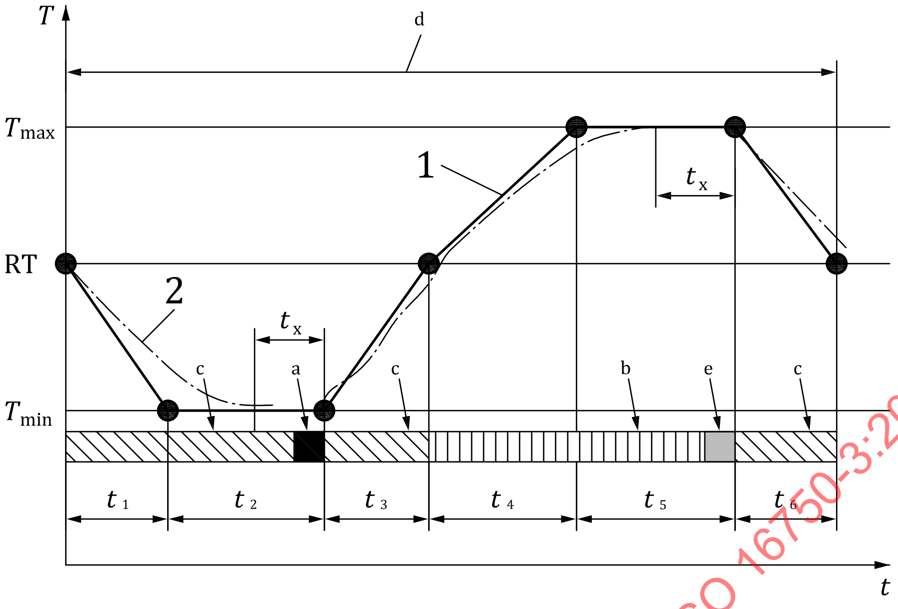
If operating mode 2.1 is technically not feasible for the separate temperature measurement, operating mode 1.2 as defined in ISO 16750-1, can be used as agreed between the customer and the supplier.

Measures regarding the functional performance, for example, de-rating of the e-motor, are allowed to avoid overheating of the DUT during high-temperature operation with self-heating effects.

The dwell time t_x of the DUT at T_{min} and T_{max} shall be more than 30 min each per temperature cycle; therefore, exposure time shall be adjusted accordingly depending on the size and other characteristics of the DUT. The customer and the supplier shall agree on a complete profile of temperature cycle including dwell time and stabilisation time depending on the size and other properties of the DUT.

NOTE This temperature profile can also be applied to large and heavy components mounted on electric drive systems or components.

Perform a functional test at the end of T_{min} and T_{max} as short as possible with operating mode 3.3 or 4.3 as defined in ISO 16750-1 (see key a in Figure 2). In addition, operate with operating mode 3.4 or 4.4 as defined in ISO 16750-1 (see key b in Figure 2) during the section from room temperature (RT) to T_{max}. During the other sections, operate with operating mode 2.1 as defined in ISO 16750-1 (see key c in Figure 2). If operating mode 4.3/4.4 is not technically feasible, operating mode 3.3/3.4 may be used if agreed between the customer and the supplier. For electric motors, active operation in operation mode 3.3 or 4.3 instead of 2.1 can be performed in order to avoid unrealistic failure mechanism, e.g. wear in the bearing of an e-motor due to the vibration input.



Key

T	temperature [°C]
t	time
1	ambient temperature
2	DUT temperature, exemplary for non-heat dissipating DUTs
T_{min}	minimum operating temperature as defined in ISO 16750-4
T_{max}	maximum operating temperature as defined in ISO 16750-4
RT	room temperature as defined in ISO 16750-1
t_1, t_2, t_3, t_4, t_5, t_6	time parameter as defined in Table 2
t_x	dwell time at T_{min} or T_{max}
[a]	Functional test with operating mode 3.3 or 4.3 as defined in ISO 16750-1.
[b]	Operating mode 3.4 or 4.4 as defined in ISO 16750-1.
[c]	Operating mode 2.1 as defined in ISO 16750-1.
[d]	One cycle.
[e]	Functional test with operating mode 3.4 or 4.4 as defined in ISO 16750-1.

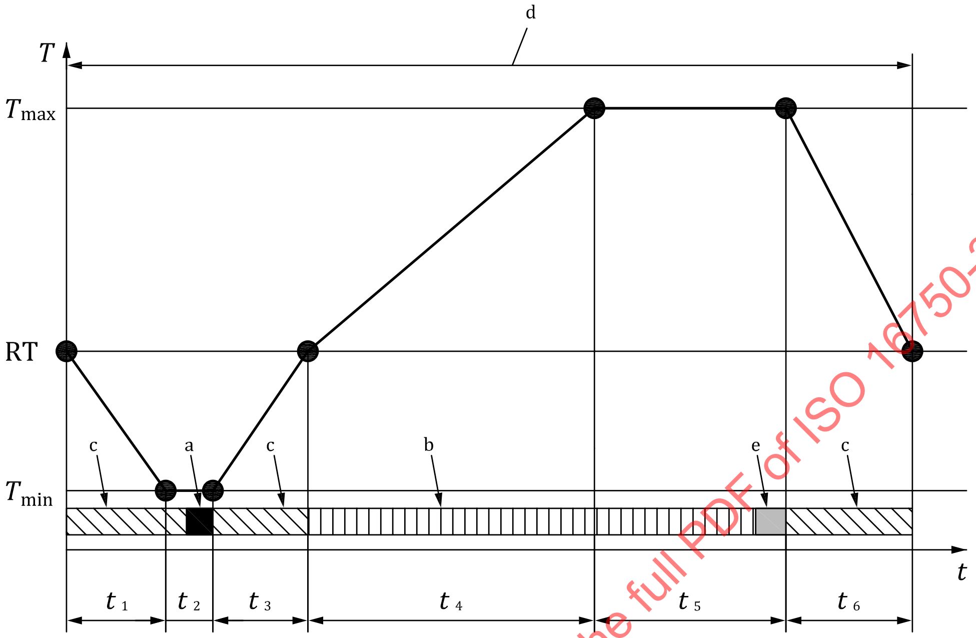
Figure 2 — Temperature cycle with specified change rate for the vibration test of large and heavy DUTs

Table 2 — Temperatures versus time duration for temperature cycling for the vibration test of large and heavy DUTs

Parameter	Duration [min]	Temperature [°C]
t_1	60	From RT to T_{min}
t_2	As agreed	Exposure time at T_{min}
t_3	60	From T_{min} to RT
t_4	90	From RT to T_{max}
t_5	As agreed	Exposure time at T_{max}
t_6	70	From T_{max} to RT
t_x	> 30	Dwell time at T_{min} or T_{max}
NOTE T_{min} and T_{max} are defined in ISO 16750-4:2023, Table 1.		

4.1.1.2.4 Temperature profile for components mounted on the combustion engine

In case of combustion engine-mounted DUTs (e.g. ECUs) a dwell time at T_{min} as given in Table 1 can lead to a failure mode that is not occurring under field conditions as the combustion engine will warm up any attached components quickly, so that an extended superposition of vibration load and T_{min} is unrealistic. Therefore, the temperature profile shall be changed as given in Figure 3 and Table 3.



Key

T	temperature [°C]
t	time
T_{min}	minimum operating temperature as defined in ISO 16750-4
T_{max}	maximum operating temperature as defined in ISO 16750-4
RT	room temperature as defined in ISO 16750-1
t_1, t_2, t_3, t_4, t_5, t_6	time parameter as defined in Table 3
a	Functional test with operating mode 3.3 or 4.3 as defined in ISO 16750-1.
b	Operating mode 3.4 or 4.4 as defined in ISO 16750-1.
c	Operating mode 2.1 as defined in ISO 16750-1.
d	One cycle.
e	Functional test with operating mode 3.4 or 4.4 as defined in ISO 16750-1.

Figure 3 — Temperature cycle for DUTs mounted on the combustion engine

Table 3 — Temperatures versus time duration for temperature cycling for the vibration test of a combustion engine-mounted DUT

Parameter	Duration [min]	Temperature [°C]
t_1	60	From RT to T_{min}
t_2	20	Exposure time at T_{min}
t_3	60	From T_{min} to RT

NOTE 1 T_{min} and T_{max} are defined in ISO 16750-4:2023, Table 1.

NOTE 2 The exposure time at T_{min}, t_2, can be shortened if agreed between the customer and the supplier based on justification from their field experience.

Table 3 *(continued)*

Parameter	Duration [min]	Temperature [°C]
t_4	160	From RT to T_{max}
t_5	110	Exposure time at T_{max}
t_6	70	From T_{max} to RT

NOTE 1 T_{min} and T_{max} are defined in ISO 16750-4:2023, Table 1.

NOTE 2 The exposure time at T_{min}, t_2, can be shortened if agreed between the customer and the supplier based on justification from their field experience.

Similar to the profile given in Table 1 also for the overlaid temperature profile for a combustion engine-mounted DUT, a short functional test at the end of the low temperature phase shall be done as well as for the duration in which room temperature or above is given. If experience from the field justifies to change the exposure time at T_{min} to avoid unrealistic failure modes during shaker testing, then this exposure time shall be adjusted accordingly.

4.1.2 Test Ia - Passenger car, combustion engine, small and lightweight DUT

4.1.2.1 Purpose

This test checks the small and lightweight DUT (e.g. small sensors and ECUs) 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 a negligible impact on combustion engine-mounted components. Shock inputs are effectively isolated by suspension, and combustion engine-mounting systems.

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

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

4.1.2.2 Test

4.1.2.2.1 General

This test shall be performed as a mixed mode vibration test according to IEC 60068-2-80.

4.1.2.2.2 Sinusoidal vibration

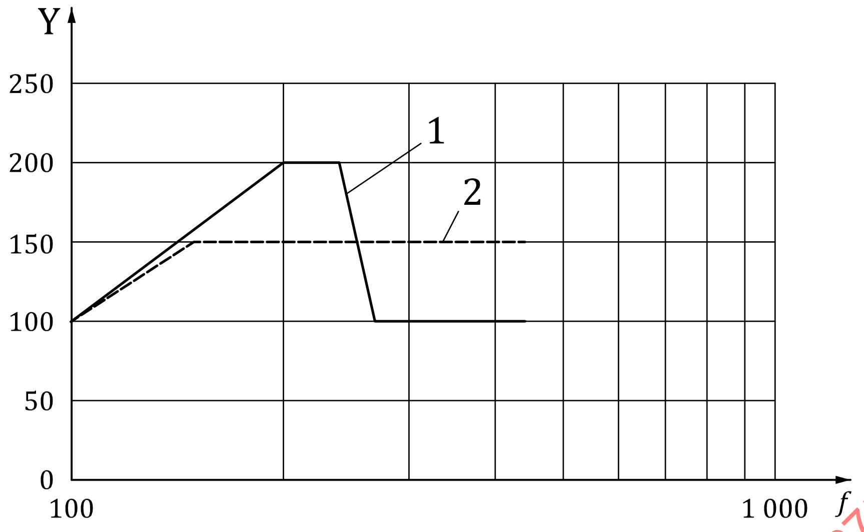
Perform the test according to IEC 60068-2-6, but using a sweep rate of ≤ 0,5 octave/min. Use a test duration of 30 h for each axis of the DUT.

NOTE The test duration is based on A.4.

Use curve 1 in Table 4/Figure 4 for the DUT intended for mounting on combustion engines with five cylinders or fewer.

Use curve 2 in Table 4/Figure 4 for the DUT test intended for mounting on combustion engines with six cylinders or more.

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



Key

Y	amplitude of acceleration [m/s^2]
f	frequency [Hz]
1	curve 1 (≤5 cylinders)
2	curve 2 (≥6 cylinders)

Figure 4 — Acceleration versus frequency

Table 4 — Values for acceleration versus frequency

Curve 1 (see Figure 4)	
Frequency [Hz]	**Amplitude of acceleration** [m/s^2]
100	100
200	200
240	200
270	100
440	100
Curve 2 (see Figure 4)	
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
200	200
240	200
255	150
440	150

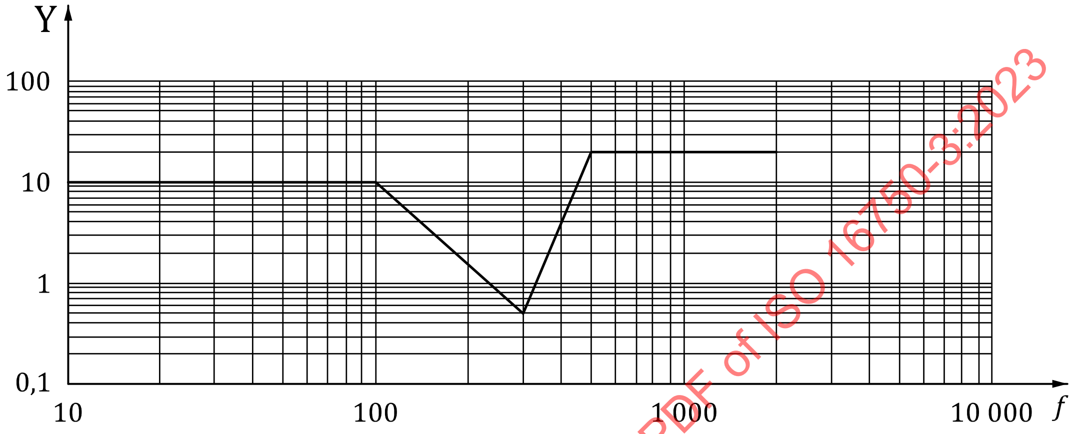
4.1.2.2.3 Random vibration

Perform the test according to IEC 60068-2-64. Use a test duration of 30 h for each axis of the DUT.

The root mean square (RMS) acceleration value shall be 181 m/s^2.

Values for power spectral density (PSD) versus frequency are referred to in Figure 5 and Table 5.

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



Key

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

f frequency [Hz]

Figure 5 — PSD of acceleration versus frequency

Table 5 — Values for PSD versus frequency

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

4.1.2.3 Requirement

Malfunctions or breakage shall not occur. Functional status class A as defined in ISO 16750-1 is required during active operating modes, and functional status class C is required during periods with other operating modes.

4.1.3 Test II — Passenger car, gearbox attached to a combustion engine, small and lightweight DUT

4.1.3.1 Purpose

This test checks the small and lightweight DUT (e.g. small sensors or transmission control units) 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 combustion engine (e.g. dominating orders) in the frequency range from 100 Hz to 440 Hz and partly from 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 is tested in 4.2.3.

4.1.3.2 Test

4.1.3.2.1 General

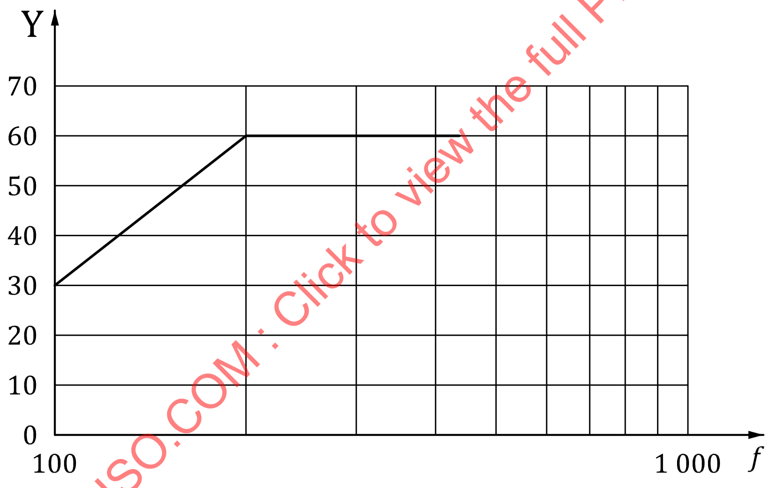
This test shall be performed as a mixed mode vibration test according to IEC 60068-2-80.

NOTE The test duration is based on A.4. The temperature in the chamber is above RT at the end of the test (3 ¾ temperature cycles).

4.1.3.2.2 Sinusoidal vibration

Perform the test according to IEC 60068-2-6, but using a sweep rate of ≤0,5 octave/min. Use a test duration of 30 h for each axis of the DUT.

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



Key

Y amplitude of acceleration [m/s^2]

f frequency [Hz]

Figure 6 — Acceleration versus frequency

Table 6 — Values for acceleration versus frequency

Frequency [Hz]	Amplitude of acceleration [m/s^2]
100	30
200	60
440	60

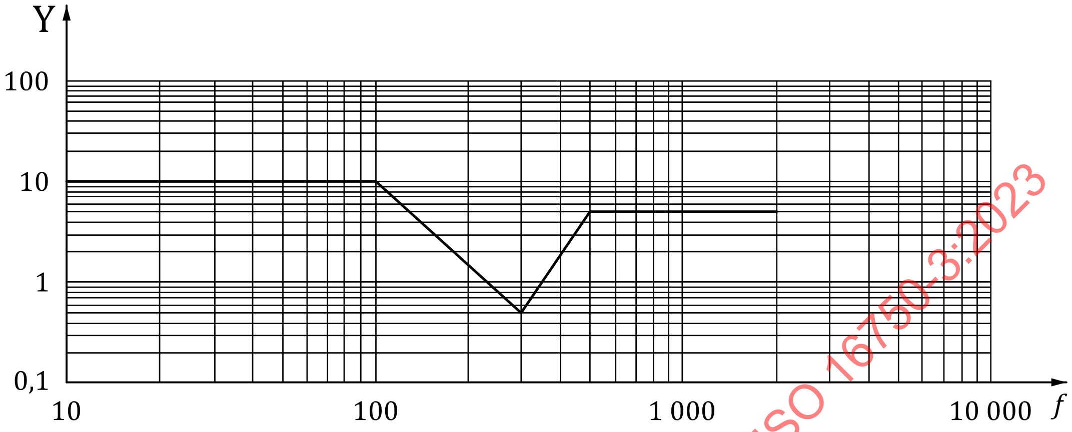
4.1.3.2.3 Random vibration

Perform the test according to IEC 60068-2-64. Use a test duration of 30 h for each axis of the DUT.

The RMS 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.

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



Key

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

f frequency [Hz]

Figure 7 — PSD of acceleration versus frequency

Table 7 — Values for PSD versus frequency

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

4.1.3.3 Requirement

Malfunctions and/or breakage shall not occur. Functional status class A as defined in ISO 16750-1 is required during active operating modes, and functional status class C is required during periods with other operating modes.

4.1.4 Test VI — Commercial vehicle, combustion engine and gearbox, small and lightweight DUT

4.1.4.1 Purpose

This test checks the small and lightweight DUT (such as small sensors or ECUs) 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 combustion 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 (see Table 10) is to be carried out with a duration of 32 h in all critical axes of the DUT. When it is required to determine the natural frequency of the DUT in the relevant test specification, the vibration response investigation shall be carried out according to IEC 60068-2-6, but using a frequency range of 10 Hz to 50 Hz with an acceleration amplitude of 10 m/s^2 as excitation at a sweep rate of ≤0,5 octave/min.

4.1.4.2 Test

4.1.4.2.1 General

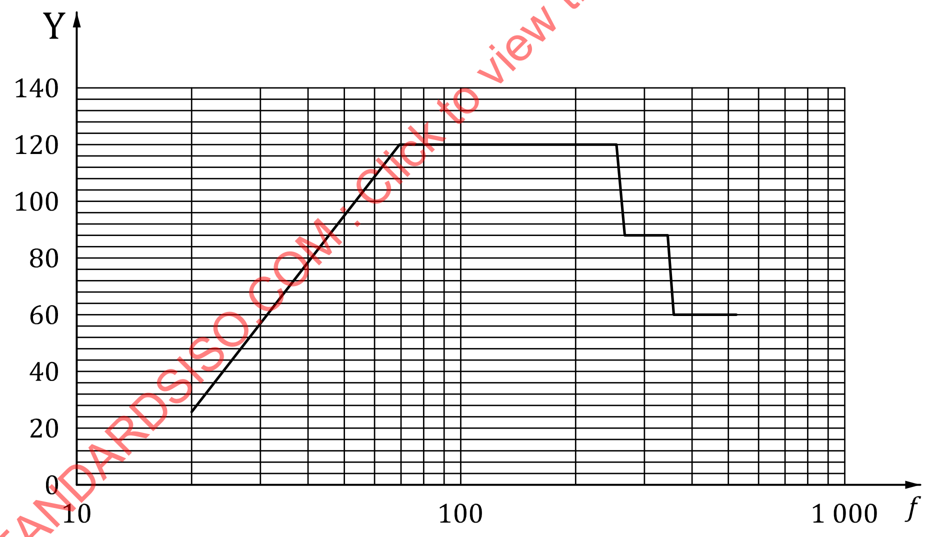
This test shall be performed as a mixed mode vibration test according to IEC 60068-2-80.

NOTE The temperature in the chamber is above RT at the end of the test (11 ¾ cycles).

4.1.4.2.2 Sinusoidal vibration

Perform the test according to IEC 60068-2-6, but using a sweep rate of ≤0,5 octave/min. Use a test duration of 94 h for each axis of the DUT (equivalent to approximatively 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.5.

Values for amplitude versus frequency are referred to in Figure 8 and Table 8.



Key

Y amplitude of acceleration [m/s^2]

f frequency [Hz]

Figure 8 — Acceleration versus frequency

Table 8 — Values for acceleration versus frequency

Frequency [Hz]	Amplitude of acceleration [m/s^2]
20	26
65	120

Table 8 *(continued)*

Frequency [Hz]	**Amplitude of acceleration** [m/s^2]
260	120
270	90
350	90
360	60
520	60

NOTE The sinusoidal profile given in previous editions of this document has been modified in three aspects. A higher amplitude of acceleration at the starting frequency was applied as even modern controllers have difficulty distinguishing the sine and random part of the SoR (sine on random) signal at this frequency. Therefore, the sine part was raised reasonably. Secondly, instead of a constant slope of displacement, now a constant slope of acceleration was applied from this first break point to the second. And lastly, instead of vertical slopes at 260 Hz and 350 Hz, slightly more shallow slopes were applied to allow for better control of the signal by the controllers.

4.1.4.2.3 Random vibration

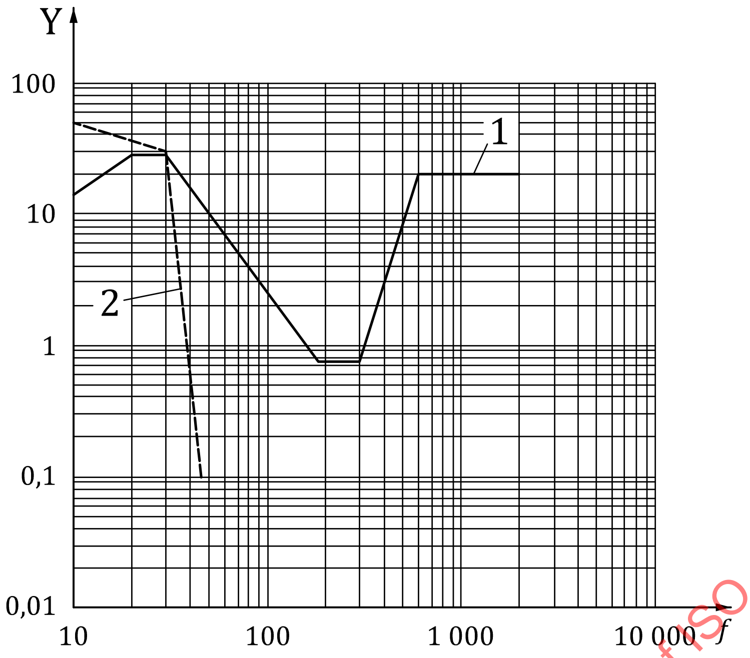
Perform the test according to IEC 60068-2-64.

Test duration:

- 94 h for each axis of the DUT (standard) (see Figure 9 and Table 9),
- 32 h additionally for each critical axis of the DUT (for natural frequencies below 30 Hz) (see Table 10).

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

The PSD versus frequency is referred to in Figure 9 and Table 9.



Key

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

f frequency [Hz]

1 standard random test profile

2 additional profile in case of f_n < 30 Hz

Figure 9 — PSD of acceleration versus frequency

Table 9 — Values for PSD versus 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
RMS acceleration value = 177 m/s^2.	

Table 10 — Values for PSD versus 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
RMS acceleration value = 28,6 m/s^2.	

4.1.4.3 Requirement

Malfunctions and/or breakage shall not occur. Functional status class A as defined in ISO 16750-1 is required during active operating modes, and functional status class C is required during periods with other operating modes.

4.1.5 Test XIII — Passenger car, hybrid-electric powertrain, combustion engine and gearbox, large and heavy DUT

4.1.5.1 Purpose

This test checks the large and heavy DUT of the hybrid-electric powertrain (e.g. electric motors or inverters) that is mounted to the combustion engine and/or gearbox of the (P)HEV for malfunctions and/or breakage caused by vibration.

The vibrations on the powertrain can be split up into three kinds:

- sinusoidal vibration that results from the unbalanced mass forces in the cylinders;
- random vibration due to all other vibration schemes of an engine, e.g. closing of valves; and
- random vibration due to the influence of rough-road conditions.

NOTE 1 If the DUT needs to be tested for a specific resonance effect, then a resonance dwell test in accordance with IEC 60068-2-6:2007, 8.3.2 can also be applied.

NOTE 2 This profile is an updated version of Test II in ISO 19453-3:2018, 4.1.2.2, see also A.9.2.

4.1.5.2 Test

4.1.5.2.1 General

Vibration of powertrain is the sine-on-random vibration induced by crankshaft rotation and engine combustion. A separate test condition covers random vibration from road surface. The test duration shall be at least as long as one temperature cycle necessary to ensure thermal stability in the DUT.

NOTE 1 The test duration is based on A.4.3 and A.4.5. The test duration and vibration load level can be adjusted accordingly based on the Basquin's formula given in A.8.

NOTE 2 When agreed between the supplier and the customer, the test duration can be adjusted based on Basquin's model by taking into account the exponent *k* of the S-N curve specific to this component (see also A.8). For the component which is freely placed or is not anticipated to be installed in a certain position and orientation (e.g. inverter), the maximum profile out of all three axes can be applied to all three axes.

NOTE 3 As the driveshaft of an electric motor is always parallel to the ground floor, it is reasonable to have a direction-specific profile, separating vertical excitations from horizontal ones.

The definition of the coordinate system is shown in Table A.4.

4.1.5.2.2 Sine-on-random vibration

4.1.5.2.2.1 General

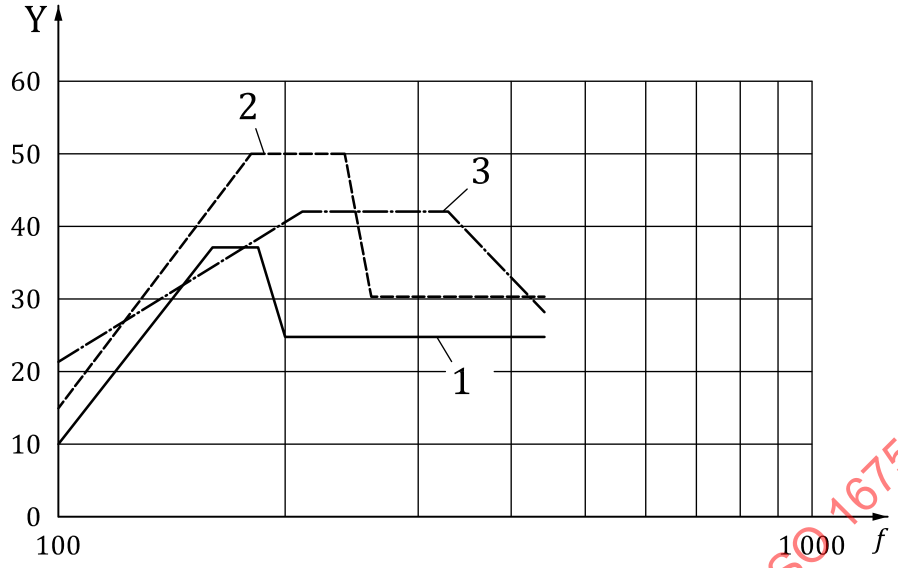
This test shall be performed as a mixed mode vibration test in accordance with IEC 60068-2-80.

4.1.5.2.2.2 Sinusoidal vibration part

A sweep rate of 0,5 octave/min or less shall be used.

The test duration is 30 h for each axis of the DUT.

The profiles in Table 11 and Figure 10 show the sinusoidal vibration part of the sine-on-random profile.



Key

Y acceleration amplitude [m/s²]

f frequency [Hz]

1 curve for X axis [a]

2 curve for Y axis [a]

3 curve for Z axis [a]

[a] X, Y and Z are the e-motor axes as defined in Table A.4.

Figure 10 — Acceleration versus frequency

Table 11 — Values for maximum acceleration versus frequency

X axis		Y axis		Z axis	
Frequency [Hz]	Acceleration amplitude [m/s²]	Frequency [Hz]	Acceleration amplitude [m/s²]	Frequency [Hz]	Acceleration amplitude [m/s²]
100	10	100	15	100	21
160	37	180	50	210	42
185	37	240	50	330	42
200	25	260	30	440	28
440	25	440	30	—	—

4.1.5.2.2.3 Random vibration part

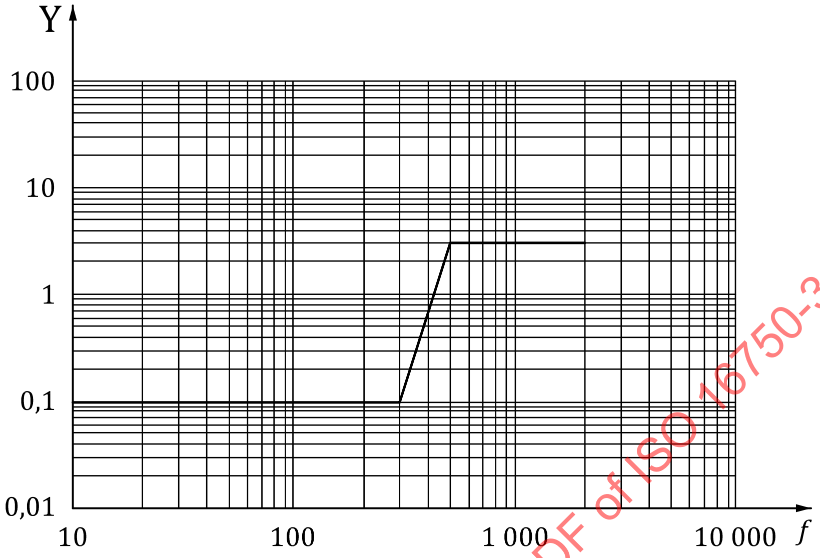
Perform the test in accordance with IEC 60068-2-64.

The test duration is 30 h for each axis of the DUT.

The RMS acceleration value shall be 68,7 m/s². For the random part of the sine-on-random profile, the vibration loads are equivalent for all three primary axes. Therefore, only one profile for all three axes shall be used.

The power spectral density (PSD) versus frequency is illustrated in Figure 11 and Table 12.

NOTE The PSD values (random vibration) are reduced in the frequency range of the sinusoidal vibration test of (100 to 500) Hz as well as in the low-frequency range of (10 to 100) Hz as the rough-road influence has been eliminated (see A.4.5).



Key

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

f frequency [Hz]

Figure 11 — PSD of acceleration versus frequency

Table 12 — Values for PSD versus frequency

Frequency [Hz]	**PSD** [$(m/s^2)^2$/Hz]
10	0,1
300	0,1
500	3
2 000	3

4.1.5.2.3 Random vibration

As the excitation from the combustion engine and gearbox at high engine speeds usually does not occur simultaneously with rough-road excitation, a separate test with a broadband random profile has been created.

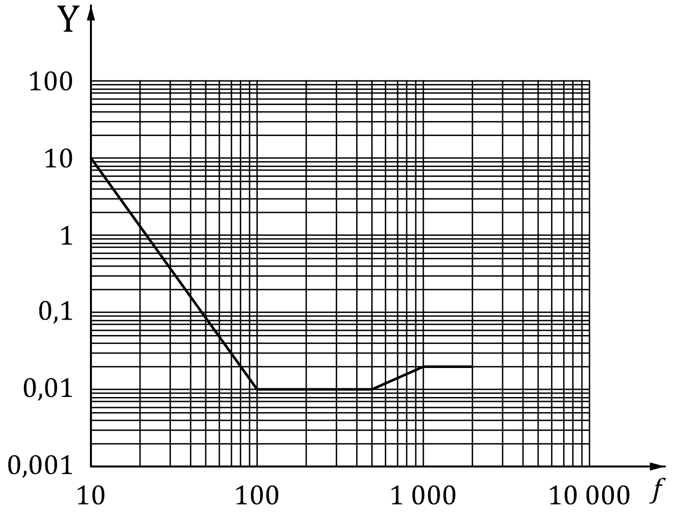
In the lowest frequency range from 10 Hz to 100 Hz, the influence of rough-road conditions is taken into account. The main failures to be identified by this test are malfunctions and/or breakage due to fatigue.

This rough-road profile shall be applied to the very same DUT that has been submitted to the sine-on-random test described above. After the mixed mode vibration test, a random vibration test is performed in accordance with IEC 60068-2-64.

The test duration is 20 h for each axis of the DUT.

The RMS acceleration value for all three primary axes shall be 9 m/s^2.

The PSD versus frequency is illustrated in Figure 12 and Table 13.



Key

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

Figure 12 — PSD of acceleration versus frequency

Table 13 — Values for PSD versus frequency

Frequency [Hz]	**PSD** $[(m/s^2)^2/Hz]$
10	10
100	0,01
500	0,01
1 000	0,02
2 000	0,02

4.1.5.3 Requirements

Malfunctions and/or breakage shall not occur.

Functional status class A as defined in ISO 16750-1 is required during active operating modes, and functional status class C is required during periods with other operating modes.

4.1.6 Test XV — Passenger car, driving electric motor

4.1.6.1 Purpose

This test checks the large and heavy DUT (electric motor driving the wheels of the vehicle through a driveshaft, possibly via a gearbox; also components attached to the electric motor, such as an inverter) for malfunctions and/or breakage caused by vibration.

NOTE This profile is an updated version of Test II in ISO 19453-3:2018, 4.1.2.2, see also A.9.4.

4.1.6.2 Test

4.1.6.2.1 General

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

NOTE 1 The test duration is based on A.5.1.2. According to Annex A, 20 h of test duration per axis are equivalent to 6 000 h (240 000 km at 40 km/h average speed) lifetime requirement of the vehicle.

NOTE 2 When the test conditions cannot be realized because the test system is not capable of exciting a heavy DUT with the given profile, the load and duration can be adjusted according to the Basquin model (see A.8).

NOTE 3 As the driveshaft of an electric motor is always parallel to the ground floor, it is reasonable to have a direction-specific profile, separating vertical excitations from horizontal ones.

NOTE 4 Besides rough road the second type of vibration for the e-powertrain is induced by imbalances of the e-motor and harmonic orders of the gearbox. If considering such a vibration in evaluation, a separate sinusoidal test can be agreed between the customer and the supplier, based on a vehicle or test bench measurement.

The definition of the coordinate system is shown in Table A.4.

4.1.6.2.2 Random vibration

Perform the test in accordance with IEC 60068-2-64 (random vibration).

The test duration is 20 h for each axis of the DUT.

The RMS acceleration values for all three primary axes shall be:

— X: 38,9 m/s^2,

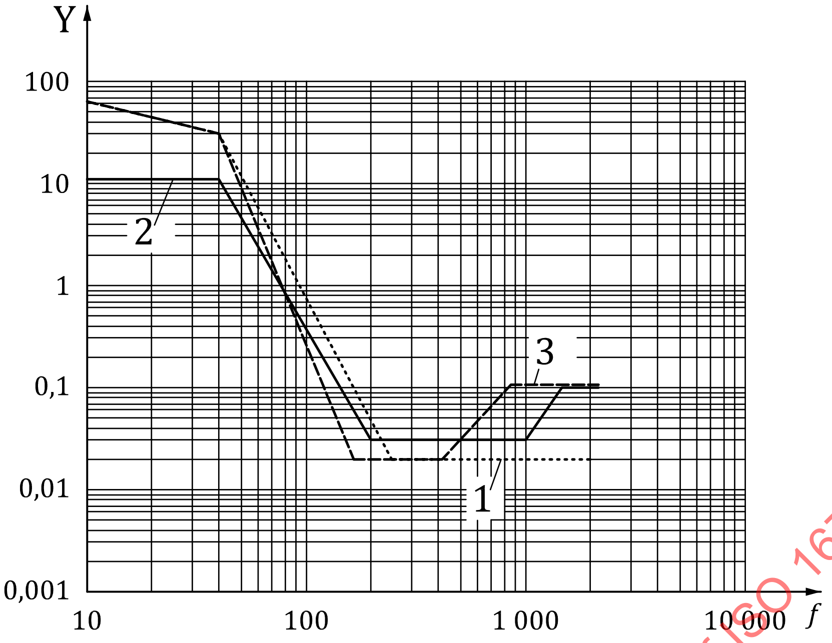
— Y: 24,5 m/s^2,

— Z: 39,0 m/s^2.

The PSD versus frequency is illustrated in Figure 13 and Table 14.

For the component which is freely placed or is not anticipated to be installed in a certain position and posture (e.g. inverter), the maximum profile out of all primary three axes shall be applied to each axis of the DUT.

Instead of the maximum profile for all three primary axes, based on the actual vehicle application(s) an enveloping of just two out of three directions may be applied if agreed between the customer and the supplier.



Key

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

f frequency [Hz]

1 curve for X axis [a]

2 curve for Y axis [a]

3 curve for Z axis [a]

[a] X, Y and Z are the e-motor axes as defined in Table A.4.

Figure 13 — PSD of acceleration versus frequency

Table 14 — Values for PSD versus frequency

X axis		Y axis		Z axis	
Frequency [Hz]	**PSD** [(m/s^2)^2/Hz]	**Frequency** [Hz]	**PSD** [(m/s^2)^2/Hz]	**Frequency** [Hz]	**PSD** [(m/s^2)^2/Hz]
10	55	10	11	10	55
40	28	40	11	40	28
240	0,02	200	0,03	160	0,02
2 000	0,02	1 000	0,03	400	0,02
		1 400	0,1	800	0,1
		2 000	0,1	2 000	0,1

4.1.6.3 Requirements

Malfunction and/or breakage shall not occur.

Functional status class A as defined in ISO 16750-1 is required during active operating modes, and functional status class C is required during periods with other operating modes.

4.1.7 Test XVII — Commercial vehicle, driving electric motor

4.1.7.1 Purpose

This test checks the large and heavy DUT (electric motor driving the wheels of the vehicle through a driveshaft, possibly via a gearbox; also components attached to the electric motor, such as an inverter) for malfunctions and/or breakage caused by vibration.

4.1.7.2 Test

4.1.7.2.1 General

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

NOTE 1 The test duration is based on an infinite-life approach in order to be independent of the lifetime requirement of the commercial vehicle in analogy to 4.1.9.2.

NOTE 2 When the test conditions cannot be realized because the test system is not capable of exciting a heavy DUT with the given profile, the load and duration can be adjusted according to the Basquin model (see A.8).

NOTE 3 As the driveshaft of an electric motor is always parallel to the ground floor, it is reasonable to have a direction-specific profile, separating vertical excitations from horizontal ones.

The definition of the coordinate system is shown in Table A.4.

4.1.7.2.2 Random vibration

Perform the test in accordance with IEC 60068-2-64 (random vibration).

The test duration is 32 h for each axis of the DUT. For more information on the test duration see A.7.

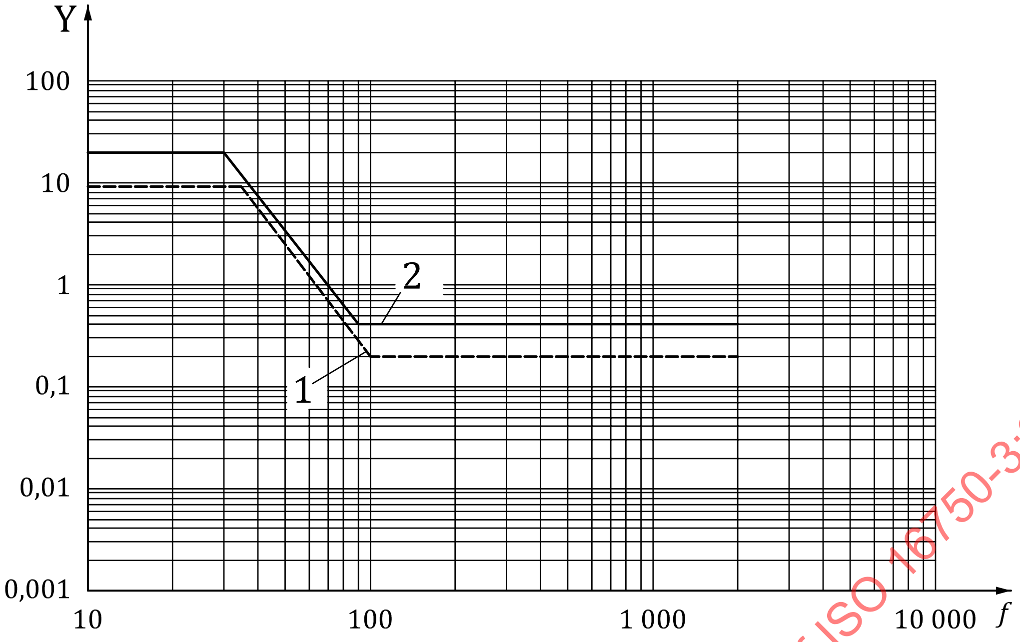
The RMS acceleration values for all three primary axes shall be:

— X and Y: 26,8 m/s^2,

— Z: 37,2 m/s^2.

The PSD versus frequency is illustrated in Figure 14 and Table 15.

The profile for Z-axis with the highest RMS value may be used for all three primary axes if agreed between the customer and the supplier.



Key

Y PSD [(m/s²)²/Hz]

f frequency [Hz]

1 curve for X and Y axis [a]

2 curve for Z axis [a]

[a] X, Y and Z are the e-motor axes as defined in Table A.4.

Figure 14 — PSD of acceleration versus frequency

Table 15 — Values for PSD versus frequency

X and Y axis		Z axis	
Frequency [Hz]	**PSD** [(m/s²)²/Hz]	**Frequency** [Hz]	**PSD** [(m/s²)²/Hz]
10	9	10	20
35	9	30	20
100	0,2	90	0,4
2 000	0,2	2 000	0,4

4.1.7.3 Requirements

Malfunction and/or breakage shall not occur.

Functional status class A as defined in ISO 16750-1 is required during active operating modes, and functional status class C is required during periods with other operating modes.

4.1.8 Test IV — Passenger car, sprung masses (vehicle body), small and lightweight DUT

4.1.8.1 Purpose

This test checks the small and lightweight DUT (e.g. small sensors or ECUs) 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.

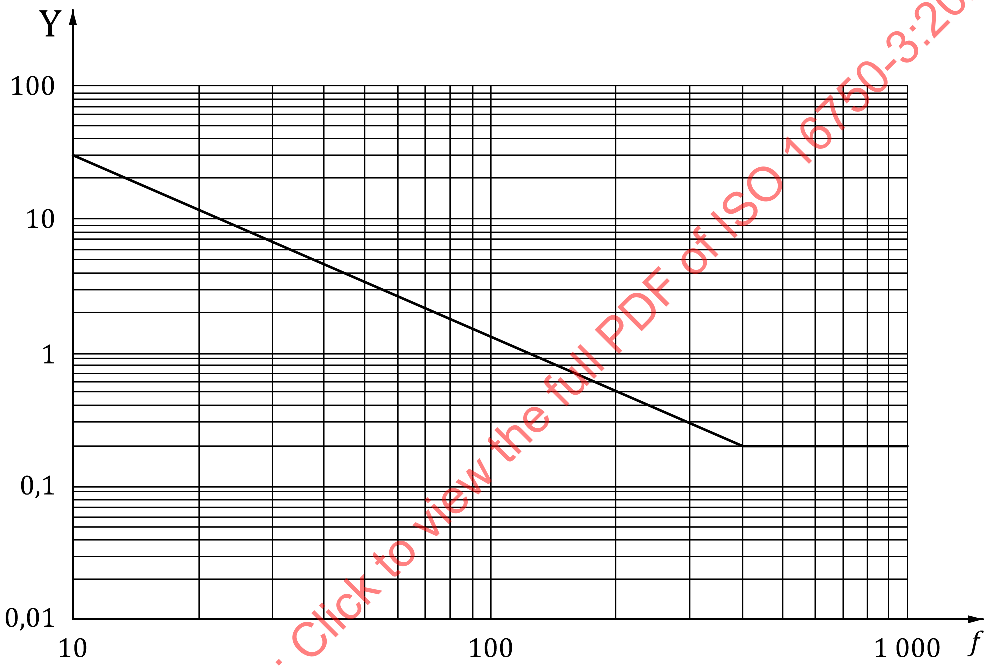
4.1.8.2 Test

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

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

The PSD versus frequency is referred to in Figure 15 and Table 16.

NOTE The test duration is based on A.5.1.2.



Key

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

f frequency [Hz]

Figure 15 — PSD of acceleration versus frequency

Table 16 — Values for PSD versus frequency

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

In Annex E a general methodology is described on how to derive a broadband random test profile for small and lightweight DUTs on the vehicle-body of passenger cars for testing on an electrodynamic 3D shaker system, including an example.

4.1.8.3 Requirement

Malfunctions and/or breakage shall not occur. Functional status class A as defined in ISO 16750-1 is required during active operating modes, and functional status class C is required during periods with other operating modes.

4.1.9 Test VII — Commercial vehicle, sprung mass (vehicle body), small and lightweight DUT

4.1.9.1 Purpose

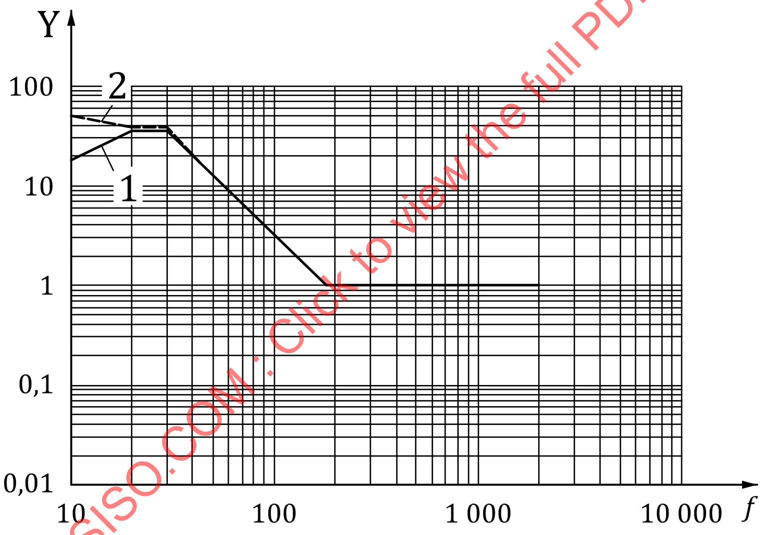
This test checks the small and lightweight DUT (e.g. small sensors or ECUs) for malfunctions and breakage caused by vibration.

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.

4.1.9.2 Test

Perform the test according to IEC 60068-2-64, random vibration. Use a test duration of 32 h for each axis of the DUT. For more information on the test duration see A.7.

The PSD versus frequency is referred to in Figure 16 and Table 17.



Key

Y PSD [(m/s²)²/Hz]

f frequency [Hz]

1 standard random test profile

2 additional profile in case of f_n < 30 Hz

Figure 16 — PSD of acceleration versus frequency

Table 17 — Values for PSD versus frequency

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

If the DUT has natural frequencies below 30 Hz, an additional test (see Table 18) shall be carried out with a duration of 32 h in all critical axes of the DUT. When it is required to determine the natural frequency of the DUT in the relevant test specification, the vibration response investigation shall be carried out according to IEC 60068-2-6, but using a frequency range of 10 Hz to 50 Hz with an acceleration amplitude of 10 m/s^2 as excitation at a sweep rate of ≤0,5 octave/min.

Table 18 — Values for PSD versus 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
RMS acceleration value = 33,7 m/s^2.	

4.1.9.3 Requirement

Malfunctions and/or breakage shall not occur. Functional status class A as defined in ISO 16750-1 is required during active operating modes, and functional status class C is required during periods with other operating modes.

4.1.10 Test XIV — Hybrid-electric/fully-electric passenger car, sprung mass (vehicle body), large and heavy DUT

4.1.10.1 Purpose

This test checks the large and heavy DUT of the electric powertrain (e.g. inverters, DC/DC converters or chargers) on the vehicle body for malfunctions and/or breakage caused by vibration.

NOTE This profile is an updated version of Test II in ISO 19453-3:2018, 4.1.2.2, see also A.9.3.

4.1.10.2 Test

4.1.10.2.1 General

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

NOTE 1 The test duration is based on A.5.1.2. According to Annex A, 20 h of test duration per axis are equivalent to 6 000 h (240 000 km at 40 km/h average speed) lifetime requirement of the vehicle.

NOTE 2 When the test conditions cannot be realized because the test system is not capable of exciting a heavy DUT with the given profile, the load and duration can be adjusted according to the Basquin model (see A.8).

The definition of the coordinate system is shown in Table A.2.

4.1.10.2.2 Random vibration

Perform the test in accordance with IEC 60068-2-64 (random vibration).

The test duration is 20 h for each axis of the DUT.

The RMS acceleration value for all three primary axes shall be:

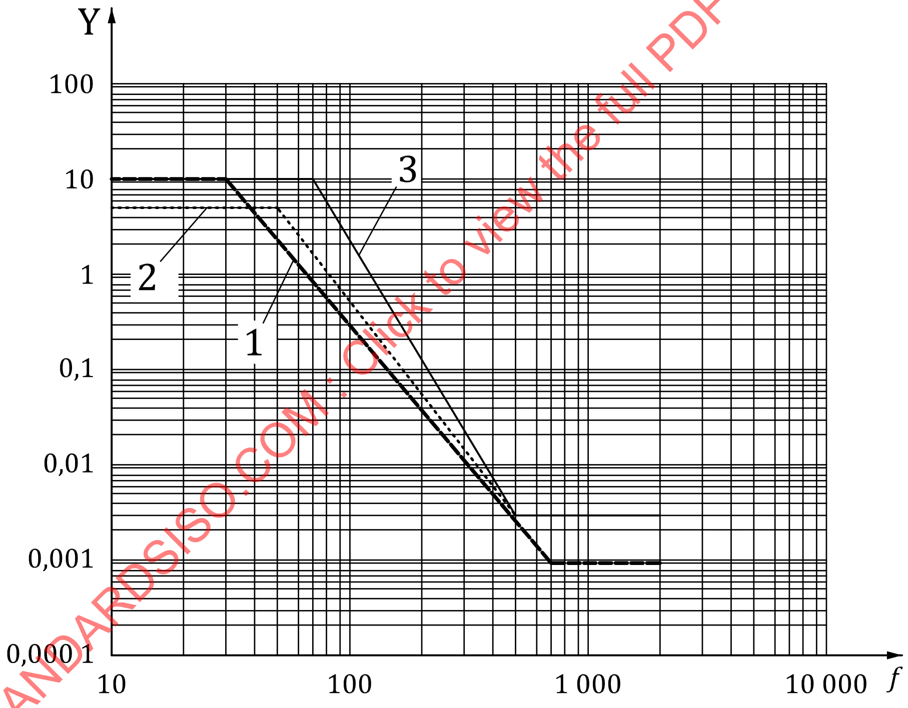
— X: 18,9 m/s^2,

— Y: 13,7 m/s^2,

— Z: 28,7 m/s^2.

The profile for Z-axis with the highest RMS value may be used for all three primary axes if agreed between the customer and the supplier.

The PSD versus frequency is illustrated in Figure 17 and Table 19.



Key

Y	PSD [(m/s^2)^2/Hz]
f	frequency [Hz]
1	curve for X axis [a]
2	curve for Y axis [a]
3	curve for Z axis [a]

[a] X, Y and Z are the vehicle axes as defined in Table A.2.

Figure 17 — PSD of acceleration versus frequency

Table 19 — Values for PSD versus frequency

X axis		Y axis		Z axis	
Frequency [Hz]	**PSD** [(m/s^2)^2/Hz]	**Frequency** [Hz]	**PSD** [(m/s^2)^2/Hz]	**Frequency** [Hz]	**PSD** [(m/s^2)^2/Hz]
10	10	10	5	10	10
30	10	50	5	70	10
700	0,001	700	0,001	500	0,003
2 000	0,001	2 000	0,001	2 000	0,003

4.1.10.3 Requirements

Malfunctions and/or breakage shall not occur.

Functional status class A as defined in ISO 16750-1 is required during active operating modes, and functional status class C is required during periods with other operating modes.

4.1.11 Test XVI — Hybrid-electric/fully-electric commercial vehicle, sprung mass (vehicle body), large and heavy DUT

4.1.11.1 Purpose

This test checks the large and heavy DUT of the electric powertrain (e.g. inverters, DC/DC converters or chargers) on the commercial vehicle body for malfunctions and/or breakage caused by vibration.

4.1.11.2 Test

4.1.11.2.1 General

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

NOTE 1 The test duration is based on an infinite-life approach in order to be independent of the lifetime requirement of the commercial vehicle in analogy to 4.1.9.2.

NOTE 2 When the test conditions cannot be realized because the test system is not capable of exciting a heavy DUT with the given profile, the load and duration can be adjusted according to the Basquin model (see A.8).

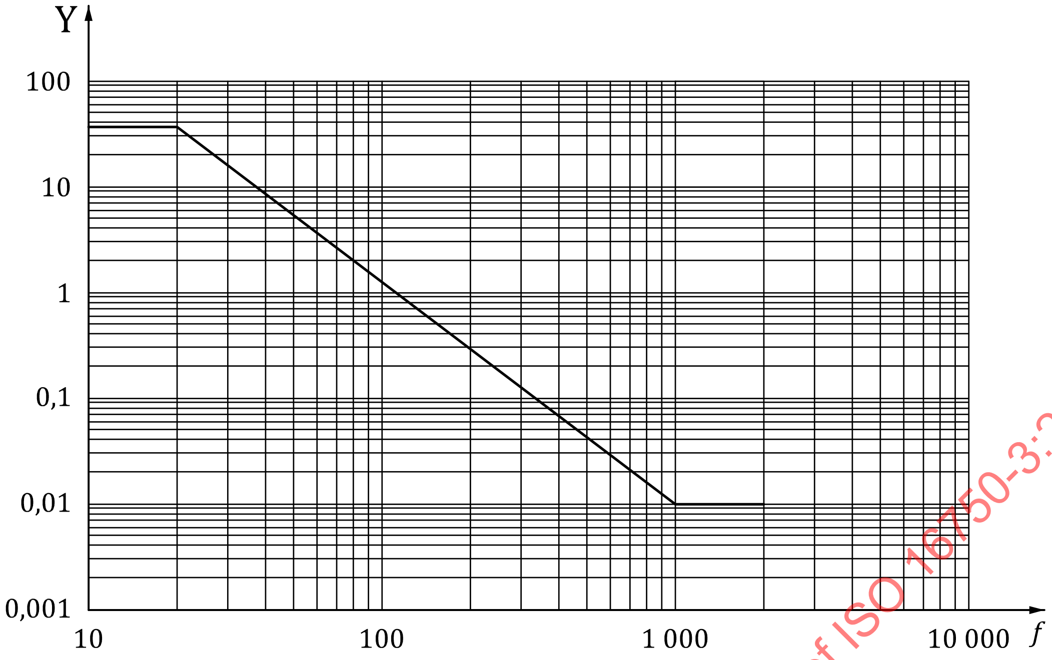
4.1.11.2.2 Random vibration

Perform the test in accordance with IEC 60068-2-64 (random vibration).

The test duration is 32 h for each axis of the DUT. For more information on the test duration see A.7.

The RMS acceleration value for all three primary axes shall be 31,9 m/s^2.

The PSD versus frequency is illustrated in Figure 18 and Table 20.



Key

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

Figure 18 — PSD of acceleration versus frequency

Table 20 — Values for PSD versus frequency

Frequency [Hz]	PSD [$(m/s^2)^2$/Hz]
10	36
20	36
1 000	0,01
2 000	0,01

4.1.11.3 Requirements

Malfunctions and/or breakage shall not occur.

Functional status class A as defined in ISO 16750-1 is required during active operating modes, and functional status class C is required during periods with other operating modes.

4.1.12 Test V — Passenger car, unsprung mass (wheel, wheel suspension), small and lightweight DUT

4.1.12.1 Purpose

This test checks the small and lightweight DUT (e.g. small wheel-speed sensors) 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. If high amplitudes below 20 Hz are found in practice of vehicle measurement, a separate test profile specifying frequencies around 20 Hz can be defined if agreed between the customer and the supplier.

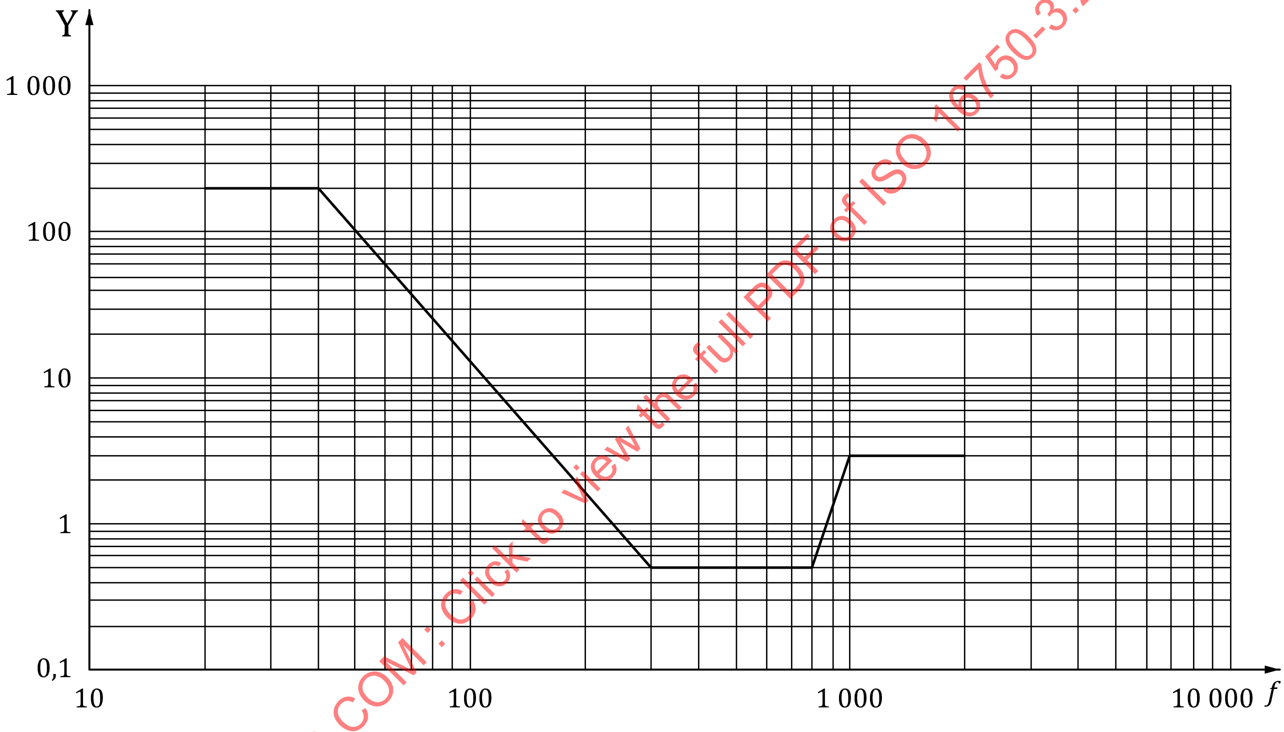
4.1.12.2 Test

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

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

The PSD versus frequency is referred to in Figure 19 and Table 21.

NOTE The test duration is based on A.5.1.2.



Key

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

f frequency [Hz]

Figure 19 — PSD of acceleration versus frequency

Table 21 — Values for PSD versus 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

4.1.12.3 Requirement

Malfunctions and/or breakage shall not occur. Functional status class A as defined in ISO 16750-1 is required during active operating modes, and functional status class C is required during periods with other operating modes.

4.1.13 Test IX — Commercial vehicle, unsprung mass, small and lightweight DUT

4.1.13.1 Purpose

This test checks the small and lightweight DUT (e.g. small wheel-speed sensors) 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.

4.1.13.2 Test

Perform the random vibration test VII as in 4.1.9.2 and in addition the sinusoidal vibration test described below.

Carry out the sinusoidal vibration test at RT.

The sinusoidal vibration test according to Table 22 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 Table 23) so that it can be performed on an electro-mechanical test stand.

Table 22 — Values for acceleration versus frequency in case of lowest natural frequency of a DUT <40 Hz

Axis as mounted in vehicle	Frequency [Hz]	Amplitude of acceleration [m/s^2]	Duration [min]	No. of cycles approx.
X-axis, Y-axis	8 to 16	150	4	2 800
	8 to 16	120	10	7 000
	8 to 32	100	20	21 000
Z-axis	8 to 16	300	4	2 800
	8 to 16	250	10	7 000
	8 to 32	200	20	21 000

Table 23 — Values for acceleration versus frequency in case of lowest natural frequency of a DUT ≥ 40 Hz

Axis as mounted in vehicle	Frequency [Hz]	Amplitude of acceleration [m/s^2]	No. of cycles approx.
X-axis, Y-axis	35	150	2 800
	35	120	7 000
	35	100	21 000
Z-axis	35	300	2 800
	35	250	7 000
	35	200	21 000

4.1.13.3 Requirement

Breakage shall not occur.

Functional status class A as defined in ISO 16750-1 is required during active operating modes, and functional status class C during periods with other operating modes.

4.1.14 Test VIII — Commercial vehicle, decoupled cab

4.1.14.1 Purpose

This test checks the small and lightweight DUT (e.g. small sensors or ECUs) 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.

4.1.14.2 Test

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

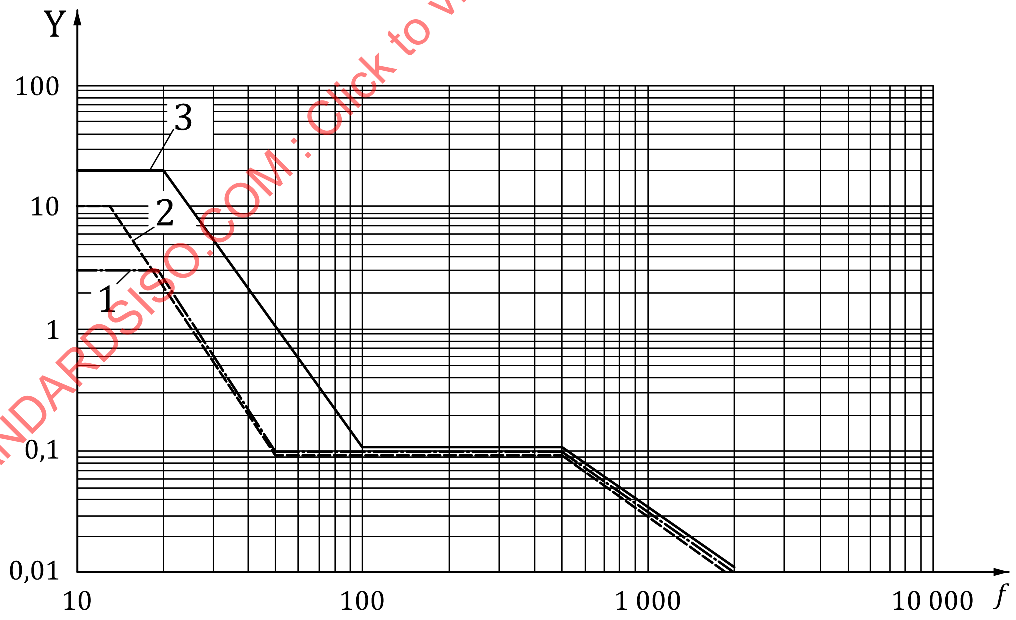
Test duration: 32 h for each axis of the DUT. For more information on the test duration see A.7.

The PSD versus frequency is referred to in Figure 20 and Table 24.

The definition of the coordinate system is shown in Table A.2.

The RMS acceleration value for all three primary axes shall be:

- X: 11,8 m/s^2,
- Y: 13,1 m/s^2,
- Z: 21,3 m/s^2.



Key

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

f frequency [Hz]

1 curve for X-axis as defined in Table A.2

2 curve for Y-axis as defined in Table A.2

3 curve for Z-axis as defined in Table A.2

Figure 20 — PSD of acceleration versus frequency

Table 24 — Values for PSD versus frequency

X axis		Y axis		Z axis	
Frequency [Hz]	**PSD** [(m/s^2)^2/Hz]	**Frequency** [Hz]	**PSD** [(m/s^2)^2/Hz]	**Frequency** [Hz]	**PSD** [(m/s^2)^2/Hz]
10	3	10	10	10	20
19	3	13	10	20	20
50	0,1	50	0,1	100	0,1
500	0,1	500	0,1	500	0,1
2 000	0,01	2 000	0,01	2 000	0,01

4.1.14.3 Requirement

Malfunctions and/or breakage shall not occur. Functional status class A as defined in ISO 16750-1 is required during active operating modes, and functional status class C is required during periods with other operating modes.

4.1.15 Test III — Passenger car, flexible plenum chamber

4.1.15.1 Purpose

This test checks the small and lightweight DUT (e.g. mass air-flow sensor) 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.

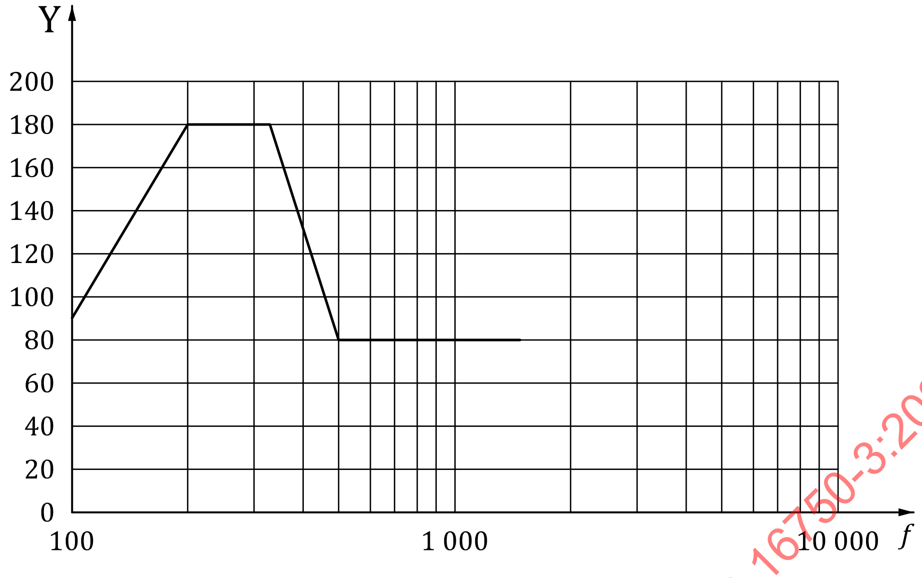
The main failure to be identified by this test is breakage due to fatigue.

4.1.15.2 Test

Perform the test according to IEC 60068-2-6 sinusoidal vibration, but a sweep rate of ≤0,5 octave/min shall be used. Use a test duration of 30 h for each axis of the DUT.

NOTE The test duration is based on A.4.

Values for amplitude versus frequency are referred to in Figure 21 and Table 25.



Key

Y amplitude of acceleration [m/s^2]

f frequency [Hz]

Figure 21 — Acceleration versus frequency

Table 25 — Values for acceleration versus frequency

Frequency [Hz]	Amplitude of acceleration [m/s^2]
100	90
200	180
325	180
500	80
1 500	80

4.1.15.3 Requirement

Malfunctions and/or breakage shall not occur. Functional status class A as defined in ISO 16750-1 is required during active operating modes, and functional status class C is required during periods with other operating modes.

4.1.16 Test XI — Passenger car, solid intake manifold

4.1.16.1 Purpose

This test checks the small and lightweight DUT (e.g. small pressure sensors, throttle bodies or ECUs) 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 combustion engine and manifold.

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

4.1.16.2 Test

4.1.16.2.1 General

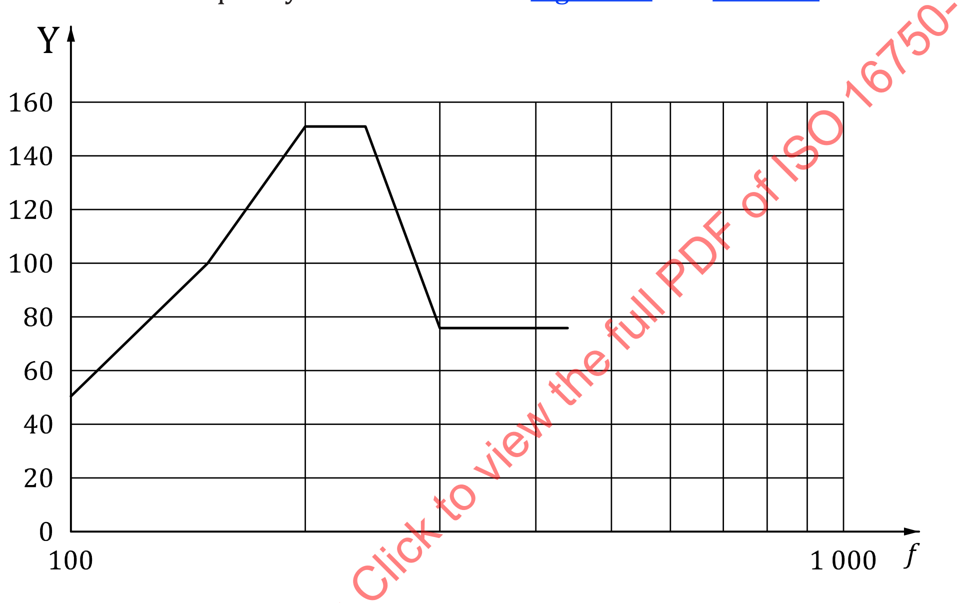
This test shall be performed as a mixed mode vibration test according to IEC 60068-2-80.

NOTE The test duration is based on A.4. The temperature in the chamber is above RT at the end of the test (3 ¾ temperature cycles).

4.1.16.2.2 Sinusoidal vibration

Perform the test according to IEC 60068-2-6, but using a sweep rate of ≤0,5 octave/min. Use a test duration of 30 h for each axis of the DUT.

Values for amplitude versus frequency are referred to in Figure 22 and Table 26.



Key

Y amplitude of acceleration [m/s^2]

f frequency [Hz]

Figure 22 — Acceleration versus frequency

Table 26 — Values for acceleration versus frequency

Frequency [Hz]	Amplitude of acceleration [m/s^2]
100	50
150	100
200	150
240	150
300	75
440	75

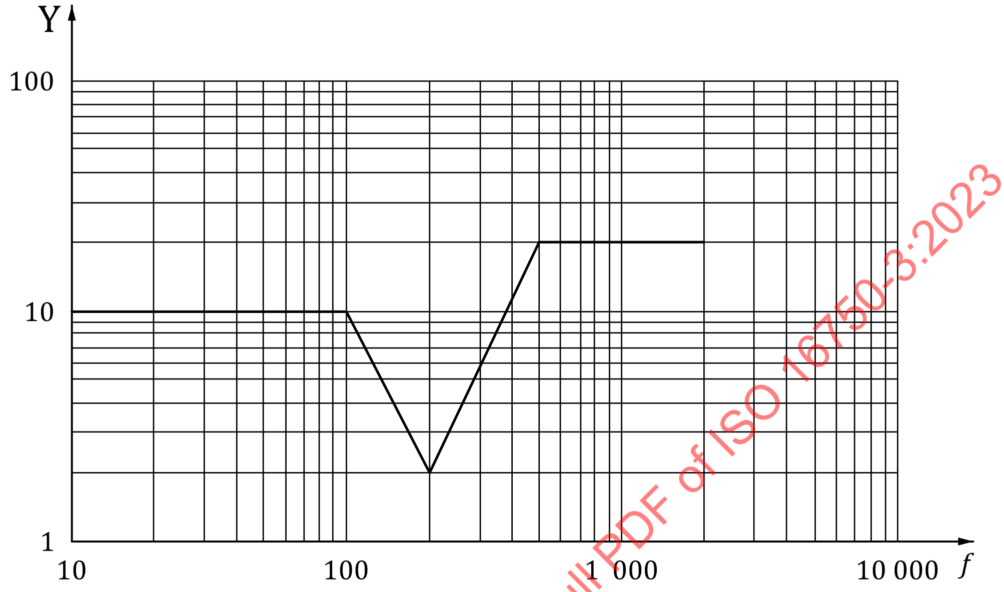
4.1.16.2.3 Random vibration

Perform the test according to IEC 60068-2-64. Use a test duration of 30 h for each axis of the DUT.

The RMS 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 is referred to in Figure 23 and Table 27.



Key

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

f frequency [Hz]

Figure 23 — PSD of acceleration versus frequency

Table 27 — Values for PSD versus frequency

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

4.1.16.3 Requirement

Malfunctions and/or breakage shall not occur. Functional status class A as defined in ISO 16750-1 is required during active operating modes, and functional status class C is required during periods with other operating modes.

4.1.17 Test Ib – Rotating machines

4.1.17.1 Purpose

This test applies for combustion engine mounted rotating machines (e.g. alternator, starter motor, A/C compressor, integrated starter generator) (see ISO 16750-1:2023, Table C.1) and checks the DUT for malfunctions and/or breakage caused by vibration. The vibrational loads during vehicle operation of passenger cars and commercial vehicles can be split up into three kinds:

- sinusoidal vibration loads resulting from rigid body motion of the combustion engine/gearbox compound, which is defined by mass/gas forces, crank train kinematics as well as the mass and inertia tensor of the combustion engine/gearbox compound;
- sinusoidal vibration loads due to structural dynamic effects of the entire system at resonance which is defined by the distribution of stiffness, mass and damping effects of the combustion engine/gearbox compound;
- random vibration loads resulting from stochastic events such as gear rattle or effects caused by clearance in the valve train and gearbox.

Effects from dynamic loads introduced by the torque transmitting interface (e.g. dynamic belt/gear loads) are not tested. Such dynamic effects shall be assessed separately based on vehicle measurements (e.g. hub load measurement).

Typical rotating machines mounted to the combustion engine are heavy, cantilevering components, which are coupled in its system dynamics and furthermore show nonlinear effects. This requires an approach of deriving load profiles that takes into account the differing dynamics from vehicle and test bench, the need to test with a very stiff test setup due to shaker controllability and comparability as well as to determine test durations based on vibration response signals.

NOTE Road excitation usually has a negligible impact on combustion engine-mounted components. Shock inputs are effectively isolated by suspension and combustion engine-mounting systems. Still, the test considers rough road excitations by introducing random loads in the lower frequency range from 10 Hz to 100 Hz.

Due to the differing dynamics of vehicle and test bench setup there might occur dynamic excitation mechanism during the vibration test which will not be relevant for field operation (e.g. bouncing effects of the rotor). Hence it is recommended to use vibration measurements from both test and vehicle in order to find out the root cause of failure and to check for relevance in field operation.

4.1.17.2 Test

4.1.17.2.1 General

This test shall be performed as a mixed mode vibration test according to IEC 60068-2-80.

Use a test duration for each of the three excitation directions according to Table 28.

Table 28 — Test duration for each of the three excitation directions

	Passenger car	Commercial vehicle
Duration per axis [h]	14	28
Lifetime request [h](combustion engine operation)	6 000	20 000

NOTE 1 The test duration is based on the comparison of typical vibrational loads in the vehicle and vibrational loads during test. The lifetimes given in Table 28 are typical values for passenger cars and commercial vehicles. For passenger cars, a mileage of 240 000 km is assumed, resulting in an average speed of 40 km/h. For commercial vehicles, a mileage of 1 000 000 km is assumed, resulting in an average speed of 50 km/h. Testing times for differing lifetime requests can be obtained by linear scaling of testing time in relation to the time of combustion engine operation. For further details on the calculation of the test duration see C.3.

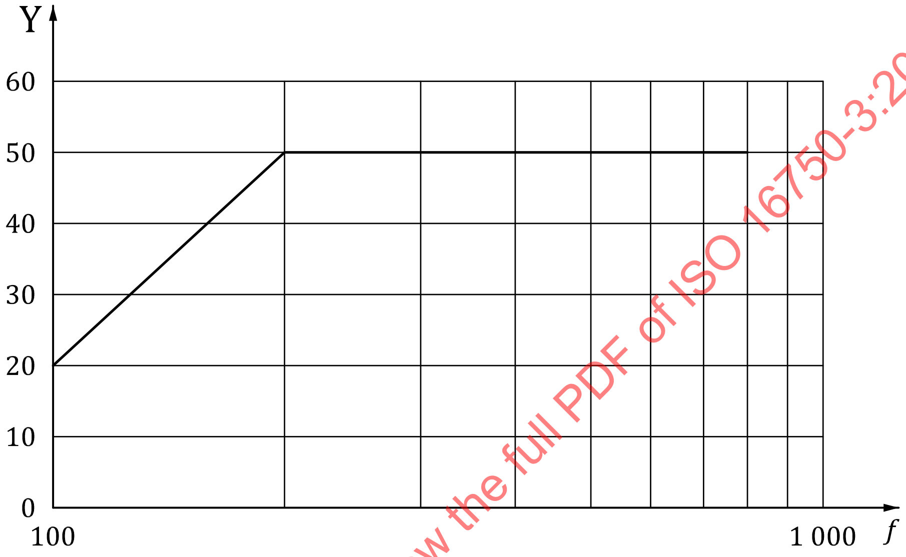
The DUTs shall be run in operating mode 3.3 with an overlaid temperature as given in Figure 3 and Table 3 for combustion engine-mounted DUTs.

NOTE 2 Minimum load of operating mode 3.3 is used to avoid any unrealistic damage to the bearings. If operation mode 3.3 is not applicable from a technical point of view (e.g. starter motor is not in operation during combustion engine operation), operation mode 2.1 can be applied.

The defined acceleration values are valid for the control position close to the mounting position of the DUT. A 2-point-average control is recommended. In order to assure shaker controllability, comparability and high frequency load injection into electronic subcomponents, a rigid setup on the shaker is required. Test setup recommendations of typical components can be found in Annex C.

4.1.17.2.2 Sinusoidal vibration

Perform the test according to IEC 60068-2-6, using a sweep rate of ≤0,5 octave/min. The required amplitude of acceleration versus frequency for all three testing directions are referred to in Figure 24 and Table 29.



Key

Y amplitude of acceleration [m/s^2]

f frequency [Hz]

Figure 24 — Acceleration versus frequency

Table 29 — Values for acceleration versus frequency

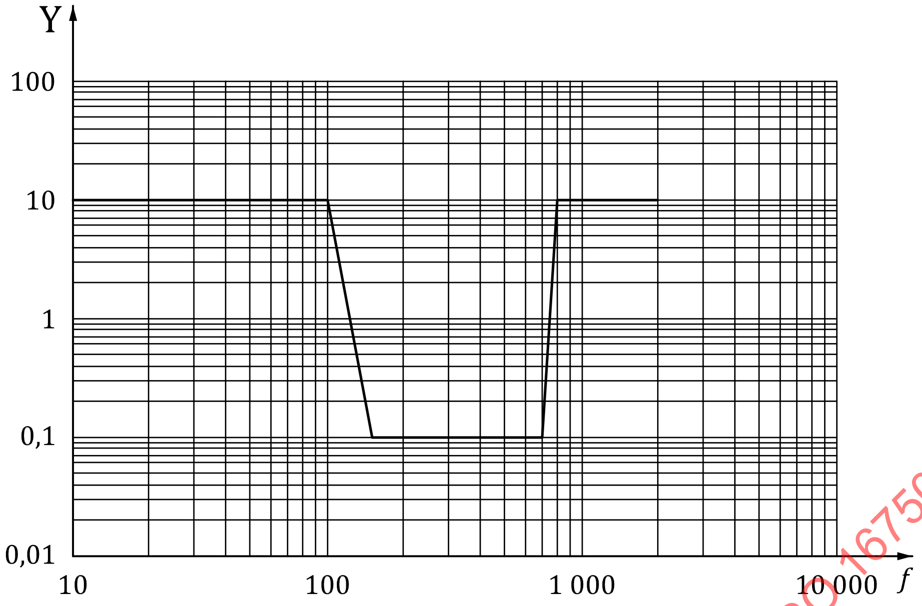
Frequency [Hz]	Amplitude of acceleration [m/s^2]
100	20
200	50
800	50

4.1.17.2.3 Random vibration

Perform the test according to IEC 60068-2-64. The RMS acceleration value shall be 115,2 m/s^2.

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

The PSD versus frequency is referred to in Figure 25 and Table 30.



Key

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

f frequency [Hz]

Figure 25 — PSD of acceleration versus frequency

Table 30 — Values for PSD versus frequency

Frequency [Hz]	**PSD** [(m/s^2)^2/Hz]
10	10
100	10
150	0,1
700	0,1
800	10
2 000	10

4.1.17.3 Requirement

Malfunctions and/or breakage shall not occur.

Functional status class A as defined in ISO 16750-1 is required during active operating modes, and functional status class C during periods with other operating modes.

4.1.18 Test XII — Passenger car, exhaust pipe

4.1.18.1 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. Due to this there may be a difference between the conditions on combustion engine and exhaust pipe, depending, for example, on the distance between the combustion 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 small and lightweight sensors (e.g. oxygen or particulate-matter sensors) with natural frequencies >1 000 Hz;
XIIb	valid for large and heavy modules (e.g. catalytic equipment including denox modules), mounted before the decoupling element;
XIIc	valid for large and heavy modules (e.g. catalytic equipment including denox modules), mounted behind the decoupling element.

4.1.18.2 Test conditions

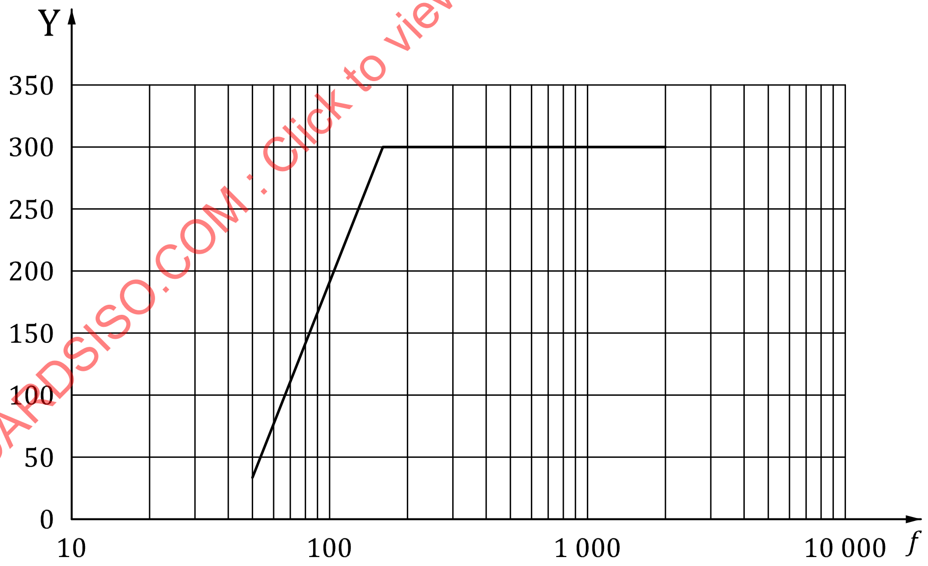
4.1.18.2.1 Test conditions XIIa: valid for small and lightweight sensors with natural frequencies >1 000 Hz

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

NOTE In this test a slower sweep rate is used for a purely sinusoidal test to accomplish a full amplitude of the resonance of the DUT.

Values for amplitude versus frequency are referred to in Figure 26 and Table 31. In the frequency range of 50 Hz to 160 Hz, amplitude of displacement is kept at constant value 0,3 mm. In the frequency range from 160 Hz to 2 000 Hz, acceleration is kept at constant value 300 m/s^2.

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



Key

Y	amplitude of acceleration [m/s^2]
f	frequency [Hz]

Figure 26 — Acceleration versus frequency

Table 31 — Values for amplitude versus frequency

Frequency [Hz]	Amplitude of displacement [mm]	Amplitude of acceleration m/s^2
50	0,3	-
160	0,3	-
2 000	-	300

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

The DUT shall be tested following to the conditions defined for combustion engine mounted components (see 4.1.2).

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

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

4.1.18.2.3.1 Test – General, for XIIc

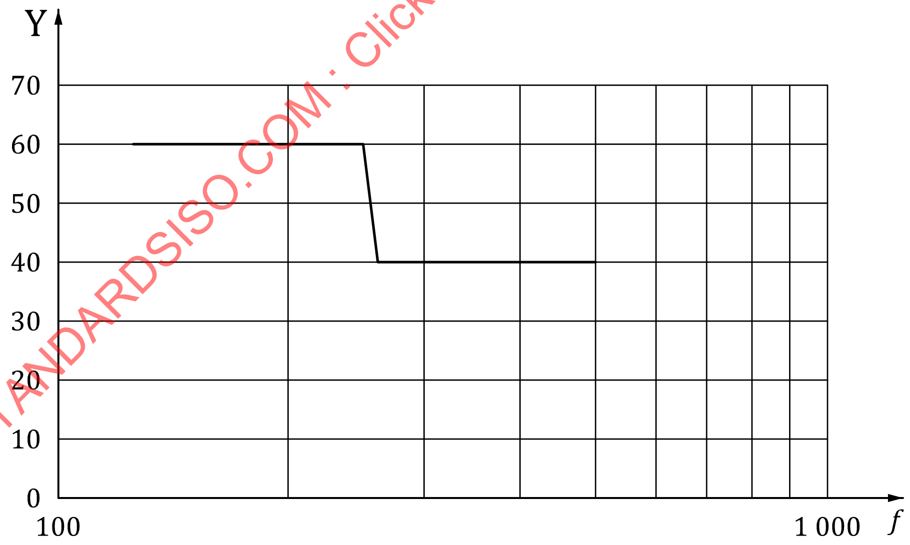
This test shall be performed as a mixed mode vibration test according to IEC 60068-2-80.

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

4.1.18.2.3.2 Sinusoidal vibration for XIIc

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

Values for amplitude versus frequency are referred to in Figure 27 and Table 32.



Key

Y amplitude of acceleration [m/s^2]

f frequency [Hz]

Figure 27 — Acceleration versus frequency

Table 32 — Values for acceleration versus frequency

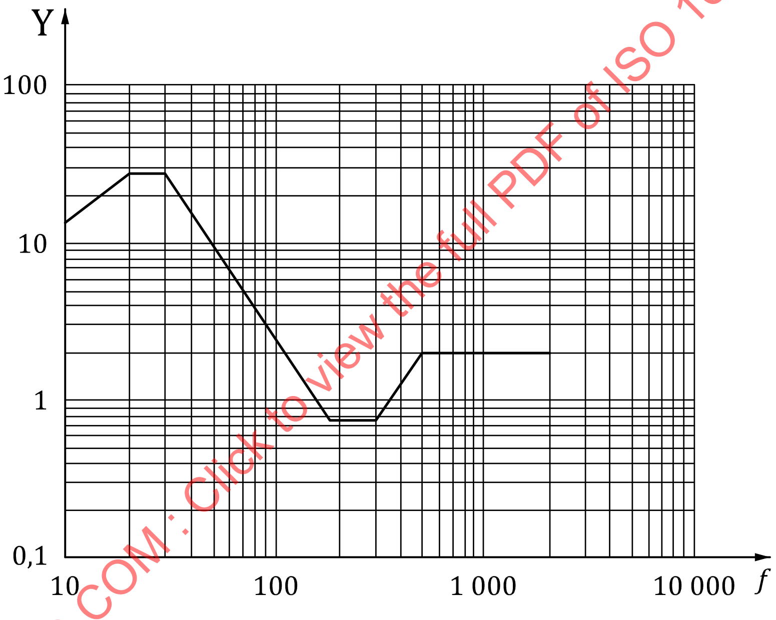
Frequency [Hz]	Amplitude of acceleration [m/s^2]
125	60
250	60
260	40
500	40

4.1.18.2.3.3 Random vibration for XIIc

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

The RMS acceleration value shall be 67,4 m/s^2.

The PSD versus frequency is referred to Figure 28 and Table 33



Key

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

f frequency [Hz]

Figure 28 — PSD of acceleration versus frequency

Table 33 — Values for PSD versus frequency

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

4.1.18.3 Requirement

Malfunctions and/or breakage shall not occur. Functional status class A as defined in ISO 16750-1 is required during active operating modes, and functional status class C is required during periods with other operating modes.

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

4.1.19.1 Purpose

This test checks the small and lightweight DUT (e.g. fuel rail pressure sensors) for malfunctions and breakage caused by vibration. This test is not applied to the whole fuel rail.

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 2 000 Hz. The main failure to be identified by this test is breakage due to fatigue.

4.1.19.2 Test

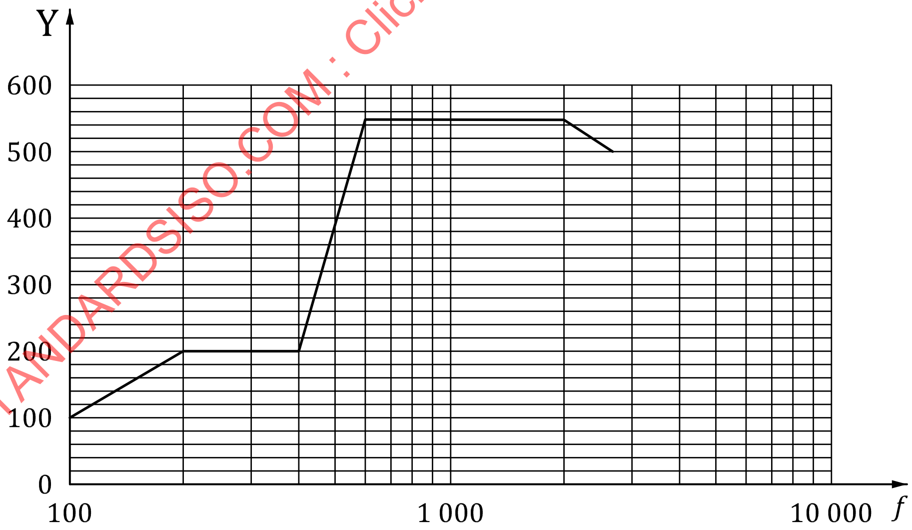
4.1.19.2.1 General

This test shall be performed as a mixed mode vibration test according to IEC 60068-2-80.

NOTE When running a test up to 2,8 kHz the characteristics of the shaker can limit the payload mass for the test.

4.1.19.2.2 Sinusoidal vibration

Perform the test according to IEC 60068-2-6, but using a sweep rate of ≤0,5 octave/min. Use a test duration of 100 h for each axis of the DUT. Values for amplitude versus frequency are referred to in Figure 29 and Table 34.



Key

Y amplitude of acceleration [m/s^2]

f frequency [Hz]

Figure 29 — Acceleration versus frequency

Table 34 — Values for acceleration versus frequency

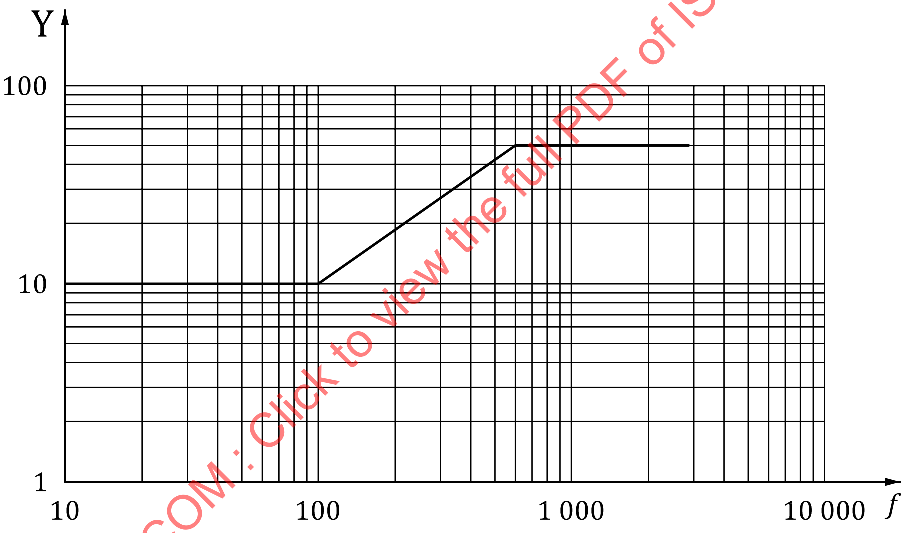
Frequency [Hz]	Amplitude of acceleration [m/s^2]
100	100
200	200
400	200
600	550
2 000	550
2 800	500

4.1.19.2.3 Random vibration

Perform the test according to IEC 60068-2-64. Use a test duration of 100 h for each axis of the DUT.

The RMS acceleration value shall be 356 m/s^2.

The PSD versus frequency is referred to in Figure 30 and Table 35.



Key

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

f frequency [Hz]

Figure 30 — PSD of acceleration versus frequency

Table 35 — Values for PSD versus frequency

Frequency [Hz]	PSD [(m/s^2)^2/Hz]
10	10
100	10
600	50
2 800	50

4.1.19.3 Requirement

Malfunctions and/or breakage shall not occur. Functional status class A as defined in ISO 16750-1 is required during active operating modes, and functional status class C is required during periods with other operating modes.

4.2 Mechanical shock

4.2.1 Shock I — Test for devices in or on doors and flaps on passenger cars

4.2.1.1 Purpose

This test checks the small and lightweight DUT (e.g. window lift motor, wiper motor for rear hatch or electronic control unit in the door) for malfunctions and breakage caused by shock of door, hatch or lid slamming.

The load occurs on closures when slammed shut. Failure mode is a 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 in Table 36 based on evidence from the vehicle. Also, shock profile A may be considered as an accelerated test condition of shock profile B. Either profile can be chosen if agreed between the customer and the supplier. Perform the test according to IEC 60068-2-27 using the following 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. If the direction of the effect is not known, the DUT shall be tested in all six spatial directions.

Table 36 — Number of shocks on passenger cars

	Shock profile A	Shock profile B
Max. shock amplitude	500 m/s^2	300 m/s^2
Shock duration	11 ms	6 ms
Driver's door, cargo door	24 000	184 000
Passenger's doors	11 000	92 000
Trunk lid, tailgate	4 400	55 000
Combustion engine/e-motor hood	1 320	5 500
Electric vehicle front trunk for charging equipment	580	2 400

NOTE The number of electric vehicle front trunk closings, given as 2 400 for shock profile B, is based on the assumption that an electric vehicle has on average to be charged every 200 km. Each charging session starts and ends with opening and closing of the front trunk to take out or put back the charging equipment. Assuming a vehicle lifetime of 240 000 km this results in 2 400 actuations.

4.2.1.3 Requirement

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

4.2.2 Shock II — 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/or breakage caused by a shock to the body and frame.

The load occurs when driving over a curb stone at high speed, etc. The failure mode is a mechanical damage (for example, a detached capacitor inside the housing of the DUT, e.g. on-board power electronics components, due to the occurring high accelerations).

4.2.2.2 Test

Perform the test in accordance with IEC 60068-2-27 using the following test parameters:

- operating mode of the DUT: 3.2 as defined in ISO 16750-1;
- pulse shape: half-sinusoidal;
- acceleration: 500 m/s^2;
- duration: 6 ms;
- number of shocks: 10 per test direction.

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

NOTE For large and heavy DUTs the actual shock load in vehicle conditions can be much lower than the 500 m/s^2 amplitude at 6 ms duration given here. Vehicle measurements with relevant use cases that create a shock event can be carried out in order to determine shock test conditions as realistic as possible for this test.

4.2.2.3 Requirements

Malfunction and/or breakage shall not occur.

The functional status shall be class A as defined in ISO 16750-1.

4.2.3 Shock III — Test for devices in or on the gearbox

4.2.3.1 Purpose

This test checks the DUT for malfunctions and/or breakage caused by a 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. The failure mode is a 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 60068-2-27 using the following test parameters:

- operating mode of the DUT: 3.2 as defined in ISO 16750-1;
- pulse shape: half-sinusoidal;
- typical maximum acceleration:
  - for commercial vehicles: 3 000 m/s^2,

  - for passenger cars: to be agreed between the customer and the supplier;
- typical duration: < 1 ms;
- temperature: to be agreed between the customer and the supplier;
- number of shocks: to be agreed between the customer and the supplier.

NOTE For commercial vehicles in single cases shock values up to 50 000 m/s^2 can be measured.

The actual shock stresses depend both on the installation position of the gearbox and 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 supplier and the customer.

The acceleration due to the shock in the test shall be applied in the same direction as the acceleration of the shock which 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 Requirements

Malfunction and/or breakage shall not occur.

The functional status shall be class A as defined in ISO 16750-1.

4.3 Free fall

4.3.1 Purpose

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

A system/component can drop down to the floor during handling (e.g. at the manufacturing line of the vehicle manufacturer). If a system/component is visibly damaged after a fall, it is replaced, but if it is not visibly damaged, it is installed in the vehicle and shall work correctly. The failure mode is a mechanical damage (for example, a detached capacitor inside the housing of the DUT, e.g. on-board power electronics components, due to the occurring high accelerations when the DUT hits the ground).

Parts that are obviously damaged by the fall shall not be checked (e.g. headlights). Parts that are likely to experience rough handling and can withstand falling without visible damage shall be checked as described below.

DUTs of small to medium size and mass (at least up to 2 kg, maximum up to 10 kg) shall be tested as a free fall with guidance of the DUT (see 4.3.2.1). DUTs that are larger and heavier shall be tested as free fall without guidance (see 4.3.2.2).

For further guidance on free fall testing please refer to Annex D.

4.3.2 Test

4.3.2.1 Free fall with guidance of the DUT

Perform free fall test with guidance for parts with a mass up to 10 kg like small sensors (e.g. oxygen sensors, speed sensors) as well as parts of medium size (e.g. ECUs, catalytic modules, radar sensors) in accordance with IEC 60068-2-31 using the following test parameters:

- number of DUTs: 3;
- falls per DUT: 2;
- drop height: selected from Table 37 depending on mass of the DUT as described in IEC 60068-2-31;

- impact surface: concrete ground or steel plate;
- seismic mass: according to requirements of IEC 60068-2-31 the seismic reaction mass of the facility shall be at least 20 times the mass of the DUT;
- orientation of the DUTs: choose one principal axis for first fall of each DUT, second fall with the given DUT at another principal axis (i.e. 90° change of orientation). Avoiding both directions of the axis for the same DUT offers a chance to learn which orientation is dominant.;

NOTE A best practice example how to cover all six spatial directions with just three DUTs is given in D.1.

- operating mode of the DUTs: 1.1 as defined in ISO 16750-1;
- temperature: to be agreed between the customer and the supplier.

The DUTs shall be visually examined after the falls.

4.3.2.2 Free fall without guidance of the DUT

Perform free fall test in accordance with IEC 60068-2-31 for parts with a mass higher than 10 kg like large and heavy components of hybrid-electric powertrain.

As described in IEC 60068-2-31:2008, Clause 1, testing should only be applied to those faces and corners where there is a risk of such treatment being encountered.

Apart from that use the test parameters and requirements given in 4.3.2.1.

4.3.3 Selection of drop height

Table 37 — Value for drop height

Mass of the DUT [kg]	**Fall height** [mm]				**DUT (examples)**	**Remark**
< 1	750	1 000[a]	1 500		Pressure sensors, exhaust sensors (oxygen, particular matter sensors), speed sensors, ultrasonic sensors, small ECU, radar sensor	Free fall with guidance of the DUT mandatory
>1 ... 10	50	100[a]	250	500[a]	ECU, catalytic module (e.g. SCR), alternator	Free fall with guidance of the DUT to be preferred
> 10... 50	25[a]				e-motor, components like stator	Free fall without guidance of the DUT

[a] This is the preferred value.

As defined in IEC 60068-2-31:2008 5.2.3, test severity is defined by the height of fall which shall be taken from Table 37, taking into account the mass of the specimen, unless real usage conditions are known or are otherwise specified.

4.3.4 Requirements

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.

Observation and measurement of function shall be performed according to agreement between the customer and the supplier, if necessary, not only within a final investigation, but also as intermediate step after each fall.

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

4.4 Surface strength/scratch and abrasion resistance

4.4.1 Purpose

This test checks the surface strength/scratch and abrasion resistance of marking and labelling printed or pasted on the surface of devices, when rubbed for cleaning or for other purposes. This test can be omitted if agreed between the customer and the supplier.

4.4.2 Test method

The test shall be carried out in accordance with legibility test (for printed surfaces of labels) or with defacement test (for labels or unprinted materials) described in UL 969:2017, Table 4.1.

Test conditions such as temperature, humidity and pre-conditioning shall be agreed between the customer and the supplier, considering the vehicle environment.

4.4.3 Requirements

The marking and labelling shall remain visible and legible following the test.

4.5 Gravel bombardment

4.5.1 Purpose

This test checks the resistance of the devices to chilled-iron grit projected onto the surface under test to simulate the impact of small stones.

The test is applied only to the devices mounted on the parts which would be attacked by chipping stones while driving.

This test can be omitted if agreed between the customer and the supplier.

4.5.2 Test method

The test shall be carried out in accordance with ISO 20567-1. Choose severity A, B, or C from ISO 20567-1:2017, Table 2 according to agreement between the customer and the supplier.

NOTE Only ISO 20567-1:2017, 8.2 and 8.3 are relevant for this test.

For the setting to the apparatus, the part of the device instead of the whole device may be used as a test specimen. The direction of test specimen when fixed on the apparatus shall be agreed between the customer and the supplier, considering the direction of the device mounted on vehicles.

4.5.3 Requirements

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

In the case that the test specimen is a part of the device and impossible to perform functional tests upon without the whole device, one of the following requirements should be chosen:

a) test the whole device in the gravel bombardment test, then perform functional test;

b) if possible after the test, reassemble the specimen with the device, and then perform a functional test;

c) if impossible after the test to reassemble the specimen with the device, alternative requirement can be agreed between the customer and the supplier.

5 Code letters for mechanical loads

For code letters for mechanical loads, see Tables 38-40. Recommended mechanical requirements for the DUT depending on the mounting location are given in Annex B (Table B.1).

Table 38 — Coding in relation to tests and requirements (4.1.2 to 4.1.7)

	Requirement according to								
Subclause	4.1.2		4.1.3		4.1.4		4.1.5	4.1.6	4.1.7
Code letter	Test Ia Sinusoidal 4.1.2.2.2	Test Ia Random 4.1.2.2.3	Test II Sinusoidal 4.1.3.2.2	Test II Random 4.1.3.2.3	Test VI Sinusoidal 4.1.4.2.2	Test VI Random 4.1.4.2.3	Test XIII	Test XV (random)	Test XX (random)
Location	Passenger car		Passenger car		Commercial vehicle		Passenger car	Passenger car	Commercial vehicle
	Combustion engine,		Gearbox attached to a combustion engine		Combustion engine, gearbox		Hybrid-electric powertrain (combustion engine, Gearbox)	(directly equipped with) electric motor	
DUT	Small and lightweight	Small and lightweight	Small and lightweight	Small and lightweight	Small and lightweight	Small and lightweight	Large and heavy	Large and heavy	
A	Curve 1	Yes	—	—	—	—	—	—	—
B	Curve 2	Yes	—	—	—	—	—	—	—
C	—	—	—	—	—	—	—	—	—
D	—	—	—	—	—	—	—	—	—
E	—	—	—	—	—	—	—	—	—
F	—	—	—	—	—	—	—	—	—
G	—	—	—	—	—	—	—	—	—
H	—	—	—	—	—	—	—	—	—
I	—	—	—	—	Yes	Yes	—	—	—
J	—	—	—	—	—	—	—	—	—
K	—	—	—	—	—	—	—	—	—
L	—	—	—	—	—	—	—	—	—
M	—	—	—	—	—	—	—	—	—
N	—	—	—	—	—	—	—	—	—
O	—	—	—	—	—	—	—	—	—
P	—	—	—	—	—	—	—	—	—
Q	—	—	—	—	—	—	—	—	—

Table 38 *(continued)*

	Requirement according to								
Subclause	4.1.2		4.1.3		4.1.4		4.1.5	4.1.6	4.1.7
Code letter	Test Ia Sinusoidal 4.1.2.2.2	Test Ia Random 4.1.2.2.3	Test II Sinusoidal 4.1.3.2.2	Test II Random 4.1.3.2.3	Test VI Sinusoidal 4.1.4.2.2	Test VI Random 4.1.4.2.3	Test XIII	Test XV (random)	Test XX (random)
Location	Passenger car		Passenger car		Commercial vehicle		Passenger car	Passenger car	Commercial vehicle
	Combustion engine,		Gearbox attached to a combustion engine		Combustion engine, gearbox		Hybrid-electric powertrain (combustion engine, Gearbox)	(directly equipped with) electric motor	
DUT	Small and lightweight	Small and lightweight	Small and lightweight	Small and lightweight	Small and lightweight	Small and lightweight	Large and heavy	Large and heavy	
R	—	—	—	—	—	—	—	—	—
S	—	—	—	—	—	—	—	—	—
T	—	—	Yes	Yes	—	—	—	—	—
U	—	—	—	—	—	Yes	—	—	—
V	Yes	Yes	—	—	—	—	—	—	—
W	—	—	Yes	Yes	—	—	—	—	—
X	—	—	—	—	—	—	Yes	—	—
Y	—	—	—	—	—	—	Yes	—	—
AA	—	—	—	—	—	—	—	Yes	—
AB	—	—	—	—	—	—	—	Yes	—
AC	—	—	—	—	—	—	—	—	Yes
AD	—	—	—	—	—	—	—	—	Yes
Z	As agreed								

Table 39 — Coding in relation to tests and requirements (4.1.8 to 4.1.16)

	Requirement according to								
Subclauses	4.1.8	4.1.9	4.1.10	4.1.11	4.1.12	4.1.13	4.1.14	4.1.15	4.1.16
Code letter	Test IV	Test VII	Test XIV (random)	Test XVI (random)	Test V	Test IX	Test VIII	Test III	Test XI
Location	Passenger car	Commercial vehicle	Passenger car	Hybrid/electric commercial vehicle	Passenger car	Commercial vehicle	Commercial vehicle	Passenger car	
	Sprung masses (vehicle body)	Sprung masses	Sprung masses (vehicle body)		Unsprung masses (wheel, suspension)	Unsprung masses	Decoupled cab	Flexible plenum chamber	Solid intake manifold
DUT	Small and lightweight	Small and lightweight	Large and heavy		Small and lightweight	Small and lightweight	Small and lightweight	Small and lightweight	Small and lightweight
A	—	—	—	—	—	—	—	—	—
B	—	—	—	—	—	—	—	—	—
C	Yes	—	Yes	—	—	—	—	—	—
D	Yes	—	Yes	—	—	—	—	—	—
E	Yes	—	Yes	—	—	—	—	—	—
F	Yes	—	Yes	—	—	—	—	—	—
G	—	—	—	—	Yes	—	—	—	—
H	—	—	—	—	Yes	—	—	—	—
I	—	—	—	—	—	—	—	—	—
J	—	Yes	—	Yes	—	—	—	—	—
K	—	Yes	—	Yes	—	—	—	—	—
L	—	Yes	—	Yes	—	—	—	—	—
M	—	Yes	—	Yes	—	—	—	—	—
N	—	—	—	—	—	Yes	—	—	—
O	—	—	—	—	—	—	Yes	—	—
P	—	—	—	—	—	—	Yes	—	—
Q	—	—	—	—	—	—	Yes	—	—

Table 39 *(continued)*

	Requirement according to								
Subclauses	4.1.8	4.1.9	4.1.10	4.1.11	4.1.12	4.1.13	4.1.14	4.1.15	4.1.16
Code letter	Test IV	Test VII	Test XIV (random)	Test XVI (random)	Test V	Test IX	Test VIII	Test III	Test XI
Location	Passenger car	Commercial vehicle	Passenger car	Hybrid/electric commercial vehicle	Passenger car	Commercial vehicle	Commercial vehicle	Passenger car	
	Sprung masses (vehicle body)	Sprung masses	Sprung masses (vehicle body)		Unsprung masses (wheel, suspension)	Unsprung masses	Decoupled cab	Flexible plenum chamber	Solid intake manifold
DUT	Small and lightweight	Small and lightweight	Large and heavy		Small and lightweight	Small and lightweight	Small and lightweight	Small and lightweight	Small and lightweight
R	—	—	—	—	—	—	Yes	—	—
S	—	—	—	—	—	Yes	—	—	—
T	—	—	—	—	—	—	—	—	—
U	—	—	—	—	—	—	—	—	—
V	—	—	—	—	—	—	—	—	—
W	—	—	—	—	—	—	—	—	—
X	Yes	—	Yes	—	—	—	—	—	—
Y	Yes	—	Yes	—	—	—	—	—	—
AA	—	—	—	—	—	—	—	—	—
AB	—	—	—	—	—	—	—	—	—
AC	—	—	—	—	—	—	—	—	—
AD	—	—	—	—	—	—	—	—	—
Z	As agreed								

Table 40 — Coding in relation to tests and requirements (4.1.17 to 4.3)

	Requirement according to							
Subclause	4.1.17	4.1.18	4.1.19	4.2.1		4.2.2	4.2.3	4.3
Code letter	Test Ib	Test XII	Test X	Mechanical shock I (Profile A)	Mechanical shock i (Profile B)	Mechanical shock II	Mechanical shock III	Free fall
Location	Passenger car			Test for devices in or on doors and flaps on passenger car		Test for devices on rigid points on the body on the frame	Test for devices In or on the gearbox	
	Rotating machines	Exhaust pipe	Components on fuel rail (gasoline engine with GDI-system)					
DUT	Large and heavy		Small and lightweight	Small and lightweight				
A	—	—	—	—	—	—	—	Yes
B	—	—	—	—	—	—	—	Yes
C	—	—	—	—	—	—	—	Yes
D	—	—	—	—	—	Yes	—	Yes
E	—	—	—	Yes	—	—	—	Yes
F	—	—	—	—	Yes	—	—	Yes
G	—	—	—	—	—	—	—	Yes
H	—	—	—	—	—	Yes	—	Yes
I	—	—	—	—	—	—	Yes	Yes
J	—	—	—	—	—	—	—	Yes
K	—	—	—	—	—	Yes	—	Yes
L	—	—	—	Yes	—	—	—	Yes
M	—	—	—	—	Yes	—	—	Yes
N	—	—	—	—	—	—	—	Yes
O	—	—	—	—	—	—	—	Yes
P	—	—	—	—	—	Yes	—	Yes
Q	—	—	—	Yes	—	—	—	Yes

Table 40 *(continued)*

	Requirement according to							
Subclause	4.1.17	4.1.18	4.1.19	4.2.1		4.2.2	4.2.3	4.3
Code letter	Test Ib	Test XII	Test X	Mechanical shock I (Profile A)	Mechanical shock i (Profile B)	Mechanical shock II	Mechanical shock III	Free fall
	Passenger car							
Location	Rotating machines	Exhaust pipe	Components on fuel rail (gasoline engine with GDI-system)	Test for devices in or on doors and flaps on passenger car		Test for devices on rigid points on the body on the frame	Test for devices In or on the gearbox	
DUT	Large and heavy		Small and lightweight	Small and lightweight				
R	—	—	—	—	Yes	—	—	Yes
S	—	—	—	—	—	Yes	—	Yes
T	—	—	—	—	—	—	Yes	Yes
U	—	—	—	—	—	—	Yes	Yes
V	—	—	—	—	—	—	—	Yes
W	—	—	—	—	—	—	Yes	Yes
X	—	—	—	—	—	—	—	Yes
Y	—	—	—	—	—	Yes	—	Yes
AA	—	—	—	—	—	—	—	Yes
AB	—	—	—	—	—	—	Yes	Yes
AC	—	—	—	—	—	—	—	Yes
AD	—	—	—	—	—	—	Yes	Yes
Z	As agreed							

6 Documentation

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

Annex A
(informative)

Guidelines for the development of test profiles for vibration tests

A.1 Scope

The aim of these guidelines is to make sure that the user of this document 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 is clarified using the recommended documentation and is described in Tables A.1 to A.5.

Table A.1 — Engine speed definition

Item	Description
Nominal speed	n_{nominal}: nominal speed with maximum power output of the combustion engine
Maximum speed	$n_{\max}$: maximum safe combustion engine speed

Table A.2 — Vehicle axes

Item	Description
Vehicle axes	X’: driving direction Y’: perpendicular to driving direction and vertical axis Z’: vertical axis

Table A.3 — Powertrain axes

Item	Description
Powertrain axes	X: crankshaft direction Y: perpendicular to crankshaft and piston direction Z: piston direction

Table A.4 — e-motor axes

Item	Description
e-motor axes	X_{EM}: driving direction Y_{EM}: perpendicular to driving direction and vertical axis Z_{EM}: vertical axis

NOTE 1 The vehicle axes in Table A.2 and the e-motor axes in Table A.4 are the same.

NOTE 2 The driveshaft of an electric motor is always parallel to the ground floor.

Table A.5 lists some basic definitions used to assess a vehicle measurement in order to create a test profile. The coordinate systems for the vehicle and powertrain are shown in Table A.2 and Table A.3 and are taken from DIN 70003, which also gives other valuable information regarding procedures for a vehicle measurement of vibrational loads.

Gathering extensive measured vibration data examples over various types of vehicles and different masses and mounting locations of components is useful to improve the vibration test profiles in this document or develop new appropriate test profiles in the future.

Table A.5 — Development of test profiles for vibration tests

Item	Documentation	Recommended documentation/ parameters	Comments
	Description of the vehicle	Technical data (e.g. power, max. min^{-1}, nominal speed, displacement, kind of combustion engine, number of cylinders)	
Powertrain mounted	Boundary conditions	Dynamometer and/or road	Full load There is some indication that higher values can occur at trailing throttle condition.
Body mounted		Proving ground/test track description	—
		Road surfaces (e.g. Belgian block, washboard, hip hop, etc.)	—
		Driving speed	—
	Sampling frequency	≥2,5 times of f_{max}	f_{max} = frequency limit for evaluation
	Block length b	≥2 k	—
	Resolution	LSB < 0,1 % of maximum value	LSB = least significant bit
	Filtering techniques and methods	Anti-aliasing filter at f_{max} with >48 db/octave, high pass filter ($f_{\text{filter}} < f_{\text{min.}}$) to avoid offset	—
	Combustion engine speed increase	Combustion engine speed increase rate, e.g. 3 000 min^{-1}/min	If the combustion engine revolution increases too fast, there is a possibility that existing resonances are not detected.
Vehicle data gathering	Frequency resolution, Δf	Make sure that the frequency resolution is higher than the difference of excitation frequency while ramping combustion engine speed. Otherwise the fast Fourier transform (FFT) values will be wrong. EXAMPLE Δf = 1 Hz leads to a window length of 1 s. But for a ramping engine speed with 1 000 min^{-1}/min during 1 s, even the 4th order will sweep more than 1 Hz.	$\Delta f = f_{\text{sampling}} / b$ e.g. 12 500/2 048 = 6,1 Hz
	Temperature	Cooling water temperature, oil temperature DUT temperature (DUT measuring point and mounting area)	Description of combustion engine conditions and DUT conditions (esp. elastic suspensioned DUT)
	Peak-hold FFT	Peak-hold	Reference for creating the sinusoidal vibration part of a sine-on-random test
	Peak-hold and all other spectra	Give information: amplitude value or RMS value shown?	—

Table A.5 *(continued)*

Item	Documentation	Recommended documentation/ parameters	Comments
Data analysis	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	—
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 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 Reference [7] with m-value (in this document referred to as k) based on most critical material.	m-value = gradient of S-N curve. Its value is 5 when the test duration is adjusted in accordance with A.8. For a powertrain mounted component, the test duration is calculated according to the combustion engine speed distribution as shown in principle in A.4. For vehicle body mounted components, the test duration is verified according to rough-road percentage in A.5.1.2. As for mixed-mode (SoR) tests an example is given in A.6.
	For powertrain mounted components	Take the engine speed distribution into account.	—
	For vehicle body mounted components	Take the mileage of bad road conditions into account.	—
	Rationale for the methods — Processes and engineering judgement	—	—

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

To be able to reproduce the vibration tests in the laboratory, the vibration fixture shall be as stiff as possible and therefore, normally much stiffer than in the vehicle.

It is also 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.

In order to reduce the risk of over-testing, the average control method according to IEC 60068-2-64 Test Fh can be applied.

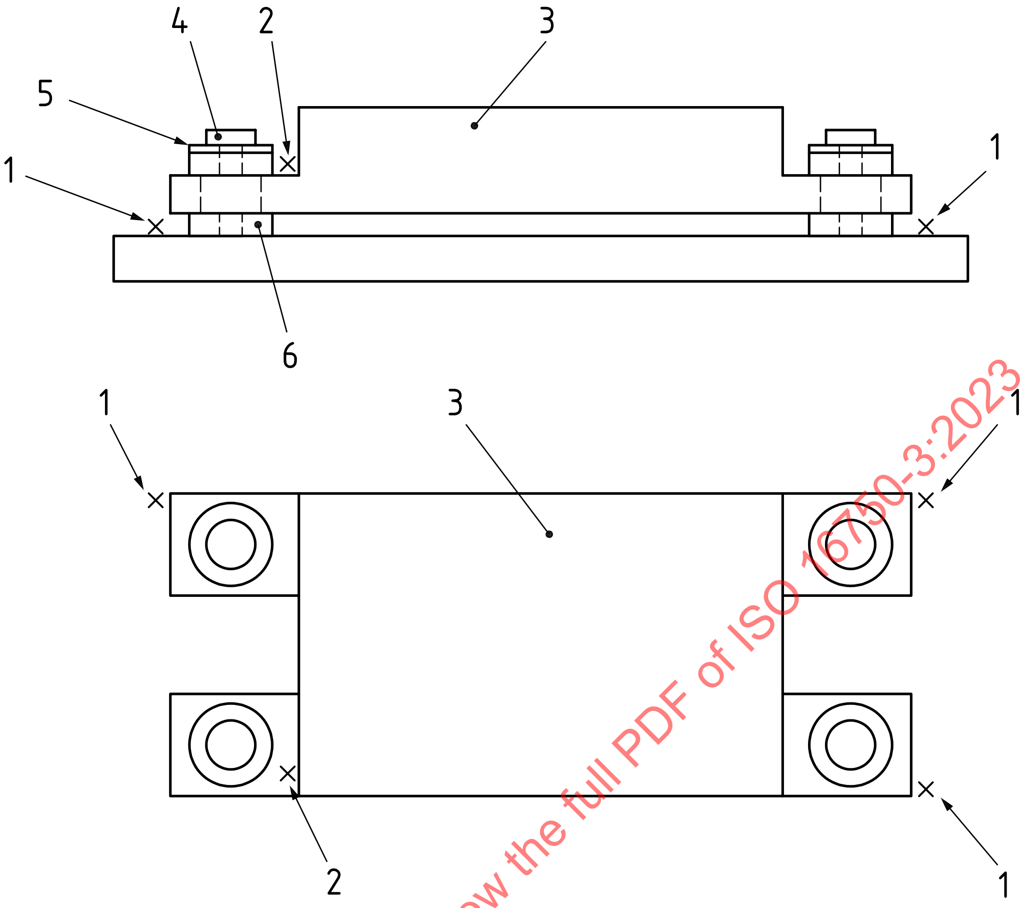
There are two different ways of carrying out average control methods (multipoint control strategies):

- 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 laboratory shall be high enough to cover the field conditions (e.g. by measuring the response of the DUT and performing spectral comparison or fatigue calculation).



Key

1	control points
2	response point on the DUT
3	DUT
4	e.g. fixed bolt
5	e.g. mount collar
6	e.g. insulator

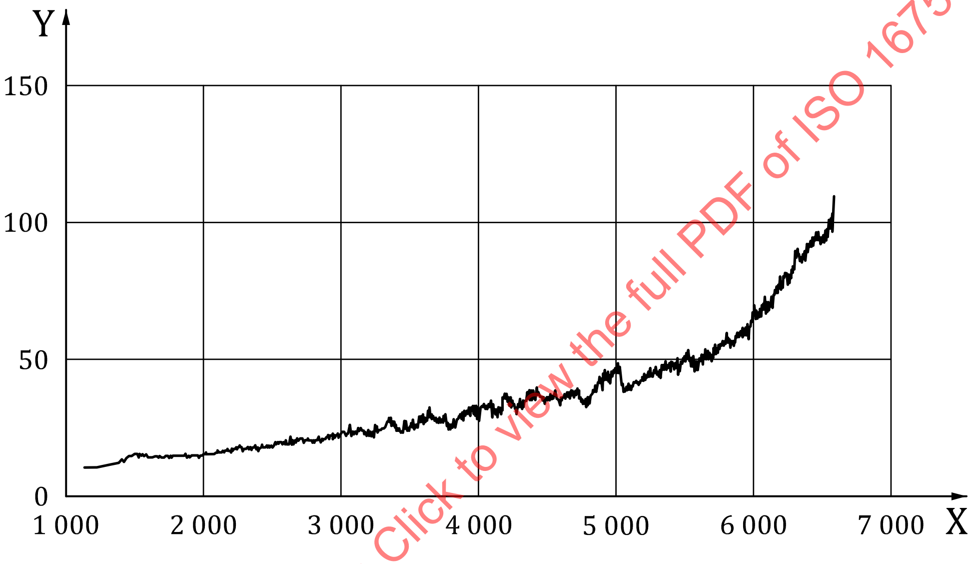
Figure A.1 — Example of a DUT and the different control points (excitation) as well as response point

Figure A.1 shows an example of a DUT (such as an ECU) that is mounted on the shaker. As described above, three control points which represent the excitation are shown as well as one response point. Dependent on the severity of the response of the DUT, this one response point may or may not be included in the averaging of the control strategy. It should be noted that the placement of the control points should be as close as possible to the fixation points of the DUT. Also, the response point should not be, for example, in the centre of an ECU casing, as the thin metal sheet will have many mode shapes also at low frequencies which are not representative of the vibrational load that the internal electronic components have to endure.

A.4 Method for determining the vibration profile and test duration on/in powertrain

A.4.1 General aspects regarding test duration

There is a general relation between the rotational speed (min^{-1}) and the vibration level caused by combustion engine rotation. For fatigue testing, it is sufficient to consider the speed range with the highest acceleration levels. Typically, the vibration levels rise more or less continuously with the speed of the combustion engine. In former times, this was not always the case. But with modern-day engine characteristics like super-/turbocharging, downsizing and high ratios of power per litre of displacement this old characteristic does not hold true anymore. This is also why in this document a paradigm shift is made in the evaluation of the engine speed distribution by taking n_{max} as the leading parameter for normalization whereas in ISO 16750-3:2012 and previous editions n_{nominal} was still the basis for normalization. An example of such an acceleration versus engine speed is given in Figure A.2, and it represents the vast majority of measurements on combustion engines, nowadays.



Key

X combustion engine speed in rpm

Y acceleration amplitude in m/s^2

Figure A.2 — Acceleration amplitude versus engine speed on a crank case

To assess the test duration it is necessary to take into account different combustion engine speed distributions and the vehicle lifetime.

A.4.2 Test duration, example for ICE without any electric propulsion

For this document three distributions were chosen for ICE vehicles without any electric propulsion system:

a) an engine speed distribution which has been gathered in 2020 and 2021 from normal drivers. This dataset consisted of some 880 trips with 20 different petrol and diesel passenger cars and an accumulated mileage of approximatively 15 000 km;

b) a “severe” engine speed distribution that was recorded during load collective measurements for pressure pulsations in the fuel injection equipment. Therefore, the vehicles were driven aggressively by test drivers in a very high combustion engine speed range;

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

The distributions are given in Figure A.3 and Table A.6.

These new sets of data were gathered in order to replace the very much outdated engine speed distribution for ICE powertrains given in ISO 16750-3:2012 and prior editions. Those engine speed distributions dated back to the 1980s and 1990s. As combustion engine technology has evolved quite significantly since then with turbo-charging, down-sizing, to name a few, it was assumed that the characteristics of such distributions have to be re-evaluated and proper conclusions drawn from this for defining test durations of combustion-engine- and gearbox-mounted components.

An extensive study made with these latest datasets mentioned in a) and b) in this subclause gave the following results.

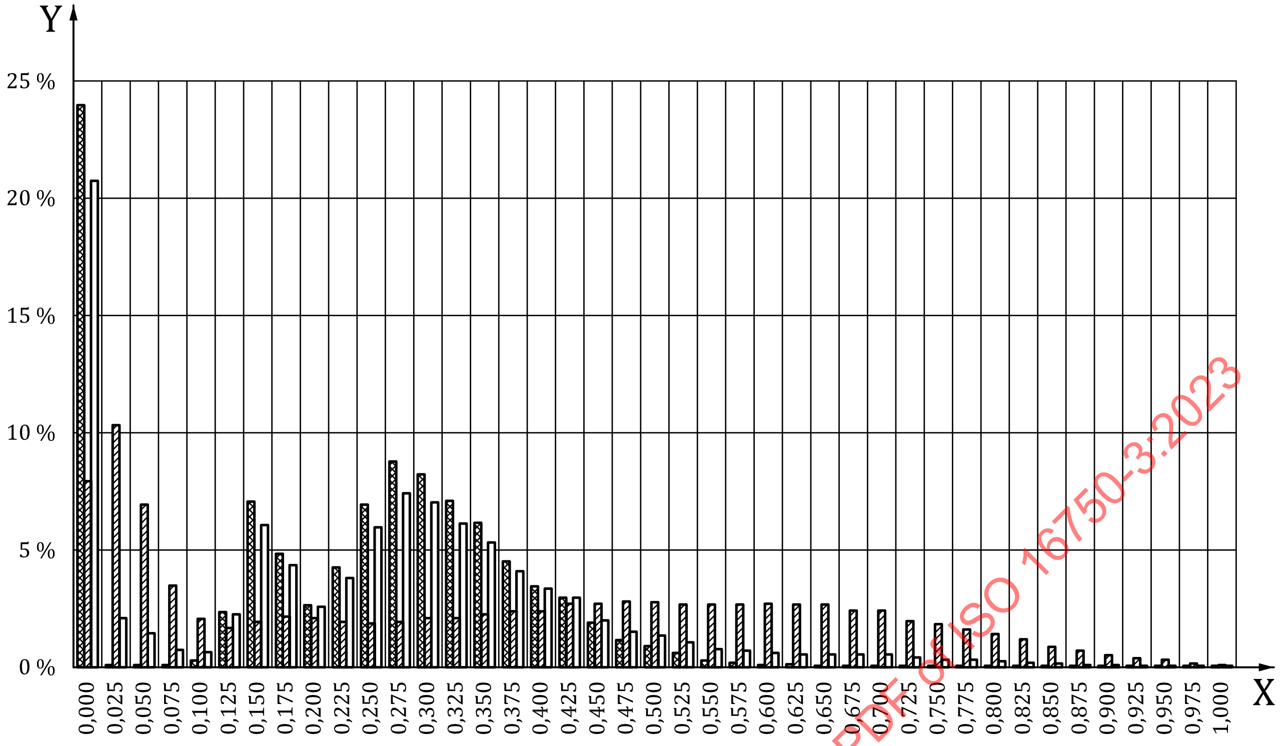
- Due to changed engine characteristics the highest vibration levels typically occur close to or at n_{max} and no longer around n_{nominal}. Therefore, any engine speed distributions need to be normalized to n_{max} and not to n_{nominal} anymore as in former times.
- Significant fatigue damage, accounting for 0,5 % dwell time of the lifetime of the vehicle, accumulates above 0,75 of the maximum speed for petrol engines and above 0,575 of the maximum speed for diesel engines.
- For the purpose of these fatigue damage calculations the somewhat outdated method of cycle-counting of zero-level-crossings, as described in A.4.4.3, is still valid, also compared to more modern algorithms such as rainflow counting.

This leads to a relevant distribution of 0,5 % in the engine speed ranges as mentioned above. So, testing 30 h along each axis is equal to approximately 6 000 h lifetime in the vehicle. With an average speed of 40 km/h this represents a mileage of 240 000 km (equivalent to 150 000 miles as stated as lifetime requirement in Reference [9], section 1962.2).

Taking into account other lifetimes/mileages/engine speed distributions shall be done by the test engineer to adapt this example to the real vehicle application, e.g. by changing the test duration proportionally to a different lifetime requirement.

Depending on the required lifetime and the required combustion engine speed distribution, the result of the calculation according to the shown method can 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.



Key

X	normalized engine speed defined as 1,00 at maximum engine speed
Y	probability [%]
▩	normal engine speed distribution
▨	severe engine speed distribution
▭	weighted engine speed distribution (80 % normal and 20 % severe)

Figure A.3 — Engine speed distributions for normal, severe and weighted distributions

Table A.6 — Engine speed distributions for normal, severe and weighted distributions

n/n_{max}	min^{-1} probability	min^{-1} probability	weighted min^{-1} probability
	px_{severe}	px_{normal}	$(20\ px_{\text{severe}} + 80\ px_{\text{normal}})/100$[a]
0,000	7,980 %	24,085 %	20,864 %
0,025	10,424 %	0,057 %	2,131 %
0,050	6,957 %	0,028 %	1,414 %
0,075	3,522 %	0,031 %	0,729 %
0,100	2,090 %	0,284 %	0,645 %
0,125	1,620 %	2,366 %	2,217 %
0,150	1,960 %	7,121 %	6,089 %
0,175	2,143 %	4,878 %	4,331 %
0,200	2,155 %	2,740 %	2,623 %
0,225	1,982 %	4,257 %	3,802 %
0,250	1,943 %	6,965 %	5,961 %
0,275	2,026 %	8,847 %	7,483 %
0,300	2,140 %	8,344 %	7,103 %

Table A.6 *(continued)*

n/n_{max}	**min^{-1} probability**	**min^{-1} probability**	**weighted min^{-1} probability**
	px_{severe}	px_{normal}	$(20\ px_{\text{severe}} + 80\ px_{\text{normal}})/100$[a]
0,325	2,116 %	7,223 %	6,202 %
0,350	2,294 %	6,174 %	5,398 %
0,375	2,446 %	4,561 %	4,138 %
0,400	2,491 %	3,554 %	3,342 %
0,425	2,693 %	3,007 %	2,944 %
0,450	2,670 %	1,894 %	2,049 %
0,475	2,818 %	1,162 %	1,493 %
0,500	2,847 %	0,921 %	1,306 %
0,525	2,748 %	0,612 %	1,039 %
0,550	2,757 %	0,288 %	0,782 %
0,575	2,677 %	0,195 %	0,691 %
0,600	2,678 %	0,129 %	0,639 %
0,625	2,634 %	0,085 %	0,595 %
0,650	2,674 %	0,054 %	0,578 %
0,675	2,482 %	0,038 %	0,527 %
0,700	2,421 %	0,032 %	0,510 %
0,725	2,023 %	0,021 %	0,422 %
0,750	1,830 %	0,014 %	0,378 %
0,775	1,652 %	0,009 %	0,338 %
0,800	1,417 %	0,007 %	0,289 %
0,825	1,246 %	0,005 %	0,253 %
0,850	0,900 %	0,005 %	0,184 %
0,875	0,730 %	0,002 %	0,148 %
0,900	0,553 %	0,002 %	0,112 %
0,925	0,427 %	0,001 %	0,086 %
0,950	0,328 %	0,000 %	0,066 %
0,975	0,197 %	0,000 %	0,040 %
1,000	0,125 %	0,000 %	0,025 %

A.4.3 Test duration, example for PHEVs

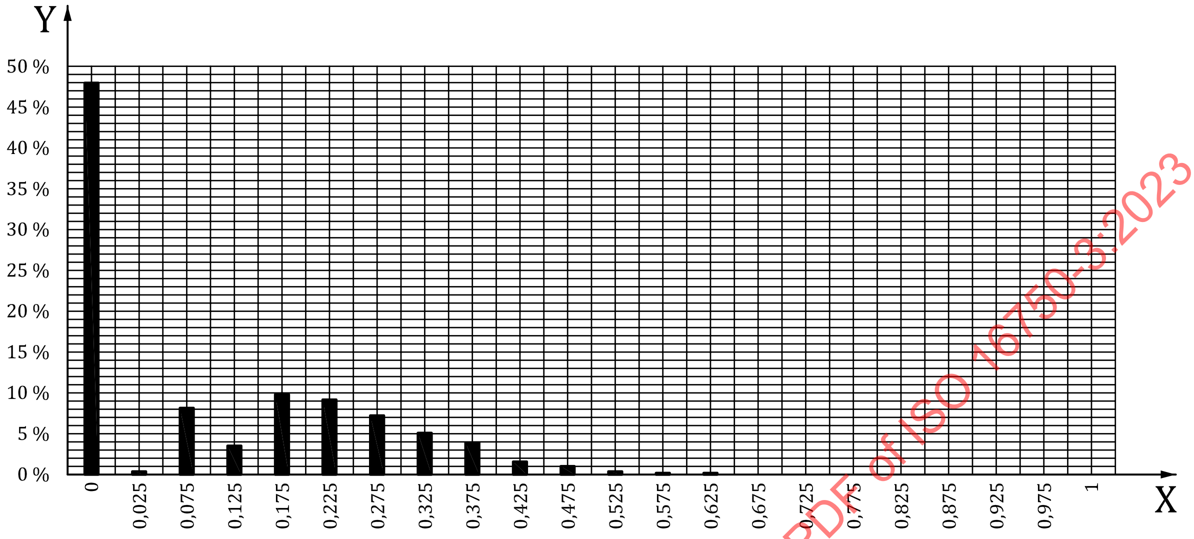
In addition to the example given for ICE without any electric propulsion system, as a second example an engine speed distribution for PHEVs is introduced.

It has been recorded using five different PHEVs, ranging from compact cars to sports sedans, with a high-voltage battery delivering a 35 km to 50 km mileage of pure electric driving which can be considered typical of the variety of PHEV models available at the time of drafting this document. During the recording, different types of roads have been used, such as inner-city road (39 %), countryside road (44 %) and highway (17 %) to give a representative mixture of usages.

Due to the capability of pure electric driving, the combustion engine is completely shut off for a significant amount of time, as shown in Figure A.4 to be slightly less than 50 % of the total time.

Apart from that, the combustion engine speed distribution is similar to that of an ICE vehicle without electric propulsion given in A.4.2. The same approach was used in determining engine speeds normalized on the maximum combustion engine speed. A probability distribution is shown in Figure A.4 and Table A.7.

Here, the probability accumulated at and above 0,725 of the normalized engine speed is 0,5 %, which accords to 30 h for a lifetime requirement of 6 000 h. This fraction of 0,725 of n_{max} is almost identical to the value of 0,75 gathered for petrol ICEs without electric propulsion, given in A.4.2.



Key

X normalized engine speed defined as 1,00 at engine speed with maximum power

Y probability [%]

Figure A.4 — Engine speed distribution in a PHEV

Table A.7 — Probability and dwell time of engine speed distribution

Normalized engine speed n_{max}	Probability
0,000	47,348 53 %
0,025	0,570 09 %
0,075	8,308 78 %
0,125	3,743 16 %
0,175	9,776 51 %
0,225	9,163 15 %
0,275	7,235 23 %
0,325	5,129 04 %
0,375	3,913 97 %
0,425	1,761 84 %
0,475	1,245 31 %
0,525	0,582 13 %
0,575	0,313 19 %
0,625	0,245 16 %
0,675	0,195 89 %
0,725	0,158 45 %
0,775	0,127 34 %

Table A.7 *(continued)*

Normalized engine speed n_{max}	Probability
0,825	0,081 57 %
0,875	0,057 88 %
0,925	0,042 79 %
0,975	0,010 41 %
1,000	0,000 00 %

A.4.4 Verification of load in combustion engine speed distribution

A.4.4.1 Procedure

As aforementioned, it is sufficient to consider the combustion engine vibration load from the combustion engine speed ranges with the highest acceleration levels. This is verified by the following steps:

a) recording of the combustion engine speed distribution as field-relevant load collectives (see A.4.3);

b) measurement of acceleration levels with a combustion engine speed increase on the chassis dynamometer (see A.4.4.2);

c) determination of the load distribution from the measured time history (cycle counting method) (see A.4.4.3);

d) analysis of the number of cycles in the classed acceleration levels and combustion engine speeds (see A.4.4.4).

e) verification of the dominant load from the high engine speed range (see A.4.4.5).

In order to demonstrate this procedure, an example was taken with a high-power petrol engine (2 l, 4 cylinders, 185 kW) by measuring the vibration on the front of the crank case and using the specific engine speed distribution for this application. This distribution showed the top 0,5 % dwell time to be at 0,85 of the maximum engine speed. This is then an even slimmer engine speed range than an average petrol engine shows with the value of 0,75 of n_{max} as given in A.4.2.

A.4.4.2 Measurement of acceleration levels with a combustion engine speed increase on the chassis dynamometer

Acceleration levels on the powertrain are measured by increasing the combustion engine speed at a constant rate on the chassis dynamometer. A measurement shown in Figure A.2 is implemented under the following conditions:

- maximum combustion engine speed: 6 550 rpm (1 as normalized speed);
- combustion engine speed at the start of measurement: 1 145 rpm (0,173 as normalized speed);
- combustion engine speed at the end of measurement: 6 543 rpm (0,999 as normalized speed);
- rate of combustion engine speed increase: 3 000 rpm/min; and
- measurement time: 1,799 min [= (6 543 – 1 145)/3 000].

A chronological data set of acceleration levels is recorded during this measurement. See Figure A.2.

A.4.4.3 Determination of the load distribution from the measured time history (cycle counting method)

There is one maximum between two zero crossings, see Figure A.5.

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

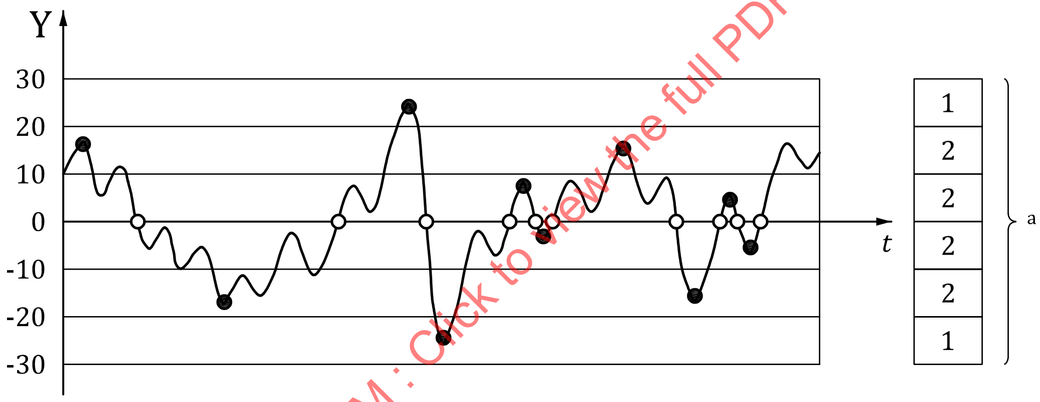
The result of this counting method gives the number of half cycles for each class, i.e. the load distribution from the measured time history. See Figure A.6.

The load distribution for the test duration is calculated by using a factor of (test time/measuring time) for each class (e.g. 4,4 h × 3 600 s/h/19,9 s = 796).

The load distribution for the vehicle lifetime is calculated by using a factor of (vehicle lifetime × percentage at relevant engine speed/measuring time) for each class (e.g. 6 000 h × 0,005 × 3 600 s/h/3,69 s = 2 926 829).

NOTE The load distribution is determined for measuring points on the DUT.

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



Key

Y class (acceleration level) [m/s^2]

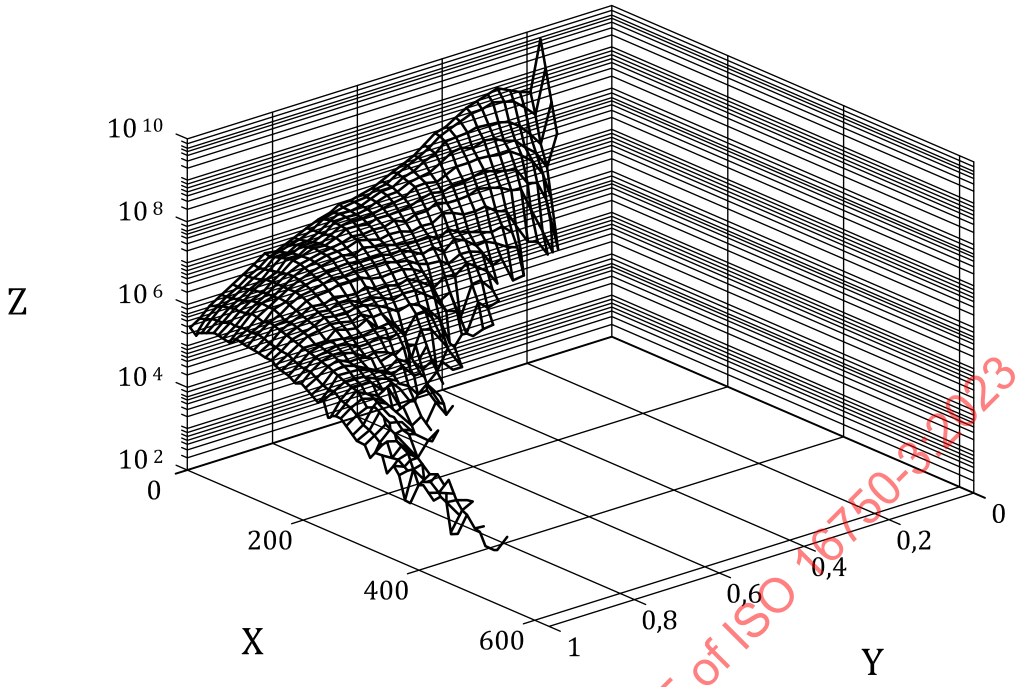
t time [s]

[a] Number of half cycles in each class.

Figure A.5 — Counting method for the load distribution

A.4.4.4 Analysis of the number of cycles in the classed acceleration levels and combustion engine speeds

By using a cycle counting method (see Figure A.5), the cycle number of vibrations is analysed for each acceleration level and each engine speed from the measured data in the previous step. As a result of this process, normalized engine speeds are classed by 0,05 and acceleration levels are also broken down into classes. The distribution of the number of cycles is also shown in Figure A.6.



Key

X absolute acceleration level [m/s^2]

Y normalized combustion engine speed

Z number of cycles in the acceleration level over the lifetime of the vehicle

Figure A.6 — Distribution of number of cycles

Furthermore, the number of cycles in real-world driving conditions is estimated from a ratio dividing the dwell time in the field-relevant engine speed distribution, by one chassis dynamometer measurement at each classed normalized combustion engine speed.

A.4.4.5 Verification of the dominant load from the high combustion engine speed range

Using the Palmgren-Miner hypothesis, fatigue damage, S, is generally defined as a dimensionless quantity by the following formulae:

$$s_\mathrm{i} = n_\mathrm{i}/N_\mathrm{i} \tag{A.1}$$

$$S = \Sigma s_i \tag{A.2}$$

where

n_i is the number of cycles of actual stress at acceleration level a_i (with a_i expressed in m/s^2);

N_i is the number of cycles to failure (fatigue life) at acceleration level a_i;

s_i is the linear cumulative damage;

i is the suffix in accordance with acceleration levels.

According to the hypotheses, fatigue (and eventually breakage) occurs when S is equal to or greater than 1. For the consequent processes in this verification, the lifetime fatigue damage in real-world driving conditions is divided into the two parts below:

$$S = S_1 + S_2 \tag{A.3}$$

where

S_1 is the partial damage in the speed range between stopping and the threshold which covers 99,5 % of the dwell time in this engine speed range of the overall lifetime(e.g. 0,75 × n_{max} for petrol engines in general, and 0,85 × n_{max} in this particular example);

S_2 is the partial damage in the highest speed range that covers 0,5 % of the dwell time of the overall vehicle lifetime.

If S_2 is far larger than S_1, i.e. the ratio S_2/S_1 is large enough (for example, 10 times or more), it is verified that the dominant part of the lifetime fatigue damage derives from the high-speed range. In detail, the ratio S_2/S_1 is calculated by the following steps:

a) select an S-N model described with exponent k and fatigue cycle number N_D (see Table A.11);

b) set a fatigue limit a_D (see Figure A.8);

c) calculate the number of cycles to failure N_i at a_i;

d) calculate $s_i = n_i/N_i$ at a_i;

e) calculate the total sum $S = \Sigma\, s_i$;

f) repeat the steps from b) to e) in this subclause changing a_D so that $S = 1$, or as close as possible;

g) calculate S_1, S_2 and S_2/S_1 under the specified a_D;

h) repeat this for all 12 S/N models with the Haibach modification;

i) calculate the ratio S_2/S_1 for all those 12 S/N models.

A calculation example according to these steps is shown in Table A.8, where the conditions and results are:

— one measurement point on the crank case of the given example was measured in all three primary axes;

— an application-specific engine speed distribution was used, N_D = 2 000 000;

— the ratio S_2/S_1 for all 12 S/N models was calculated.

The large ratio of S_2/S_1 means that the damage from the high-speed range is dominant and the damage below is negligible. This results in a test duration of 30 h per axis of the DUT as mentioned in A.4.2.

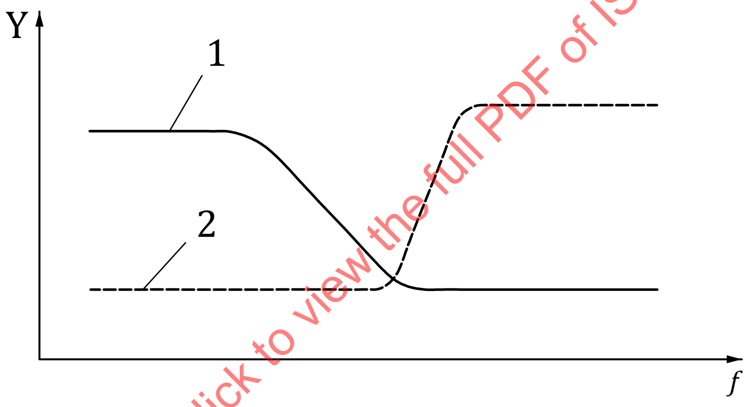
Table A.8 — Comparison of the ratios of S_2/S_1 based on the S-N model and the measurement direction of the given example in all three primary axes

	N_D = 2x10^6 k=3,5	N_D = 2x10^6 k = 5	N_D = 2x10^6 k = 7	N_D = 2x10^6 k = 10	N_D = 10^7 k = 3,5	N_D = 10^7 k = 5	N_D = 10^7 k = 7	N_D = 10^7 k = 10	N_D = 5x10^7 k = 3,5	N_D = 5x10^7 k = 5	N_D = 5x10^7 k = 7	N_D = 5x10^7 k = 10
X	2,8	9,7	41,2	415,7	2,3	5,8	17,7	118,0	1,6	3,6	9,9	54,9
Y	1,5	3,9	9,4	27,2	1,2	2,5	5,4	15,6	0,9	1,7	3,7	10,8
Z	2,2	7,8	24,5	128,9	2,0	5,3	13,0	49,3	1,4	3,3	8,0	28,4

This shows that in the vast majority of the cases the top engine speed range is dominant over the engine speed range below. In a few cases the ranges are approximately on par, however on average in this example the top engine speed range with 0,5 % of the dwell time is 28,9 times more damaging than the 99,5 % of the remaining vehicle lifetime.

A.4.5 Sources for vibration in an SoR profile for powertrain-mounting

Since road vibration to powertrain-mounted components attenuates through mount insulators, the influence of vibration during flat road driving is negligible, but it is taken into account during rough-road driving. Considering that the percentage of rough roads is approximately 10 %, the duration of the random vibration test could be 600 h, i.e. 10 % of 6 000 h of lifetime. However, this is too long, therefore it has been changed from 600 h to 20 h by the following procedure described in A.5.1.2. In 4.1.2.2, a vibration profile for combustion engine mounted components is defined to take into account not only engine vibration but also road vibration, where the engine vibration occurs due to its high-speed rotation (see Figure A.7) and the road vibration is due to the most severe conditions during rough-road driving. However, the profile containing both types of excitations is too severe for large and heavy DUTs in hybrid- and fully-electric vehicles, and a new sequential test has been developed, which is composed of a sine-on-random test covering engine vibration in high engine speed driving conditions and a random test covering road vibration in low speed driving conditions.



Key

Y	PSD
f	frequency
1	low speed driving on rough roads
2	high combustion engine speed driving on flat roads

Figure A.7 — Vibration loads and vehicle speed

The vibration severity is lower than in the profiles for small and lightweight DUTs due to the increased mass and inertia of the DUT.

For small and lightweight DUTs, one profile is applied to all axes (X, Y and Z), enveloping measured loads in each axis. For large and heavy DUTs, a different profile is applied to each axis because powertrain components are usually mounted in a certain position and orientation, and the vibration of each axis can be different.

A.5 Method for determining the vibration profile and test duration for DUT mounted on the body

A.5.1 General

A.5.1.1 Enveloping vibration profile

The vibration profile for rough-road driving is representative of the on-body condition. As electrical and electronic (E/E) components for HEV, EV traction have the weight of several to tens of kilograms, the RMS of acceleration is reduced, resulting from the inertia of high masses of the DUT.

Most of on-body components are installed in various positions and orientations using mounting brackets; therefore, the profile is defined by enveloping vibration profiles of X, Y and Z.

A.5.1.2 Test duration

A test duration of 8 h each axis has been customary for almost 30 years. Introducing random vibration for on-body components in the late 1970's fatigue calculations were performed to change from (at that time mostly used) sinusoidal testing to random vibration, the duration of 8 h was developed step by step on experience.

As described in A.5.2.2, later a verification was needed to show, that 8 h are sufficient to cover the stress in vehicle which occurs during vehicle lifetime (meanwhile the required lifetime had been increased up to 6 000 h).

The calculated example (A.5.2.2) shows as a result for the taken ECU, 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 vehicle during 5 400 h on a test track.

To calculate with 90 % rough road part during 6 000 h lifetime is absolutely worst case. Normally it is calculated with less than 50 % rough road part (see A.5.2.2, NOTE 3.) The E/E components for HEV, EV traction are larger and heavier than the DUT covered by previous editions of this document, therefore an assumption of 90 % is too severe and the percentage of rough road was reduced to 50 % as the allowable level.

The test duration here is calculated to 4,4 h (= 8 h × 50 %/90 %). However, the components have a high heat capacity and 4,4 h is not long enough to cover even one temperature cycle done in parallel with vibration test.

In this case, the test duration for random test was extended to 20 h to be able to cover at least one temperature cycle. How to perform such an extension, please refer to A.8.

A.5.2 Verification of the shortened test duration using fatigue calculation

A.5.2.1 General

This subclause describes the verification of 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.5.2.2 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.5.2.5, A.5.2.6 and Figure A.5) 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.5.2.6 and Figure A.8.

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.5.2.3 Test parameters for random vibration

A random vibration test is performed using the following 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;
— RMS acceleration value:	33 m/s^2;
— test spectrum:	see Table A.9.

Table A.9 — 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 4.1.8.2. At the resonance of the ECU (about 600 Hz) the difference is negligible.

A.5.2.4 Acceleration distributions of random vibration test and vehicle driving

Based on the cycle counting method in A.4.4.3, acceleration distributions, as shown in Table A.10, were calculated for the random vibration test and the vehicle driving (rough-road part 50 %):

- 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 %).

Table A.10 — Acceleration distribution after cycle counting

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.11 — 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	Exponent "*k*" of S/N graph	Hypotheses	Calculated fatigue level for the random vibration test (12 "S/N models")	Needed fatigue level for 5 400 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.5.2.5 Further guidance on classification methods

Evaluation of random vibration is usually done based on statistics using a classification method. For calculation of the described example the method of zero crossing peak counting was chosen (see Figure A.5). 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.

Determination of the load distribution shall be done for measuring points on the DUT. The load on the measurement points shall be relatable to the damage (e.g. measurement point on PCB as done for the ECU or on tip of a beam).

NOTE The calculation is performed for vehicle load against lab load relatively, therefore using the chosen simple method seems to be permissible.

For calculation of absolute fatigue values the test engineer has to check whether another classification method is more suitable. Classification methods are standardized, refer, for example, to DIN 45667.

A.5.2.6 Calculation of the fatigue limits

For the determination of the fatigue limit a_D one S/N model — described by the exponent 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.

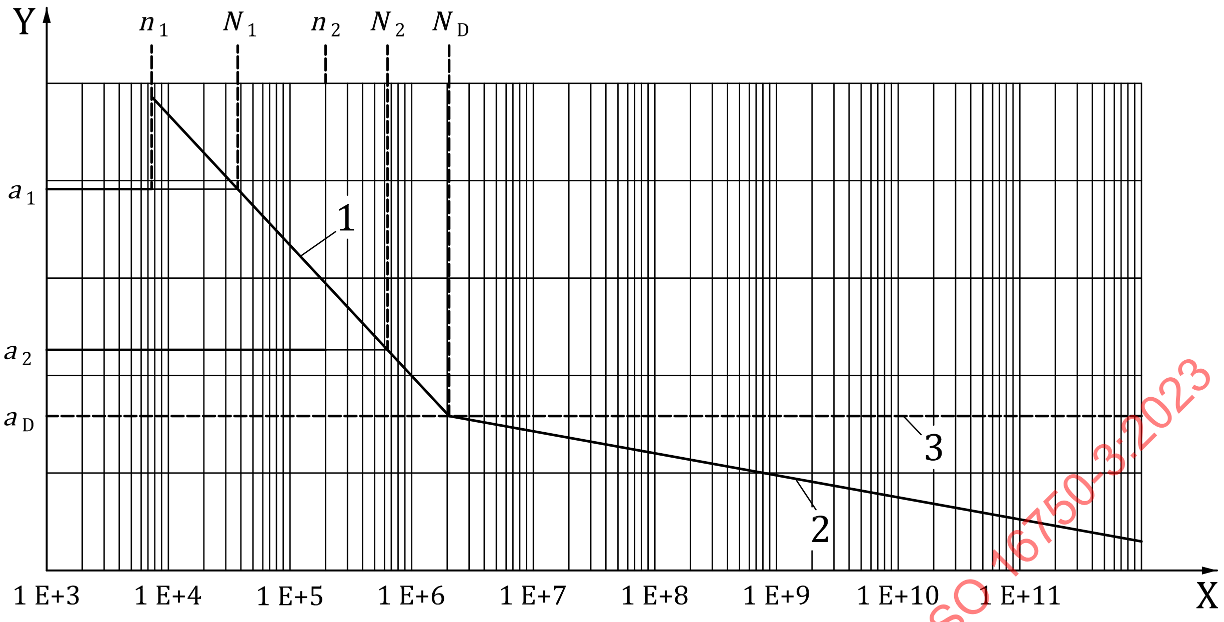
By means of iteration the a_D value is varied until a damage of “1” occurs.

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 exponents 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.11 and Figure A.8.



Key

1	slope of S-N curve, proportional to 1/*k*
2	haibach-modification: Slope proportional to 1/(2*k*-1)
3	miner original
X	number of cycles
Y	acceleration amplitude
a_D	fatigue limit, in m/s^2
N_D	fatigue cycle number
a_1 ,a_2	acceleration level, in m/s^2
n_1 ,n_2	number of cycles of actual stress at a_1 ,a_2
N_1 ,N_2	number of cycles to failure at a_1 ,a_2

Figure A.8 — Haibach hypotheses — Linear damage accumulation "S"

If representative values for *k* are needed, then refer to relevant documents, e.g. examples for *k* are given in MIL-STD-810H, there stated as *m*.

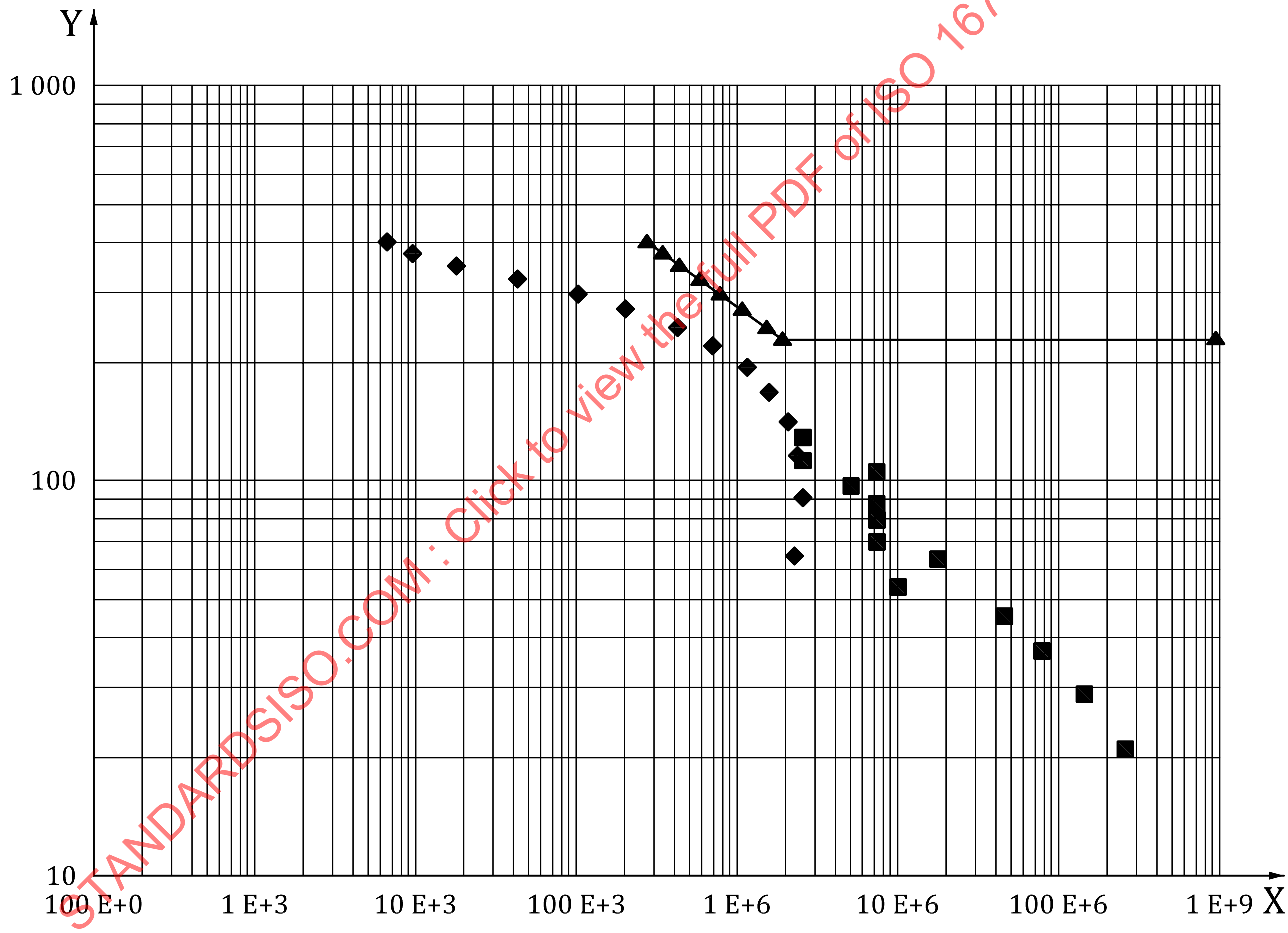
An example for this methodology is given in Table A.12 and Figure A.9.

Table A.12 — 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/s^2)		**Measurement in car; road bumps** (5 400 h)	
Acceleration [m/s^2]	**Cycles** (*n*)	**Acceleration** [m/s^2]	**Number of S/N cycles**	**Acceleration** [m/s^2]	**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

Table A.12 *(continued)*

Random vibration test (8 h)		**Corresponding “S/N graph”** (2x10^6; k = 5; a_D = 229 m/s^2)		**Measurement in car; road bumps** (5 400 h)	
Acceleration [m/s^2]	**Cycles** (n)	**Acceleration** [m/s^2]	**Number of S/N cycles**	**Acceleration** [m/s^2]	**Cycles** (n)
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



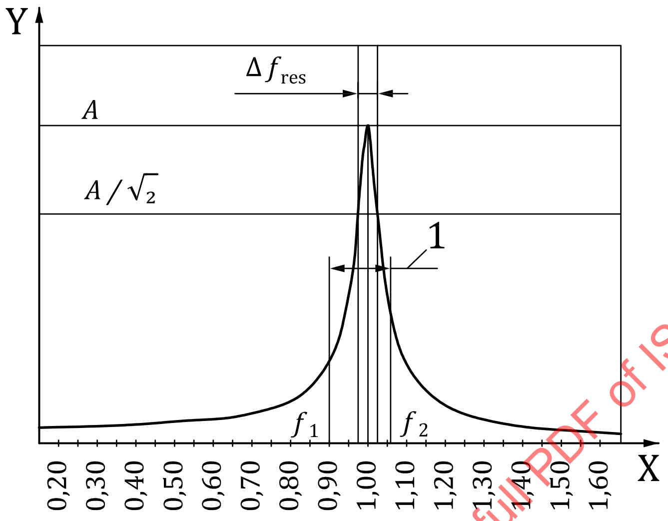
Key

Y	acceleration
X	cycles
◆	random vibration test (8 h)
■	measurement in vehicle
─▲─	corresponding Woehler graph to random vibration test (2 × 10^6; k = 5; a_D = 229 m/s^2)

Figure A.9 — Load distribution and S/N curve one model

A.6 Test duration for a sinusoidal test not governed by an engine speed distribution

When a sinusoidal test is to be performed on a DUT and an engine speed distribution is not known, then the one given in this document can be used, see A.4.2. However, sometimes this typical distribution is not suitable for a certain application, e.g. when the maximum of the distribution is at low engine speeds with high dwell times. In this case, or when a sinusoidal test is to be performed in a dedicated frequency range with known resonances, the test duration can be calculated using the so-called 20 h/octave rule.



Key

X	f / f_{res}
Y	amplification factor of the resonance
Δf_{res}	bandwidth of resonance frequency (f_{res})
f_2	upper limit of test frequency range
f_1	lower limit of test frequency range
1	test frequency range

Figure A.10 — Explanation of the resonance bandwidth

The test duration is based on the number of damage-relevant load cycles L_C within the resonance bandwidth. The resonance bandwidth is the frequency range in which the response amplitude is at or above the maximum response amplitude $A/\sqrt{2}$ as shown in Figure A.10.

The test duration can be calculated by the following Formula (A.4):

$$t = \frac{L_C \times \ln \frac{f_2}{f_1}}{\Delta f_{res} \times 3\,600} \qquad \text{(A.4)}$$

where

t is the test duration, expressed in hours.

For 10^7 damage-relevant load cycles and a minimum resonance bandwidth of 100 Hz this then gives a test duration of 19,25 h per octave ($f_2/f_1 = 2$). This is rounded up to 20 h/octave.

For test VI (see 4.1.4), the ratio of the upper limit frequency and the lower limit frequency of the sinusoidal vibration test is 26 (=520 Hz/20 Hz). It corresponds to 4,7 octaves, calculated with the equation $2^{4,7}$=26. Therefore, the test duration of test VI becomes 94 h = 20 h/octave × 4,7 octaves.

Performing a test in mixed mode (sine on random), the test duration shall 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, for example, in 4.1.4.2.2.

A.7 Test duration with an infinite-life approach for vehicle-body-mounted DUTs

When designing vibration tests for vehicle-body-mounted DUTs in commercial vehicles a wide variety of lifetime requirements needs to be covered, e.g. from 8 000 to 20 000 operating hours. In order to become independent from this variety an infinite-life approach may be taken.

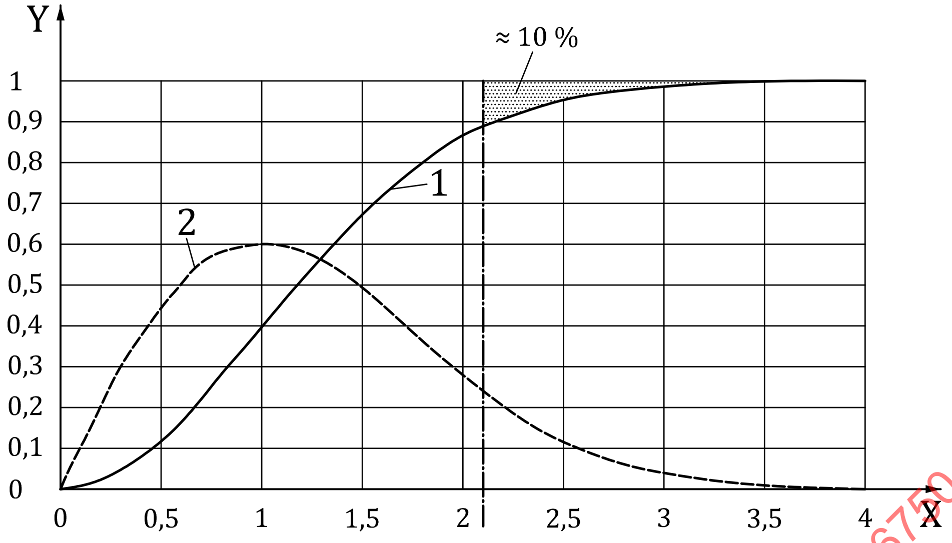
In this approach it is assumed that if you test up to a certain number of load cycles at a given load level, and the DUT does not fail that it would survive an infinite number of additional load cycles on this level as the vibrational load is considered to be (well) below the fatigue limit of the material at a critical design feature.

This fatigue cycle number L_C is given as, e.g. 10^7 load cycles for steel. The number might vary for other materials. For some materials, no distinct fatigue limit is evident.

When aiming for infinite-life testing up to 10^7 load cycles, then it is clear that the vibrational load must be below the fatigue limit a_D of the S-N curve where the S-N exponent changes from k to (2k-1) in the Haibach modification, see also Figure A.8. Otherwise, if the vibrational load is higher, then the DUT will fail much earlier than the 10^7 load cycles.

However, only those load cycles are considered damage-relevant that occur within the resonance bandwidth. The resonance bandwidth can be determined by dividing the maximum peak of the resonance by the square root of 2. This then gives the upper and lower frequency limit, see Figure A.10.

When a DUT is excited at its resonance frequency by a broadband random signal (with Gaussian distribution) the response can be estimated as that of a single-mass oscillator with a Rayleigh distribution, see Figure A.11.



Key

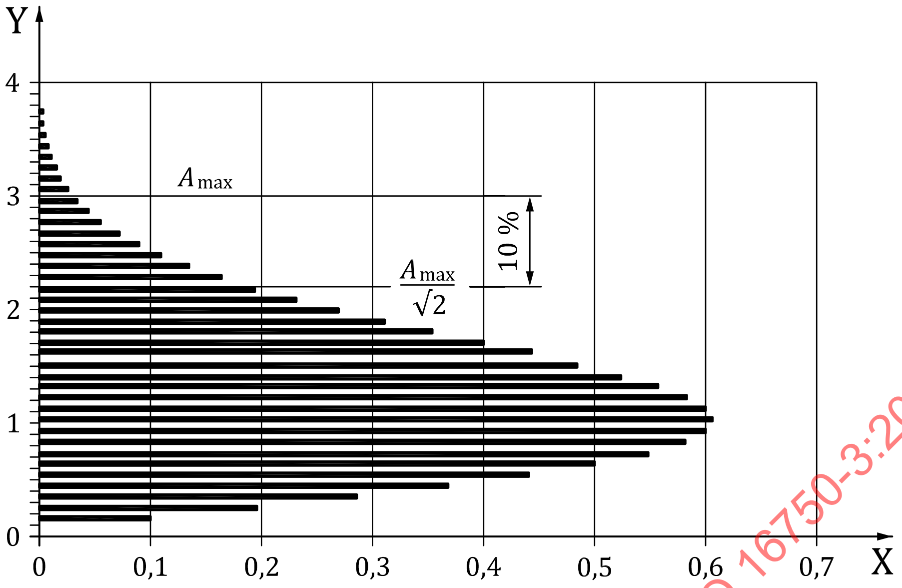
X	peak / RMS
Y	probability density function
1	accumulated distribution of the amplitudes
2	Rayleigh distribution of the amplitudes

Figure A.11 — Rayleigh distribution of a single-mass oscillator at its resonance frequency

In the response of a test object (single-mass-oscillator concept) to a random excitation one can assume that the peaks are given as three times of the effective value (RMS), also called 3σ. Of course, in an individual application this peak value of the response (multiple of σ) can differ to any other value based on the dynamic behaviour of the test object.

In the Rayleigh distribution with the ratio of peak/RMS on the x-axis the $3\ \sigma$ value is divided by the square root of 2, giving a factor of 2,12 within the resonance bandwidth. In the accumulated distribution this results in roughly the top 10 % of load cycles that are considered damage relevant.

In Figure A.12 the resonance bandwidth described in Figure A.10 is applied to the Rayleigh distribution shown in Figure A.11.



Key

X	probability density function
Y	peak / RMS
A_{max}	maximum amplitude (here: 3σ)

Figure A.12 — Damage-relevant load cycles within resonance bandwidth for the Rayleigh distribution

In order to test for 10^7 damage-relevant load cycles ten times the number of load cycles need to be tested, e.g. 100 million instead of 10 million load cycles.

In order to shorten test durations, test acceleration approaches may be used. With +20 % load increase (= 1,2) and a Basquin exponent k of 5 this then results in a test acceleration factor of 2,49.

For a given resonance frequency f_{res} the total number of load cycles N is given as Formula (A.5)

$$N = f_{\text{res}} \times 3\,600 \times t \qquad \text{(A.5)}$$

NOTE Test duration is expressed in hours.

When we use test acceleration to compensate the fact that we can only consider 10 % of the occurring load cycles as damage-relevant, testing for 32 h per axis gives a minimum resonance frequency [see Formula (A.6)]:

$$\frac{10\times L_{\text{C}}}{t\times 3\,600\times 2{,}49} = \frac{10\times 10^7}{32\,\text{h}\times 3\,600\,\frac{\text{s}}{\text{h}}\times 2{,}49} = f_{\text{res,min}} = 349\,\text{Hz} \qquad \text{(A.6)}$$

Given the boundary conditions in this example the infinite life approach with 32 h per axis will lead to at least 10^7 damage-relevant load cycles for any resonance frequency at or above 349 Hz.

A.8 The explanation for Basquin model

A.8.1 General

When a testing condition cannot be achieved to its full level because the fixture and/or DUT are too heavy, then the following guideline shows how to adjust vibration load and test duration. Vice-versa, the procedure can be used for test acceleration.