INTERNATIONAL STANDARD

ISO 19453-3

First edition
2018-03

Road vehicles — Environmental conditions and testing for electrical and electronic equipment for drive system of electric propulsion vehicles —

Part 3: Mechanical loads

Véhicules routiers — Spécifications d'environnement et essais de l'équipement électrique et électronique pour les véhicules à propulsion électrique —

Partie 3: Contraintes mécaniques

Reference number
ISO 19453-3:2018(E)

ISO copyright office
CP 401 • Ch. de Blandonnet 8
CH-1214 Vernier, Geneva
Phone: +41 22 749 01 11
Fax: +41 22 749 09 47
Email: copyright@iso.org
Website: www.iso.org

Published in Switzerland

Contents

Page

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

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

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

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

For an explanation on 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 the following URL: 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*.

A list of all parts in the ISO 19453 series can be found on the ISO website.

Road vehicles — Environmental conditions and testing for electrical and electronic equipment for drive system of electric propulsion vehicles —

Part 3: **Mechanical loads**

1 Scope

This document specifies requirements for the electric propulsion systems and components with maximum working voltages according to voltage class B. It does not apply to high voltage battery packs (e.g. for traction) and systems or components inside. It describes the potential environmental stresses and specifies tests and requirements recommended for different stress levels on/in the vehicle.

This document describes mechanical loads.

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

ISO 19453-1, *Road vehicles — Environmental conditions and testing for electrical and electronic equipment for drive system of electric propulsion vehicles — Part 1: General*

ISO 19453-4:2018, *Road vehicles — Environmental conditions and testing for electrical and electronic equipment for drive system of electric propulsion vehicles — Part 4: Climatic loads*

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*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 16750-1 and ISO 19453-1 apply.

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

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

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

4 Tests and requirements

4.1 Vibration

4.1.1 General

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

The following basic idea of environmental test methods is expressed in MIL-STD-810G:2008, Foreword.

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. 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 one can get 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 use of a bracket for mounting can result in higher or lower loads. Vibration tests shall be carried out according to actual vehicle conditions.

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

Loads outside the designated test frequency ranges shall be considered separately.

NOTE Deviations from the load on the DUT can occur, should vibration testing be carried out according to this document on a heavy and bulky DUT, as mounting rigidity and dynamic reaction on the vibrator table excitation are different compared to the situation in the vehicle. 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.

During the vibration test, subject the DUT to the temperature cycle in accordance with IEC 60068-2-14, with electric operation according to Figure 1. Alternatively, a test at constant temperature may be agreed on.

Operate the DUT electrically as indicated in Figure 1 at T_{min} (short functional test after the DUT completely reached T_{min}). This functional test shall be as short as possible — only long enough to check the proper performance of the DUT. This minimizes self-heating of the DUT. A long period of electric operation is started at room temperature (RT) in order to allow possible condensation of humidity on the DUT. A permanent operation starting at T_{min} would prevent this due to the electric power dissipation.

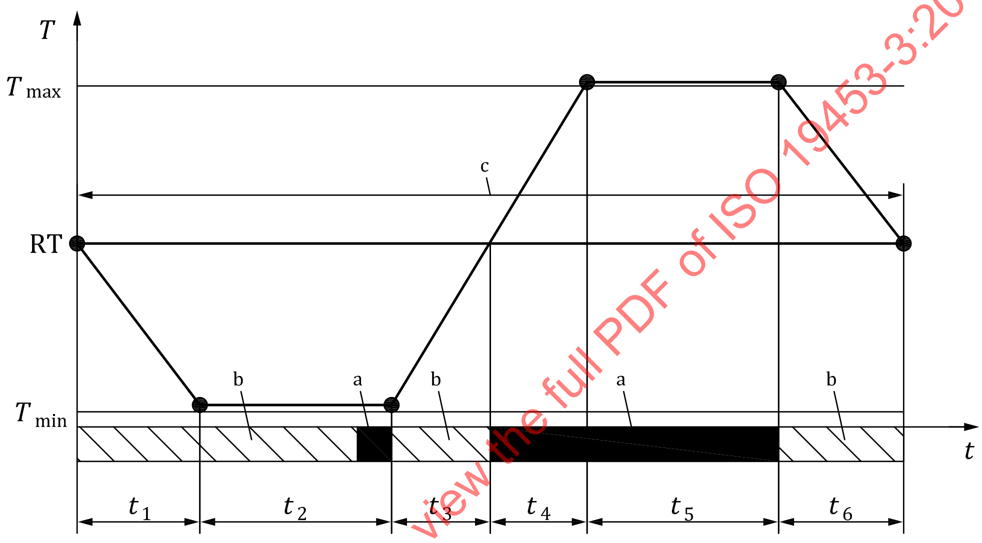
Additional drying of test chamber air is not permitted.

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

In case of doubt, a separate measurement shall be performed to determine what soak time at max. or min. ambient temperature is necessary to warrant that this desired temperature is also reached in the core of the DUT. The core temperature shall be maintained for at least one hour during the vibration test; therefore the temperature cycle shall be adjusted accordingly.

Measures regarding the functional performance are allowed to avoid overheating of the DUT during high-temperature operation with self-heating effects.

The complete profile of temperature cycle duration of T_{min} and that of T_{max} shall be more than 1 h. The supplier and the customer shall agree on a complete profile of temperature cycle.



Key

T	temperature, in °C
t	time, in h
T_{min}	minimum operating temperature as defined in ISO 19453-4
T_{max}	maximum operating temperature as defined in ISO 19453-4
RT	room temperature as defined in ISO 19453-1
t_1, t_2, t_3, t_4, t_5, t_6	time parameter (as defined in Table 1)
a	Operating mode 4.2 as defined in ISO 19453-1.
b	Operating mode 2.1 as defined in ISO 19453-1.
c	One cycle.

Figure 1 — Temperature profile for the vibration test

If operating mode 4.2 is not technically feasible, operating mode 3.2 may be used. For electric motors, active operation in operating mode 3.2 or 4.2 can be performed in order to avoid unrealistic failure mechanisms, e.g. wear in the bearings due to the vibration input.

Table 1 — Temperature versus time for the vibration test

Parameter	Duration h	Temperature
t_1	As agreed	From RT to T_{min}
t_2	> 1	Stabilized time at T_{min}
t_3	As agreed	From T_{min} to RT
t_4	As agreed	From RT to T_{max}
t_5	> 1	Stabilized time at T_{max}
t_6	As agreed	From T_{max} to RT
NOTE T_{min} and T_{max} are defined in ISO 19453-4:2018, Table 1. (codes A to X). In the vehicle environment, some equipment can experience different conditions regarding temperature, temperature gradients and duration: in all these cases, code Z is used.		

4.1.2 Tests

4.1.2.1 Test I — Passenger car, powertrain (combustion engine, gearbox)

4.1.2.1.1 Purpose

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

4.1.2.1.2 Test

4.1.2.1.2.1 General

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.4.1.2 and A.4.1.3. The test duration and vibration load level can be adjusted accordingly based on the Basquin's equation given in A.6.

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 slope *k* of the S-N curve specific to this component (see also A.6). 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.3.

4.1.2.1.2.2 Sine-on-random vibration

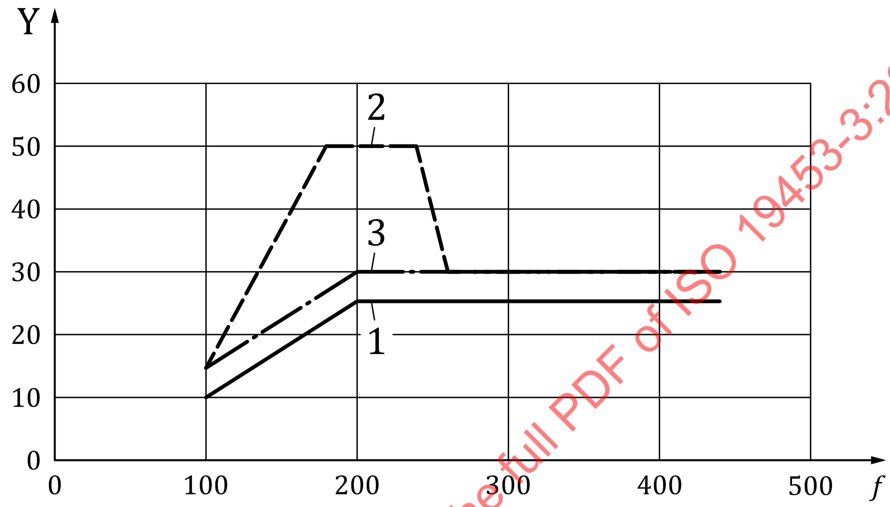
This test shall be performed as a mixed mode vibration test in accordance with IEC 60068-2-80.

a) Sinusoidal vibration part

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

The test duration is 33 h for each axis of the DUT.

The profiles in Table 2 and Figure 2 show the sinusoidal vibration part of the sine-on-random profile.



Key

Y acceleration amplitude, in m/s²

f frequency, in Hz

1 curve for X axis

2 curve for Y axis

3 curve for Z axis

Figure 2 — Acceleration versus frequency

Table 2 — 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	15
200	25	180	50	200	30
440	25	240	50	440	30
—	—	260	30	—	—
—	—	440	30	—	—

b) Random vibration part

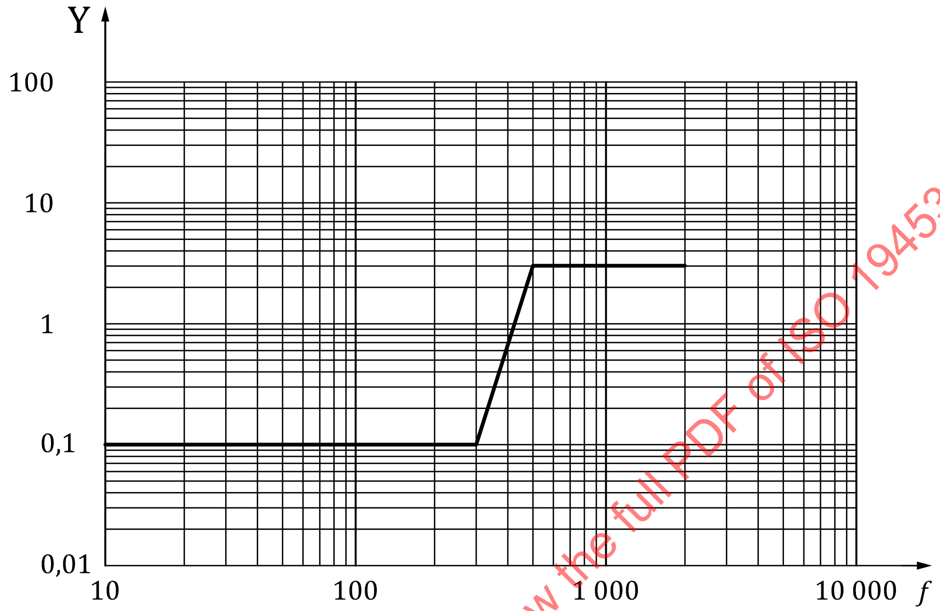
Perform the test in accordance with IEC 60068-2-64.

The test duration is 33 h for each axis of the DUT.

The RMS acceleration value shall be 68,7 m/s^2. 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 3 and Table 3.

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.4.1.1).



Key

Y PSD, in (m/s^2)^2/Hz

f frequency, in Hz

Figure 3 — PSD of acceleration versus frequency

Table 3 — Values for PSD and frequency

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

4.1.2.1.2.3 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.

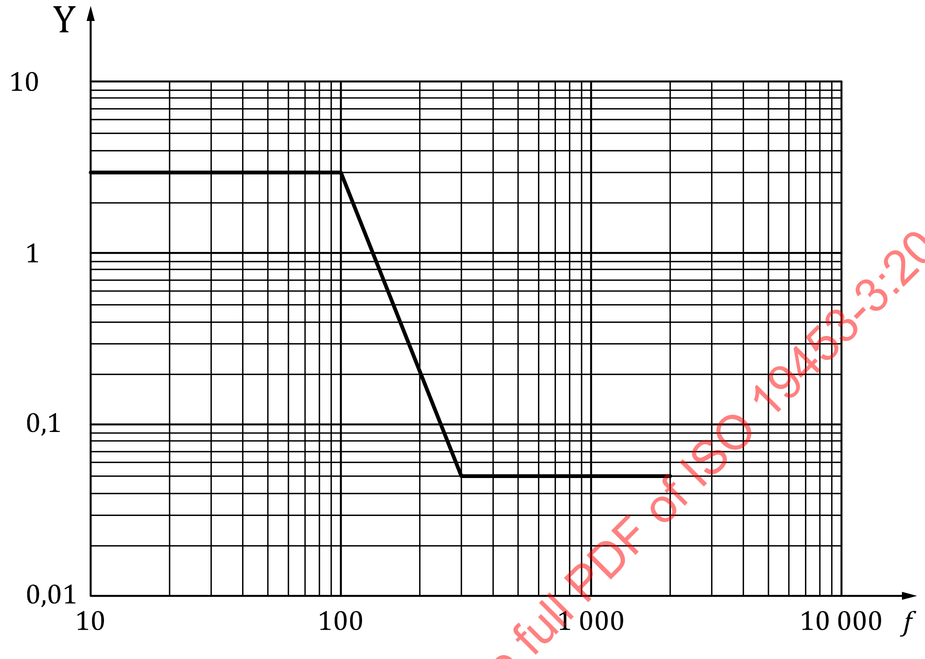
In the lowest frequency range from 10 Hz to 100 Hz, the influence of rough-road conditions is taken into account. The main failures to be identified by this test are malfunctions and/or breakage due to fatigue.

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 10 h for each axis of the DUT.

The RMS acceleration value for all three primary axes shall be 21,4 m/s2.

The PSD versus frequency is illustrated in Figure 4 and Table 4.



Key

Y PSD, in (m/s2)2/Hz

f frequency, in Hz

Figure 4 — PSD of acceleration versus frequency

Table 4 — Values for PSD versus frequency

Frequency Hz	PSD (m/s2)2/Hz
10	3
100	3
300	0,05
2 000	0,05

4.1.2.1.3 Requirements

Malfunctions and/or breakage shall not occur.

Functional status class A as defined in ISO 19453-1 is required during operating mode 3.2 and/or 4.2 as defined in ISO 19453-1, and functional status C is required during periods with other operating modes.

4.1.2.2 Test II — Passenger car, sprung masses (vehicle body)

4.1.2.2.1 Purpose

This test checks the DUT on the vehicle body for malfunctions and/or breakage caused by vibration.

4.1.2.2.2 Test

4.1.2.2.2.1 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 and A.5.1.3. 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 as 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.6).

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

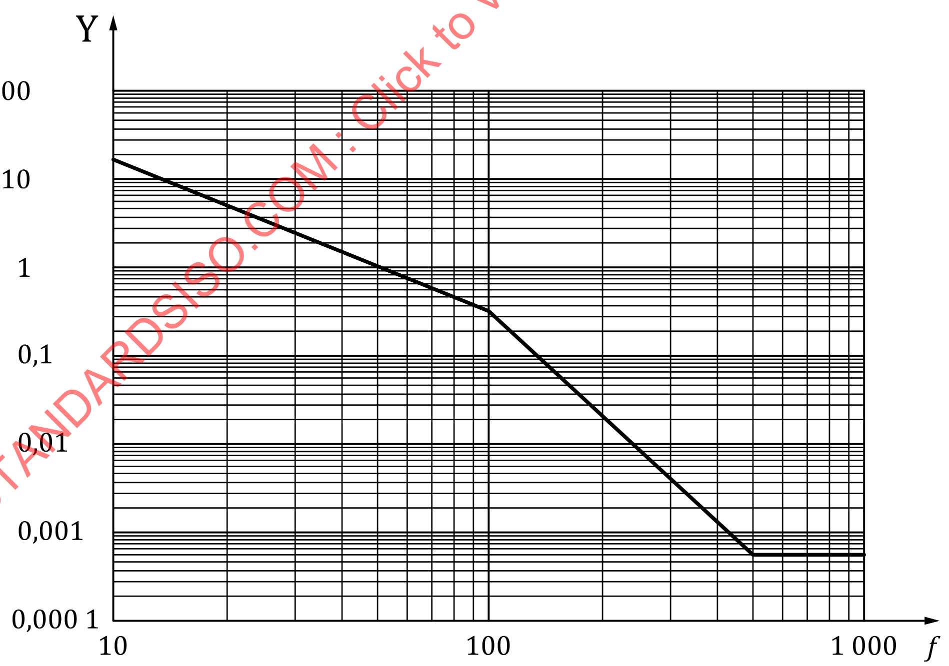
4.1.2.2.2.2 Random vibration

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 13,3 m/s^2.

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



Key

Y PSD, in (m/s^2)^2/Hz

f frequency, in Hz

Figure 5 — PSD of acceleration versus frequency

Table 5 — Values for PSD and frequency

Frequency Hz	PSD $(m/s^2)^2/Hz$
10	17
100	0,33
500	0,000 6
1 000	0,000 6

4.1.2.2.3 Requirements

Malfunctions and/or breakage shall not occur.

Functional status class A as defined in ISO 19453-1 is required during operating mode 3.2 and/or 4.2 as defined in ISO 19453-1, and functional status C is required during periods with other operating modes.

4.1.2.3 Test III — Electric vehicle, (directly equipped with) electric motor

4.1.2.3.1 Purpose

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

4.1.2.3.2 Test

4.1.2.3.2.1 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 and A.5.1.3. 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 as 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.6).

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.

4.1.2.3.2.2 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:

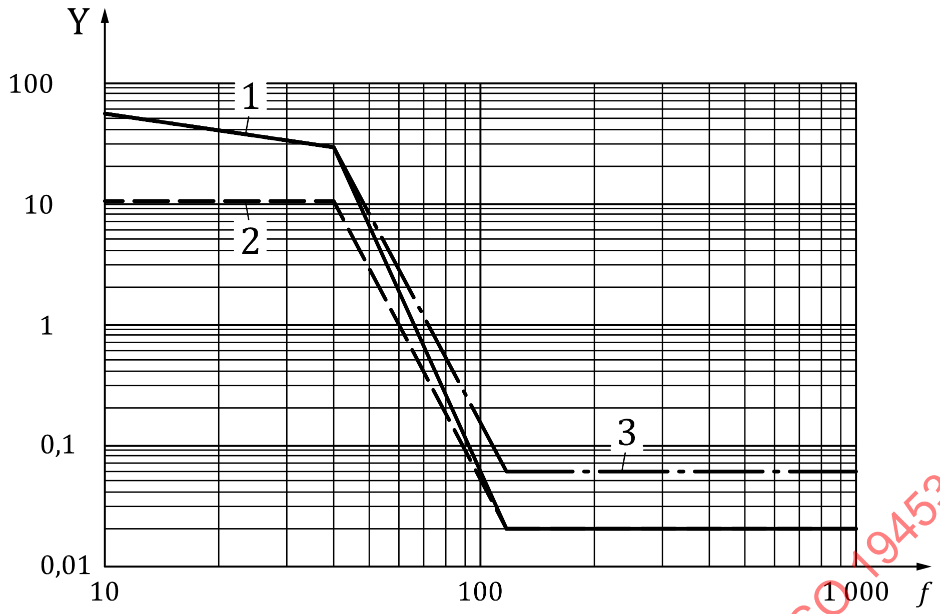
— X: 35,1 m/s^2,

— Y: 20,5 m/s^2,

— Z: 36,2 m/s^2.

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

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 all primary three axes.



Key

Y PSD, in $(m/s^2)^2/Hz$
f frequency, in Hz
1 curve for X axis
2 curve for Y axis
3 curve for Z axis

Figure 6 — PSD of acceleration versus frequency

Table 6 — Values for PSD and frequency

Frequency Hz	**PSD** $(m/s^2)^2/Hz$		
	X axis	**Y axis**	**Z axis**
10	55	11	55
40	28	11	28
120	0,02	0,02	0,06
1 000	0,02	0,02	0,06

4.1.2.3.3 Requirements

Malfunction and/or breakage shall not occur.

Functional status class A as defined in ISO 19453-1 is required during operating mode 3.2 and/or 4.2 as defined in ISO 19453-1, 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 on rigid points on the body and on the frame

4.2.1.1 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 (e.g. a detached capacitor inside the housing of the DUT, such as on-board power electronics components, due to the occurring high accelerations).

4.2.1.2 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 19453-1;

— 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.

4.2.1.3 Requirements

Malfunction and/or breakage shall not occur.

The functional status shall be class A as defined in ISO 19453-1.

4.2.2 Shock II — Test for devices in or on the gearbox

4.2.2.1 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).

4.2.2.2 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 19453-1;

— pulse shape: half-sinusoidal;

— typical maximum acceleration: 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.

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.

4.2.2.3 Requirements

Malfunction and/or breakage shall not occur.

The functional status shall be class A as defined in ISO 19453-1.

4.3 Free fall

4.3.1 Purpose

This test checks the 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 (e.g. a detached capacitor inside the housing of the DUT, such as on-board power electronics components, due to the occurring high accelerations when the DUT hits the ground).

4.3.2 Test

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

Perform the test sequence 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 7;

— impact surface: concrete ground or steel plate;

— orientation of the DUTs: first fall of each DUT on a different dimensional axis; second fall with the given DUT on the same dimensional axis, but on the opposite side of the housing;

— operating mode of the DUTs: 1.1 as defined in ISO 19453-1;

— temperature: to be agreed between the customer and the supplier.

The DUTs shall be visually examined after the falls.

Table 7 — Value for drop height

Code	Drop height mm
A	250
B	100
C	25
Z	As agreed
NOTE Further information on a suitable drop height depending on the mass of the DUT can be found in IEC 60068-2-31:2008, 5.2.3.	

4.3.3 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.

The functional status shall be class C as defined in ISO 19453-1.

4.4 Surface strength/scratch and abrasion resistance

The supplier and the customer shall agree on tests and requirements (e.g. marking and labelling on control elements and keys shall remain visible).

4.5 Gravel bombardment

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

5 Code letters for mechanical loads

For code letters for mechanical loads, see Table 8. Recommended mechanical requirements for the DUT depending on the mounting location are given in Annex B (Table B.1).

Table 8 — Coding in relation to tests and requirements

	Requirement according to					
Section	4.1.2.1	4.1.2.2	4.1.2.3	4.2.1	4.2.2	4.3
Code letter	**Test I**	**Test II**	**Test III**	**Shock I**	**Shock II**	**Free fall**
A	yes	—	—	—	—	yes
B	yes	—	—	—	yes	yes
C	—	yes	—	—	—	yes
D	—	yes	—	yes	—	yes
E	—	—	yes	—	—	yes
F	—	—	yes	—	yes	yes
Z	As agreed					

6 Documentation

For documentation, the designations outlined in ISO 19453-1 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 — Test profile definition

Item	Description
Nominal speed	$n_{nominal}$: nominal speed with maximum power output of the engine
Maximum speed	n_{max}: maximum safe 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 (as the driveshaft of an electric motor is always parallel to the ground floor) Y_{EM}: perpendicular to driving direction and vertical axis Z_{EM}: vertical axis

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 Tables A.2 and A.3 and are taken from DIN 70003, which also gives other valuable information regarding procedures for a vehicle measurement of vibrational loads.

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 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	—
Vehicle data gathering	Sampling frequency	≥ 2,5 times of f_{max}	f_{max} = frequency limit for evaluation
	Block length b	≥ 2 k	—
	Resolution	LSB < 0,1 % of max. value	LSB = least significant bit
	Filtering techniques and methods	Anti-aliasing filter at f_{max} with > 48 db/octave, high pass filter ($f_{filter} < f_{min.}$) to avoid offset	—
	Engine speed increase	Engine speed increase rate, e.g. 3 000 min^{-1}/min	If the engine revolution increases too fast, there is a possibility that existing resonances are not detected.
	Frequency resolution, Delta f	Make sure that the frequency resolution is higher than the difference of excitation frequency while ramping engine speed. Otherwise the fast Fourier transform (FFT) values will be wrong. Example: Delta f = 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 $f = f_{sampling} / b$ 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 engine conditions and DUT conditions (esp. elastic suspensioned DUT)

Table A.5 *(continued)*

Item	Documentation	Recommended documentation/ parameters	Comments
Data analysis	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?	—
	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	E.g. describe all key points including data reduction (averaging/enveloping)	—
	Methods and procedures used to determine or calculate the test duration	Explain assumptions and models used to correlate field stress and service life with test stress and duration, e.g. as in MIL-STD-810G with *m*-value 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.6 For powertrain mounted component, the test duration is calculated according to the 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.
	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 car.

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.

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

NOTE 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.

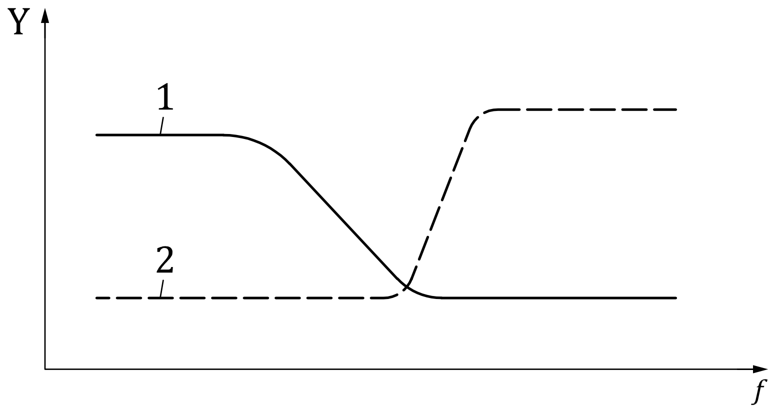
It shall be ensured that the DUT is not "undertested"; the stress in the laboratory shall be high enough to cover the field conditions (e.g. by measuring the response of the DUT and spectra comparison or fatigue calculation).

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

A.4.1 General

A.4.1.1 Vibration profile

In ISO 16750-3, a vibration profile for 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 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 components covered by this document, 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 (see Figure A.1).



Key

Y PSD, in $(m/s^2)^2$/Hz

f frequency, in Hz

1 low speed driving on rough roads

2 high engine speed driving on flat roads

Figure A.1 — Vibration loads and vehicle speed

The vibration severity is lower than in the profiles in ISO 16750-3 due to the increased mass and inertia of the DUT, compared to small sensors or ECUs covered by ISO 16750-3.

In ISO 16750-3, one profile is applied to all axes (X, Y and Z), enveloping measured loads in each axis. In this document, 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.4.1.2 Test duration

There is a general relation between the rotational speed (min^{-1}) and the vibration level caused by engine rotation. For fatigue testing, it is sufficient to consider the speed range with the highest acceleration levels. According to the measurement result of an actual plug-in hybrid electric vehicle (PHEV), as shown later, the accumulated dwell time in the engine speed range between 0,9 $n_{nominal}$ and n_{max} was found to be 0,55 % of the overall lifetime requirement of the vehicle.

From the above result, the test duration of 33 h for each axis in sine-on-random test was calculated by assuming a 6 000 h lifetime. This means a mileage of 240 000 km at a vehicle speed of 40 km/h on average.

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 10 h by the following procedure.

A.4.1.3 Readjusting of vibration profile with an example of test acceleration

According to the duration change from 600 h to 10 h, the vibration profile is readjusted by the following formula which is based on the Basquin model, known as a theoretical method to accelerate fatigue tests with equivalent damage. A general explanation of the model is provided in A.6.

$$\frac{W_1}{W_2} = \left(\frac{T_2}{T_1}\right)^{\frac{1}{m}}$$

$$W_2 = \frac{W_1}{\left(\frac{T_2}{T_1}\right)^{\frac{1}{m}}}$$

$$= \frac{W_1}{\left(\frac{10}{60}\right)^{\frac{1}{5}}}$$

$$= 2{,}3 \times W_1$$

where

W_1 is the RMS level in the original test duration from rough-road driving;

W_2 is the RMS level in the readjusted test duration of 10 h;

T_1 is the endurance testing time in the original test duration from rough-road driving;

T_2 is the endurance testing time in the readjusted test duration;

m is the acceleration coefficient.

A.4.2 Verification of load in engine speed distribution

A.4.2.1 Procedure

As aforementioned, it is sufficient to consider the engine vibration load from the high speed range between 0,9 $n_{nominal}$ and n_{max} with the highest acceleration levels. This is verified by the following steps:

a) recording of the engine speed distribution in the market driving (see A.4.2.2.1);

b) measurement of acceleration levels with an engine speed increase on the chassis dynamometer (see A.4.2.2.2);

c) determination of the load distribution from the measured time history (cycle counting method) (see A.4.2.2.3);

d) analysis of the number of cycles in the classed acceleration levels and engine speeds (see A.4.2.2.4);

e) verification of the dominant load from the high engine speed range (see A.4.2.2.5).

A.4.2.2 Result of the case study

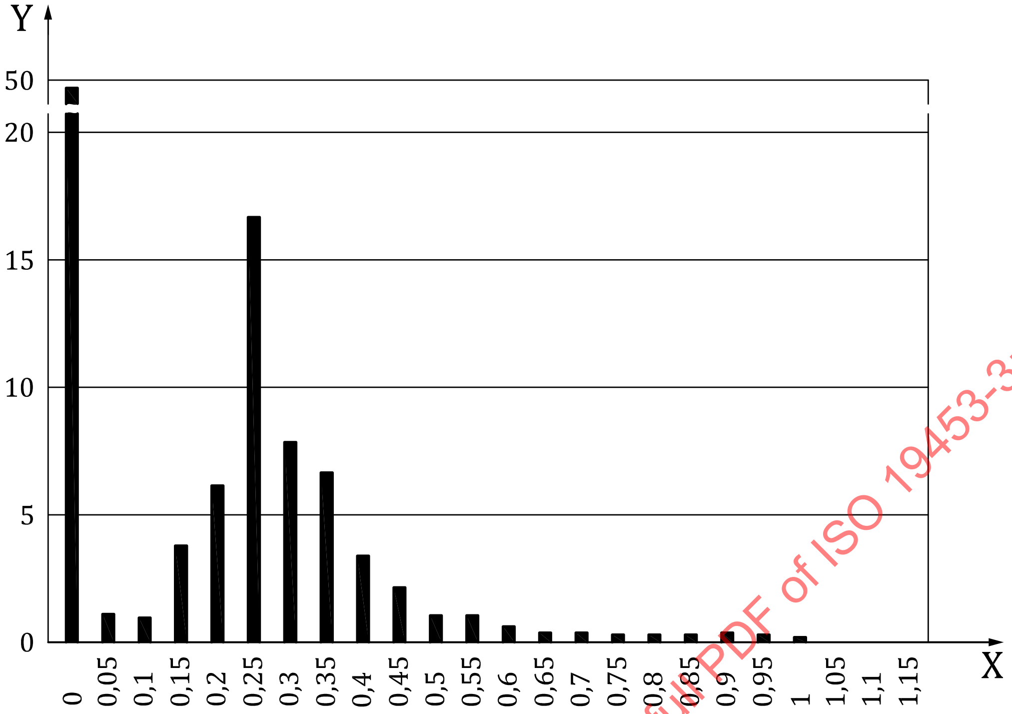
A.4.2.2.1 Recording of the engine speed distribution in the market driving

When starting this study, an engine speed distribution is chosen. It has been recorded using a PHEV with a HV battery delivering a 35 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.

Apart from that, the engine speed distribution is similar to that of ISO 16750-3:2012, A.4. The same approach was used in determining engine speeds normalized on the nominal engine speed with the highest power output. A probability distribution is shown in Figure A.2 and Table A.6.

Here, the probability accumulated at and above 0,9 of the normalized engine speed is 0,55 %, which accords to 33 h for a lifetime requirement of 6 000 h.



Key

Y probability, in %

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

Figure A.2 — Engine speed distribution in a PHEV

Table A.6 — Probability and dwell time of engine speed distribution

Normalized engine speed $n_{nominal}$	Probability %	Subtotal of probability %	Dwell time h	Subtotal of dwell time h
0	48,862	99,45	2 931,70	5 967
0,05	0,899		53,97	
0,1	0,711		42,65	
0,15	3,705		222,32	
0,2	6,023		361,37	
0,25	16,614		996,83	
0,3	7,790		467,42	
0,35	6,524		391,44	
0,4	3,197		191,84	
0,45	1,970		118,17	
0,5	0,922		55,33	
0,55	0,871		52,28	
0,6	0,457		27,41	
0,65	0,245		14,71	
0,7	0,200		12,03	
0,75	0,162		9,70	
0,8	0,148		8,86	
0,85	0,143		8,61	
0,9	0,199	0,55	11,97	33
0,95	0,178		10,66	
1	0,098		5,91	
1,05	0,057		3,44	
1,1	0,017		1,04	
1,15	0,004		0,21	

A.4.2.2.2 Measurement of acceleration levels with an engine speed increase on the chassis dynamometer

Acceleration levels on the powertrain are measured by increasing the engine speed at a constant rate on the chassis dynamometer. A measurement shown in Figure A.3 is implemented under the following conditions:

— normalized engine speed: 1 for nominal 5 500 rpm at engine maximum power;

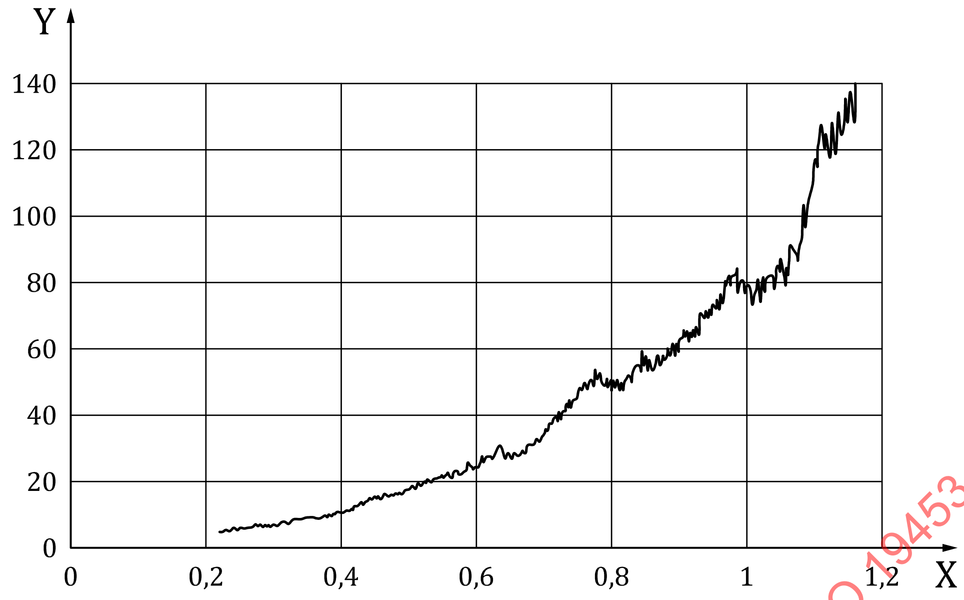
— engine speed at the start of measurement: 1 217 rpm (0,221 as normalized speed);

— engine speed at the end of measurement: 6 386 rpm (1,161 as normalized speed);

— rate of engine speed increase: 3 000 rpm/min; and

— measurement time: 1,723 min [= (6 386 – 1 217)/3 000].

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



Key

Y acceleration amplitude, in m/s^2

X normalized engine speed

Figure A.3 — Acceleration levels on powertrain

A.4.2.2.3 Determination of the load distribution from the measured time history (cycle counting method)

There is one maximum between two zero crossings.

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

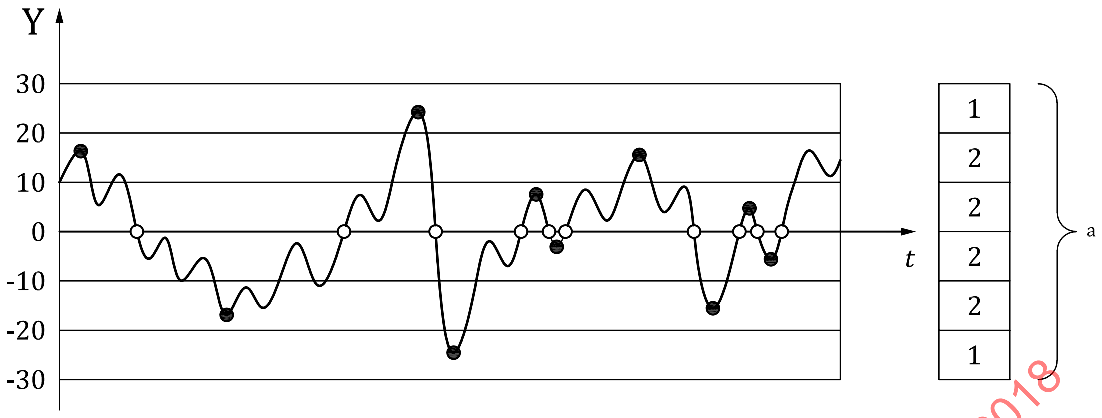
The result of this counting method gives the number of half cycles for each class, i.e. the load distribution from the measured time history. See Figure A.4.

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 car lifetime is calculated by using a factor of (car lifetime × percentage of rough roads/measuring time) for each class (e.g. 6 000 h × 0,5 × 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), in m/s^2

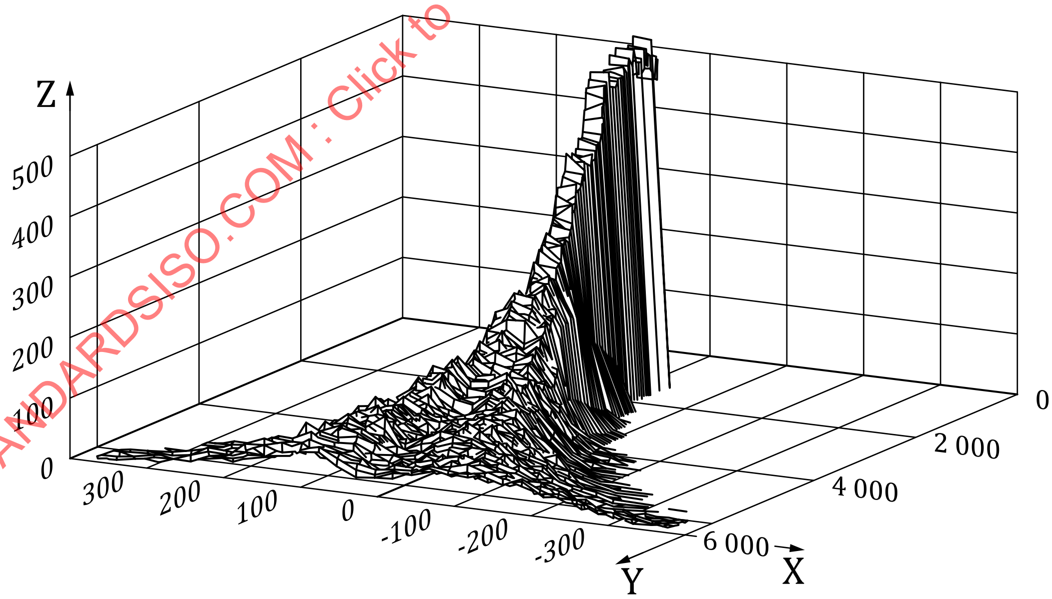
t time, in s

a Number of half cycles in each class.

Figure A.4 — Counting method for the load distribution

A.4.2.2.4 Analysis of the number of cycles in the classed acceleration levels and engine speeds

By using a cycle counting method (see A.4.2.2.3), 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, the number of cycles for the respective classes is calculated as shown in Table A.15, where 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.5.



Key

X acceleration level, in m/s^2

Y engine speed, in min^{-1}

Z number of cycles in the acceleration level

Figure A.5 — Distribution of number of cycles

Furthermore, the number of cycles in the market driving is estimated from a ratio dividing dwell time in the market driving by one chassis dynamometer measurement at each classed normalized engine speed. A calculation example is shown for a normalized engine speed of 1,15 and an acceleration level of 371,2 m/s^2 as follows:

— measurement time during chassis dynamometer measurement: 1,723 min (see A.4.2.2.2);

— measurement time for each engine speed classed by 0,05: 0,091 min (= 1,723/19 classes);

— dwell time in the market for a normalized speed of 1,15: 0,21 h (see Table A.6);

— time ratio between market driving and measurement: 139 times (= 0,21 × 60/0,091);

— number of cycles measured on chassis dynamometer for the speed: 23 cycles (see Table A.15);

— number of cycles in the market driving: 3 200 cycles (≃ 23 × 139).

The calculation above takes 19 classes for normalized engine speed. Although the number of classes in Table A.15 is 24, there is no cycle during the 4 classes from 0 to 0,15 for this measurement, and in the other 20 classes, the start and end speeds of 0,2 and 1,15 have imperfect data when measured on chassis dynamometer. Therefore, 19 classes are taken into account instead of 20. Even if classes in low speed range with small acceleration levels are omitted, it is expected that their influence on the final calculation result will be limited.

The same calculations are applied for all classes of speeds and accelerations and the number of cycles in the market driving is calculated as shown in Table A.16. The total sum of numbers of cycles for each acceleration level shown at the bottom line of the table is used as actually imposed stress for theoretical verification in the next step (e.g. number of cycles of 105 089 for an acceleration level of 371 m/s^2).

A.4.2.2.5 Verification of the dominant load from the high engine speed range

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

$$s_i = n_i / N_i$$

$$S = \sum s_i$$

where

n_i is the number of cycles to imposed 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 the market driving is divided into the two parts below:

$$S = S_1 + S_2$$

where

S_1 is the partial damage in the speed range between stopping and 0,9 $n_{nominal}$;

S_2 is the partial damage in the speed range between 0,9 $n_{nominal}$ and n_{max}.

If S_2 is far larger than S_1, i.e. the ratio S_2/S_1 is large enough, 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 a S-N model described with slope k and fatigue cycle number N_D (see Table A.12);

b) set a fatigue limit a_D (see Figure A.6);

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) 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.

A calculation example according to these steps is shown in Table A.7, where the conditions and results are:

— $k = 3{,}5$ and $2\,k - 1 = 6$,

— $N_D = 2\,000\,000$,

— $a_D = 270$ as specified at $S = 1$,

— $S_1 = 0{,}079\,2$,

— $S_2 = 0{,}933$,

— $S = S_1 + S_2 = 1{,}01$,

— $S_2/S_1 = 11{,}8$ was finally calculated.

The large ratio of S_2/S_1 means that the damage from the high speed range at and above 0,9 $n_{nominal}$ is dominant and the damage below 0,9 is negligible. This results in a test duration of 33 h per axis of the DUT as mentioned in A.4.1.2.

Table A.7 — Comparison between accumulative damages

Acceleration level m/s^2	Number of cycles			Cycles for material fatigue limit (S-N)	Accumulative damage		
	S_1	S_2	S (= S_1+S_2)		S_1	S_2	S (= S_1+S_2)
12,0	$5{,}17 \times 10^{10}$	$8{,}45 \times 10^{7}$	$5{,}18 \times 10^{10}$	$2{,}63 \times 10^{15}$	$1{,}97 \times 10^{-5}$	$3{,}22 \times 10^{-8}$	$1{,}97 \times 10^{-5}$
36,0	$2{,}48 \times 10^{9}$	$1{,}07 \times 10^{8}$	$2{,}58 \times 10^{9}$	$3{,}60 \times 10^{12}$	$6{,}87 \times 10^{-4}$	$2{,}96 \times 10^{-5}$	$7{,}17 \times 10^{-4}$
60,0	$4{,}21 \times 10^{8}$	$1{,}21 \times 10^{8}$	$5{,}41 \times 10^{8}$	$1{,}68 \times 10^{11}$	$2{,}50 \times 10^{-3}$	$7{,}17 \times 10^{-4}$	$3{,}22 \times 10^{-3}$
83,8	$1{,}33 \times 10^{8}$	$1{,}20 \times 10^{8}$	$2{,}53 \times 10^{8}$	$2{,}23 \times 10^{10}$	$5{,}96 \times 10^{-3}$	$5{,}35 \times 10^{-3}$	$1{,}13 \times 10^{-2}$
108	$5{,}20 \times 10^{7}$	$9{,}43 \times 10^{7}$	$1{,}46 \times 10^{8}$	$4{,}94 \times 10^{9}$	$1{,}05 \times 10^{-2}$	$1{,}91 \times 10^{-2}$	$2{,}96 \times 10^{-2}$
132	$1{,}99 \times 10^{7}$	$6{,}43 \times 10^{7}$	$8{,}43 \times 10^{7}$	$1{,}48 \times 10^{9}$	$1{,}34 \times 10^{-2}$	$4{,}34 \times 10^{-2}$	$5{,}68 \times 10^{-2}$
156	$7{,}58 \times 10^{6}$	$4{,}02 \times 10^{7}$	$4{,}78 \times 10^{7}$	$5{,}44 \times 10^{8}$	$1{,}39 \times 10^{-2}$	$7{,}39 \times 10^{-2}$	$8{,}78 \times 10^{-2}$
180	$2{,}57 \times 10^{6}$	$2{,}27 \times 10^{7}$	$2{,}53 \times 10^{7}$	$2{,}31 \times 10^{8}$	$1{,}11 \times 10^{-2}$	$9{,}86 \times 10^{-2}$	$1{,}10 \times 10^{-1}$
204	$8{,}16 \times 10^{5}$	$1{,}27 \times 10^{7}$	$1{,}35 \times 10^{7}$	$1{,}09 \times 10^{8}$	$7{,}50 \times 10^{-3}$	$1{,}17 \times 10^{-1}$	$1{,}24 \times 10^{-1}$
228	$3{,}67 \times 10^{5}$	$6{,}87 \times 10^{6}$	$7{,}24 \times 10^{6}$	$5{,}59 \times 10^{7}$	$6{,}57 \times 10^{-3}$	$1{,}23 \times 10^{-1}$	$1{,}30 \times 10^{-1}$
252	$1{,}39 \times 10^{5}$	$3{,}59 \times 10^{6}$	$3{,}73 \times 10^{6}$	$3{,}06 \times 10^{7}$	$4{,}53 \times 10^{-3}$	$1{,}17 \times 10^{-1}$	$1{,}22 \times 10^{-1}$
275	$3{,}48 \times 10^{4}$	$2{,}13 \times 10^{6}$	$2{,}17 \times 10^{6}$	$1{,}87 \times 10^{7}$	$1{,}87 \times 10^{-3}$	$1{,}14 \times 10^{-1}$	$1{,}16 \times 10^{-1}$
299	$5{,}86 \times 10^{3}$	$1{,}17 \times 10^{6}$	$1{,}17 \times 10^{6}$	$1{,}39 \times 10^{7}$	$4{,}20 \times 10^{-4}$	$8{,}36 \times 10^{-2}$	$8{,}41 \times 10^{-2}$

Table A.7 *(continued)*

Acceleration level m/s^2	Number of cycles			Cycles for material fatigue limit (S-N)	Accumulative damage		
	S_1	S_2	S (= S_1+S_2)		S_1	S_2	S (= S_1+S_2)
323	$0,00 \times 10^0$	$5,90 \times 10^5$	$5,90 \times 10^5$	$1,06 \times 10^7$	$0,00 \times 10^0$	$5,54 \times 10^{-2}$	$5,54 \times 10^{-2}$
347	$0,00 \times 10^0$	$3,43 \times 10^5$	$3,43 \times 10^5$	$8,29 \times 10^6$	$0,00 \times 10^0$	$4,14 \times 10^{-2}$	$4,14 \times 10^{-2}$
371	$0,00 \times 10^0$	$2,44 \times 10^5$	$2,44 \times 10^5$	$6,56 \times 10^6$	$0,00 \times 10^0$	$3,72 \times 10^{-2}$	$3,72 \times 10^{-2}$
				Sum	$7,92 \times 10^{-2}$	$9,33 \times 10^{-1}$	1,0

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

A.5.1 General

A.5.1.1 Vibration profile

Based on ISO 16750-3, 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

The test duration is 8 h in ISO 16750-3, where a rough-road part of 90 % is described as the absolutely worst case and less than 50 % rough-road part is normally taken for calculation (see ISO 16750-3:2012, A.5.2, NOTE 3.) The E/E components for HEV, EV traction are larger and heavier than the DUT covered by ISO 16750-3, 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.

A.5.1.3 Readjusting of vibration profile with an example of test acceleration

According to the duration change from 4,4 h to 20 h, the vibration profile is readjusted by the Basquin model. For details, see A.6.

$$W_2 = \frac{W_1}{\left(\frac{20}{4,4}\right)^{\frac{1}{5}}} = 0,74 \times W_1$$

where

W_1 is the RMS level in the original test duration of 4,4 h from rough-road driving;

W_2 is the RMS level in the readjusted test duration of 20 h.

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

A.5.2.1 Result

Although the percentage of rough road is changed to 50 %, it is verified that a 4,4 h random vibration test is sufficient to cover the stress in the car which occurs during the car lifetime. The stress (fatigue limits) which results from a test duration of 4,4 h is about 1,65 (1,20 – 1,99) times higher than the stress in driving condition (3 000 h on a test track). This shows that a test duration of 4,4 h is sufficient. The verification result is stated as follows.

A.5.2.2 Procedure

Although the data used herein is from an ECU described in ISO 16750-3, the same approach can be applied to components covered by this document:

a) vibration measurement in the car on the test track (road bumps) and during the random vibration test with at least two measurement points, one at the mounting location (input or excitation) and one on the DUT;

b) determination of the load distribution by means of a cycle counting method (see A.4.2.2.3) during the measuring time;

c) choosing the car lifetime and the "rough-road percentage" (the car lifetime is 6 000 h and the rough-road percentage 50 %);

d) calculation of the load distribution by multiplying the count result in each class with the factor (see A.5.2.4):

— (test duration/measuring time during test),

— (car lifetime × rough-road percentage/measuring time during vehicle driving).

e) calculation of the fatigue limit that corresponds to a damage of 1, using the "Haibach" modification.

These calculations are based on the Woehler curve "Haibach" modification; for more details, see A.5.2.5.

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. Measurements and calculations like this have been done for many years (> 20) and in many applications.

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 rough public roads.

A.5.2.3 Test parameters for random vibration

— test equipment: electro-dynamic shaker;

— mounting assembly: DUT firmly fixed on the shaker;

— control point: on the shaker;

— direction: perpendicular to printed circuit board (PCB);

— RMS acceleration level: 33 m/s^2;

— test spectra: see Table A.8.

Table A.8 — 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 from the spectrum documented in 4.1.2.2.2.2.

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

Based on the cycle counting method in A.4.2.2.3, acceleration distributions 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 4,4 h (= 8 h × 50 %/90 %) in the random vibration test (see Table A.9);

— load distribution from a measuring time of 3,69 s on the rough road (road bumps, 50 km/h), calculated for 3 000 h (car lifetime 6 000 h, rough-road part 50 %) in rough-road driving (see Table A.10).

Table A.9 — Acceleration distributions of random vibration test

Random vibration test of 4,4 h	
Acceleration classes a_i m/s^2	Number of cycles n_i
403,4	3 616
377,4	5 223
351,3	10 046
325,3	24 109
299,3	57 861
273,3	112 909
247,2	241 489
221,2	401 008
195,2	644 908
169,2	886 398
143,1	1 169 273
117,1	1 354 509
91,09	1 448 131
65,06	1 303 077

Table A.10 — Acceleration distributions of vehicle driving

Rough-road driving for 3 000 h	
Acceleration classes a_i m/s²	Number of cycles n_i
129,4	1 464 844
112,7	1 464 844
104,4	4 394 531
96,04	2 929 688
87,69	4 394 531
79,34	4 394 531
70,99	4 394 531
62,64	10 253 906
54,28	5 859 375
45,93	26 367 188
37,58	46 875 000
29,23	84 960 938
20,88	150 878 906
12,53	383 789 063

A.5.2.5 Comparative verification between random test and driving stress

For this study, the Haibach modification is used comparing stresses between the random vibration test and the rough-road driving.

The fatigue damage is given in the same way as shown in A.4.2.2.5. It is possible to calculate the damage of the random vibration test and the vehicle driving, and to compare them. Furthermore, if all 12 a_D values coming from the vibration test are higher than the ones from the vehicle driving, then the stress on vehicle is permissible.

The value of a_D is calculated the same way as shown in the calculation steps from a) to f) in A.4.2.2.5.

Those steps are done respectively for the random vibration test and the vehicle driving.

In the random vibration test with duration of 4,4 h, a calculation result is shown in Table A.11 at S = 1 using the Haibach modification with N_D = 2 000 000 and k = 3,5.

Table A.11 — Fatigue limit calculation using the Haibach modification

a_i m/s2	n_i	N_i[a]	s_i[a]
403,4	3 616	241 482	0,015
377,4	5 223	304 897	0,017
351,3	10 046	391 820	0,026
325,3	24 109	512 821	0,047
299,3	57 861	686 415	0,084
273,3	112 909	943 455	0,120
247,2	241 489	1 340 573	0,180
221,2	401 008	1 977 936	0,203
195,2	644 908	4 155 303	0,155
169,2	886 398	9 796 691	0,090
143,1	1 169 273	26 769 716	0,044
117,1	1 354 509	89 153 868	0,015
91,09	1 448 131	402 399 420	0,004
65,06	1 303 077	3 031 078 645	0,000
Sum			1,000

NOTE N_D = 2 000 000; k = 3,5 and $2k$ - 1 = 6.

[a] a_D = 220,5 m/s2

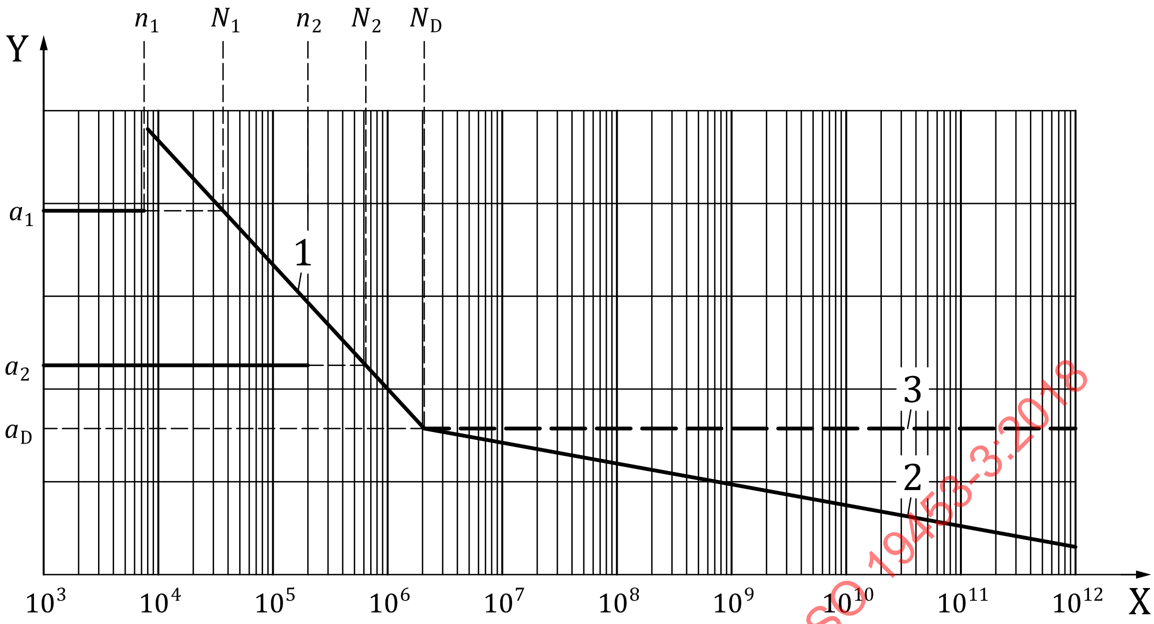
Without very extensive investigations and experiments, it is impossible to know whether the chosen S-N model is realistic. Therefore, it makes sense to cover a wide range for each S-N parameter (e.g. from specialized literature). Twelve models are currently used as shown in Table A.12 ("Haibach hypothesis", "4 slopes k" and "3 fatigue limit cycles N_D").

NOTE "Miner original" is no longer used because according to this acceleration, levels lower than a_D have no contribution to the whole damage. According to present knowledge, the use of the "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 (vehicle and test), because in a comparison some of the wrong assumptions are compensated.

The load distribution from the selected example and the corresponding S-N graph (one model) are shown in Figure A.6. In relation to Figure A.6, the fatigue damage S, fatigue limit a_D and fatigue cycle number N_D are stated in A.4.2.2.5.

The verification result is shown in Table A.12, as to whether it is allowable to change the test duration for random vibration to 4,4 h (= 8 h × 50 %/90 %) in accordance with reducing the rough-road part from 90 % to 50 %. It was possible to confirm that the random vibration test is more severe than the measured vehicle condition.



Key

Y	acceleration level, in m/s²
X	number of cycles
1	slope, *k*
2	Haibach-modification slope, 2*k*-1
3	Miner original
a_D	fatigue limit, in m/s²
N_D	fatigue cycle number
a_1 ,a_2	acceleration level, in m/s²
n_1 ,n_2	number of cycles to impose stress at a_1 ,a_2
N_1 ,N_2	number of cycles to failure at a_1 ,a_2

Figure A.6 — S-N graph showing an example of linear damage accumulation

Table A.12 — 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 N_D	Slope *k* of S-N graph	Hypotheses	Calculated fatigue level for the random vibration test of 4,4 h (12 "S-N models")	Needed fatigue level for 3 000 h rough-road driving (12 "S-N models")	Comparison
2 000 000	3,5	Haibach	221 m/s²	150 m/s²	OK
	5	Haibach	224 m/s²	135 m/s²	OK
	7	Haibach	234 m/s²	130 m/s²	OK
	10	Haibach	253 m/s²	127 m/s²	OK
10 000 000	3,5	Haibach	148 m/s²	113 m/s²	OK
	5	Haibach	167 m/s²	109 m/s²	OK
	7	Haibach	189 m/s²	109 m/s²	OK
	10	Haibach	217 m/s²	111 m/s²	OK

Table A.12 *(continued)*

Fatigue cycles of the S-N model N_D	Slope k of S-N graph	Hypotheses	Calculated fatigue level for the random vibration test of 4,4 h (12 “S-N models”)	Needed fatigue level for 3 000 h rough-road driving (12 “S-N models”)	Comparison
50 000 000	3,5	Haibach	95 m/s^2	79 m/s^2	OK
	5	Haibach	122 m/s^2	83 m/s^2	OK
	7	Haibach	151 m/s^2	89 m/s^2	OK
	10	Haibach	185 m/s^2	96 m/s^2	OK

A.6 The explanation for Basquin model

A.6.1 Scope

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.

A.6.2 Outline

A typical failure mode due to vibration stress is fatigue. The equivalent fatigue time or vibration intensity level can be calculated using Formula A.1:

$$\frac{W_1}{W_2} = \left(\frac{T_2}{T_1} \right)^{\frac{1}{m}} \tag{A.1}$$

where

W_1 is the vibration acceleration level 1;

W_2 is the vibration acceleration level 2;

T_1 is the endurance testing time 1;

T_2 is the endurance testing time 2;

m is the acceleration coefficient.

m can have different numerical values depending on the material (usually from 3 to 9). The general value of the metal fatigue in random vibration is $m = 4$ but, as DUT consists of various components, $m = 5$ was adopted.

A.6.3 Calculation example

When a vibration test is intended with the following profile (see Figure A.7 and Table A.13) but it cannot be run to its full level due to technical limitations, then a procedure is given to adjust the given test duration of 22 h for each axis.

